National Centre for Scientific Research:
NSCR "Demokritos"

Institute of Microelectronics

Annual Report 2008

Aghia Paraskevi, Athens, Greece
www.imel.demokritos.gr

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PREFACE

IMEL (Institute of Microelectronics) was established in 1986 as one of the eight Research Institutes of NCSR (National Center for Scientific Research) "Demokritos", a medium size, multidisciplinary Research Center under the General Secretariat for Research and Technology of the Ministry of Development. Today it is the National Center of Excellence in Micro- and Nanofabrication, Nanoelectronics and MEMs.

IMEL has developed experience and expertise, as well as unique technological advantages, which place it among the main EU Research Institutes in the field of Silicon technologies.

The strong advantages of IMEL are as follows:

- Its excellent staff, composed of a small number of experienced senior scientists, surrounded by a large number of young researchers, all fully devoted to their work
- Research facilities for silicon processing, micro and nanofabrication, characterization, testing, design, modeling and simulation of materials, structures, devices and systems, which are unique in Greece
- Important expertise and know-how, as well as important proprietary technologies, materials and devices. IMEL's intellectual property (IP) portfolio continues to expand and opens important possibilities for collaboration with industry and transfer of know how

Research at IMEL is carried out at the EU level through its participation in European research projects, networks of excellence and technology platforms. EU projects cover a number of specific priorities of the EU Research Framework Programme, including mainly Information and Communication Technologies (ICT), Nanotechnology, Materials and Production Processes (NMP), Energy, Health and Environment. IMEL's success in the above peer reviewed R&D funded programmes represents one of the strongest endorsements of IMEL's R&D competence and reflects the world-class standing of the Institute.

On the national level the expertise and infrastructure of IMEL are unique in Greece, which makes its role also unique in developing novel technologies, in transfering technology and know-how to the industry and in developing human potential through education and training activities. Furthermore, IMEL has developed mechanisms to promote the field at the national level through the establishment and coordination of thematic networks and scientific societies (MMN Network, Micro & Nano scientific society).

IMEL is a member of the European Academic and Scientific Association for Nanoelectronics (AENEAS-technology platform ENIAC) that aims at promoting scientific collaborations with industry and providing skills and expertise for the execution of common projects, studies, as well as education and training in Nanoelectronics.

In the year 2008, the European Institute of Nanoelectronics named SINANO has also been established, with IMEL as one of its 16 founding members.

The year 2008 was a very successful year for IMEL. The installation of new equipment in the new building has been completed. Both the processing laboratory and the electrical characterization facilities were certified under ISO 9001. Within the EU ICT I3 project ANNA contract No 026134, IMEL provides access to its infrastructure for Si processing and electrical/optical characterization of materials, devices and structures to researchers from all around Europe.

In this annual report, the research and education activities and research output of IMEL are presented. I would like to acknowledge all those who contributed to a successful year, namely researchers, research engineers, PhD and post-doctoral students, and technical and administrative staff of the Institute. Acknowledgement is also due to the technical and administrative staff of NCSR Demokritos for their support.

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Dr A. G. Nassiopoulou
Director of IMEL
Member of the Board of Management
of NCSR Demokritos

IMEL at a glance

IMEL at a glance

IMEL is one of the eight research Institutes of the multidisciplinary research center "NCSR Demokritos" in Aghia Paraskevi, a suburb situated 10 kilometers from the center of Athens.

Main Objectives of IMEL

The main objectives of IMEL are as follows:

- Long-term research into understanding phenomena, mastering processes and developing research tools.
- Development of fundamental knowledge
- Development of novel high added-value technology products and production processes
- Development of human potential by education and training activities
- Services in advanced technology
- Transfer of technology and know-how

The objectives of IMEL are in line with the government policy to promote excellence in research, high technology development and innovation at Research Institutes and to promote collaboration between academia and industry.

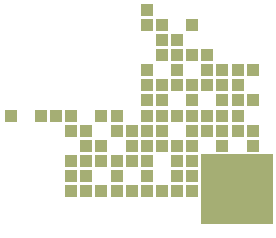
Due to the infrastructure available at IMEL for silicon processing and micro- nanofabrication, electronics and sensors, and the existing expertise and know-how developed, the role of the Institute is significant in contributing to increase the technological level of the country and to spread the knowledge through collaboration with Academia in research and education activities.

Research orientation

IMEL is mainly devoted to silicon technologies and their diverse applications in information processing, storage, transmission systems and telecommunications, environmental systems, medicine, healthcare, food industry etc.
Research Activities at IMEL are structured in 3 programmes, each one being composed of smaller projects as follows:

A. MICRO and NANOFABRICATION

- ➢ Lithographic Polymers and Processes
- ➢ Plasma Processing and Simulation for Micro and Nano Patterning
- ➢ Front-end Processes for Micro and Nanodevices
- ➢ Thin Films by physical and chemical deposition



B. NANOSTRUCTURES and NANOELECTRONIC DEVICES

- ➢ Nanostructures for Nanoelectronics, Photonics and Sensors
- ➢ Materials and Devices for Memory Applications
- ➢ Molecular Materials as Components of Electronic Devices

C. SENSORS and MEMs

- ➢ Porous Silicon Technology for Sensors and on-chip Integration
- ➢ Mechanical & Chemical Sensors
- ➢ Bio-microsystems
- ➢ Thin Film Devices for Large Area Electronics
- ➢ Energy harvesting materials and devices
- ➢ Circuits and Devices for Optoelectronic Interconnections

Education and Training at IMEL

Due to its unique infrastructure at a national level and the important expertise and know-how of its researchers, IMEL plays an important role in post-graduate education. In collaboration with Greek universities, It participates very actively in the following educational programmes, by providing special courses and laboratory training:

1. Post-graduate program in "Microelectronics" in collaboration with the University of Athens (for MSc and PhD degrees)
2. Master program in "Microsystems and Nanoelectronic devices" in collaboration with the National Technical University of Athens
3. Post-graduate program in "Nanosciences and Nanotechnologies" in collaboration with the University of Thessaloniki (for MSc and PhD degrees)

Laboratories and Central Fabrication Facilities at IMEL

The facilities and equipment of IMEL include a full silicon processing laboratory in a clean room area, complemented by characterization laboratories (electrical, optical, structural), micromachining and packaging equipment, resist development laboratory, as well as testing facilities and design, modeling and simulation tools. The clear room is equipped with lithography (optical, e- beam) and etching tools, thermal and chemical processing, ion implantation, deposition of metals, dielectrics and poly-nanocrystalline silicon by physical and chemical processes (LPCVD, sputtering, e-gun and thermal evaporation), and process inspection equipment.

Electrical characterization equipment

FEG SEM JEOL JSM-7401F

RF probe station

Lithography and etching area

Lithography equipment

High density plasma etcher

Management

The management of the Institute is carried out by its Director, who is elected for a 5 year term by an International Scientific Committee and is assisted by a Deputy Director and an Institute Advisory Board, both elected every 2 years by the Researchers. The Director represents the Institute in the Board of management of the Centre, and is responsible for the overall functioning of the Institute. An external International Scientific Advisory Committee, which discusses with the Director and the scientific staff the Institute research priorities and policy, has been involved with IMEL since 2000. A scientist is in charge of the processing laboratory, which is a central facility used by all scientific groups.

Personnel

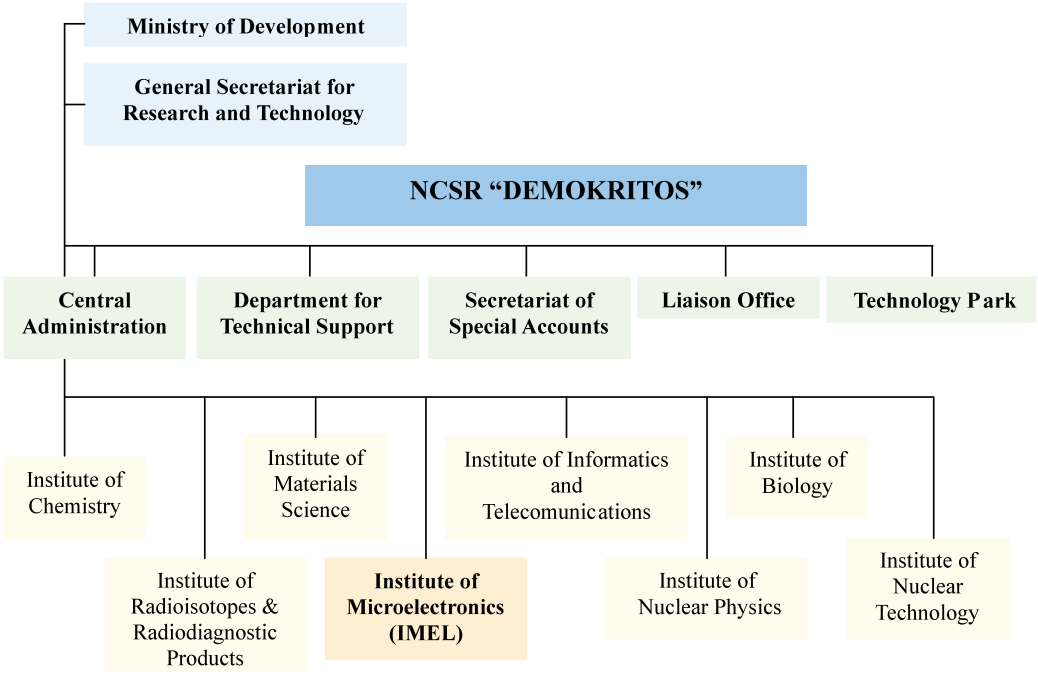
The personnel of IMEL includes 16 key researchers and several post-doctoral scientists and PhD students. It also includes a group of technicians that operate the central fabrication facility (details in annex I).

Scientific staff

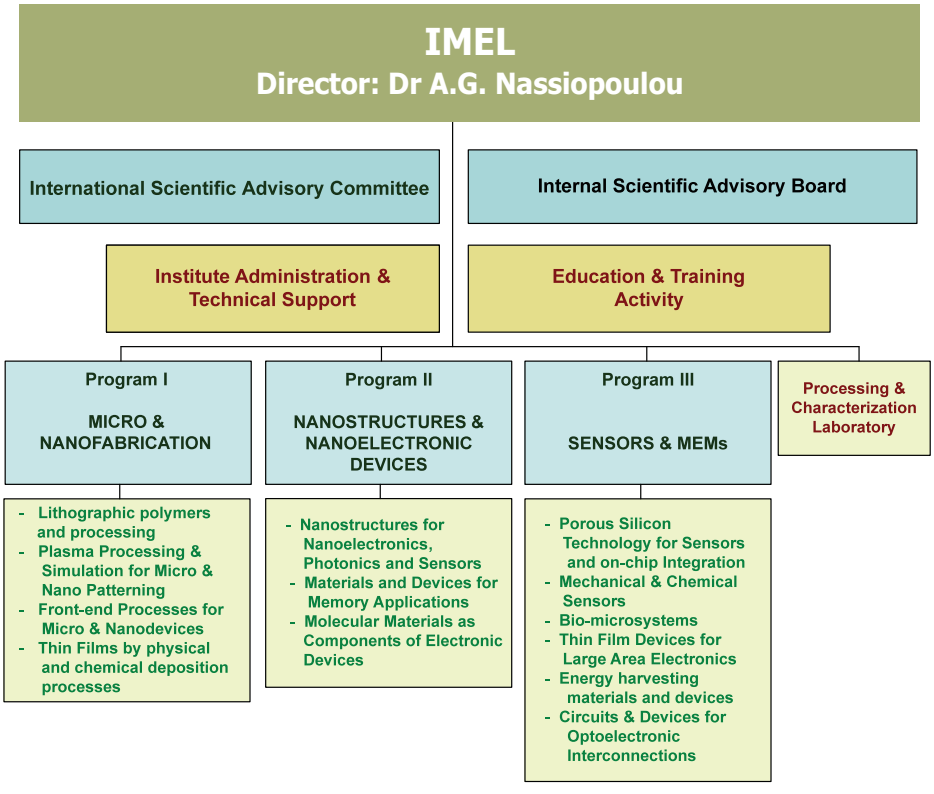
Personnel of IMEL

ORGANIZATIONAL STRUCTURE

Organizational structure of NCSR Demokritos



Organizational structure of IMEL



Main Research Results

FUNCTIONAL MOLECULAR MATERIALS FOR LITHOGRAPHY AND ORGANIC/MOLECULAR ELECTRONICS

Project Leader: P. Argitis

Key Researchers: P. Argitis, I. Raptis

Permanent research staff: A. Douvas, M. Vasilopoulou

Post-doctoral Research Associates: L. Palilis, M. Chatzichristidi, G. Patsis, D. Niakoula

Ph.D. candidates: D. Drygiannakis, D. Georgiadou, T. Manouras, P. Pavli, N. Tsikrikas

MSc and undergraduate students: A. Botsialas, A. Kapela

Collaborating researchers from other IMEL groups: E. Gogolides, N. Glezos, K. Misiakos, P. Normand

External Collaborators: N. Stathopoulos (TEI Piraeus), G. Pistolis, E.A. Couladouros, V.P. Vidali, (IPC-NCSRD), P.S. Petrou, S.E. Kakabakos, (IRRP-NCSRD), F. Watt, J. Van Kan (CIBA-NUS, Singapore), E.S. Valamontes (TEI of Athens), Th. Speliotis (IMS-NCSRD)

Research orientation:

a. Optimization of lithographic materials and patterning processes - Development of new resists for high resolution, low LER ithography

Current activities include resists based on polymer back-bone breaking, resists based on unconventional imaging approaches, and experimental/simulation studies for supporting material and process optimization.

b. Lithographic materials and processes for micro-nano structure fabrication in MEMs and Nano-biotechnology

Investigation of material and process issues related to conventional and novel lithographic schemes proposed for patterning in the areas of MEMs, bio-MEMs and related fields

c. Materials research for organic/molecular electronics

Materials research and device architecture studies for molecular/organic electronics. Current activities include materials for molecular memories, organic light emitting diodes (OLEDs), photovoltaics and new optoelectronic devices.

Funding

- **Nano2Life**, EU FP6 Network of Excellence (NMP), 2004-2008
- **GSRT-PENED 03ED276**, "Critical sub-100nm Industrial scale Patterns for CMOS - NANO Architectures, (CMOS-NANO), 2005-2008
- **GSRT-NON-EU 467**, "Proton Beam NANOlithography for high aspect ratio structures of optical COMPonents" (PB.NANOCOMP), 2006-2008

MAIN RESULTS IN 2008

A. Optimization of lithographic materials and patterning processes - Development of new resists for high resolution, low LER ithography

E-beam and Proton-beam lithography simulation for the patterning of high resolution structures

Several alternative lithographic technologies have been suggested as potential candidates for the mass-production of integrated circuits in the next technology nodes (22nm and beyond) such as nanoimprint lithography, interference lithography etc. One of those technologies is the Mask-Less Electron Beam Lithography (ML-EBL). One of the very recent approaches in this area is the application of a shaped beam through Patterned Beam Defining Aperture (3rd-order imaging approach). The effect of beam edge acuity on resolution and LER of that particular approach is reported.

A 3D accurate electron beam matter interaction model is combined with a detailed material stochastic simulation for the simulation of e-beam edge. The particular EBL simulator is capable to handle multi-layer substrates, a feature very important in the case of direct writing.

The energy deposited (EDF) from a point beam is calculated by a Monte Carlo module. The EDF is then convoluted with the beam used for the actual writing either with trapezoidal or aussian profile (Fig. 1). The resulted convoluted EDF is used as input in the stochastic simulation module, which models in detail the polymer chains in the resist film, photoacid generator (PAG) initiation, acid diffusion, and finally resist dissolution. This way it is possible to simulate the LER and correlate it with the edge acuity of the original beam profile. Fig. 2a, shows a 45nm square pattern simulated with the trapezoidal (left) and the rectangular beam (right). The initiate PAG concentration, and the resulted shape of the square after resist dissolution in the case of a resist film consisting of linear, or randomly grafted chains are also shown in Fig. 2. Measuring LER on the final resist edges results in the LER values shown in Fig. 3, while the corresponding average CDs are shown in Fig. 4. These quantitative graphs indicate that indeed increasing edge acuity decreased LER and improved nominal CD replication on the printed pattern.

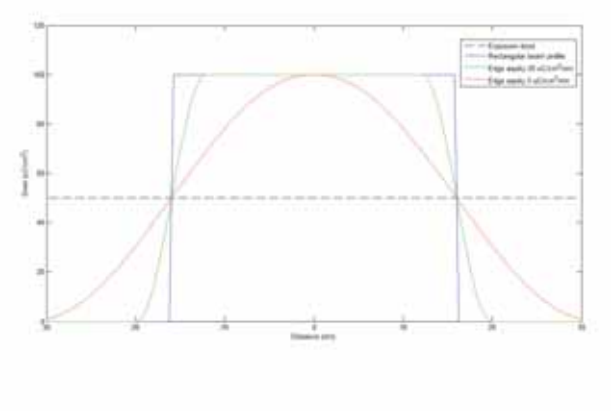


Fig. 1: E-beam Simulation with rectangular, trapezoidal, or Gaussian beam. All functions have the same maximum dose and the same full-width-half-maximum.

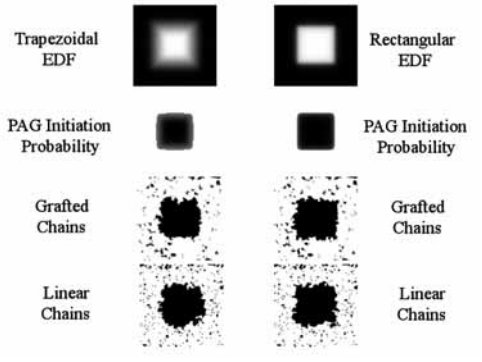


Fig. 2: Grafted and linear chains with 20 monomers / chain, Monomer radius= 0.5nm. Holes nominal CD= 45nm. EDF is determined from 3D Monte Carlo simulation and with convolution with the trapezoidal or the rectangular function.

Stochastic simulation studies of molecular resists

The influence of resist material and its architecture becomes very high in the sub-45nm patterning scales in parameters like critical dimension and line-edge roughness (LER). Molecular resist exhibited very low LER compared with polymer chains of the same overall radius of gyration. Two positive molecular resist architecture, (their digital representation is shown in Fig.2), are modeled with our stochastic lithography simulator in order to predict their LER behavior. The architecture and conformations of the overall molecule followed the modeling of a randomly grafted chain and each part of it could be a different chemical group, modeling the different properties of the molecular resist. This algorithmic representation improvement resulted in very compact molecular resist film lattices with very low free volume (5 – 10% depending on the molecular architecture in 2D and even less than 5% in 3D lattices. For M21 molecules with 0.2nm/cell, 20%PAG concentration and 0.6nm diffusion length, the resulting values for a 50nm trench were LER (3σ) ≈ 0.51 nm and LWR (3σ) ≈ 0.69 nm. Another molecule, M17 of approximately the same size with M21, under the same condition of simulated processing lithography resulted in LER (3σ) ≈ 0.60 nm and LWR (3σ) ≈ 0.75 nm. The values are very promising and recent experimental data verified the low LER/LWR values of these materials.Fig.3, shows a 32nm design rule CMOS inverter gate fabrication-modeling using M17.

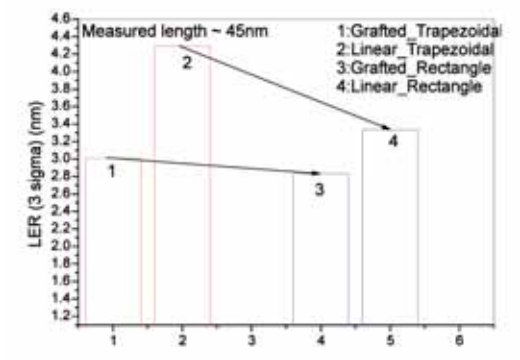


Fig. 3: E-beam Simulation with Trapezoidal and Rectangular Beam Shape. LER decreases with increasing edge acuity especially for linear chains.

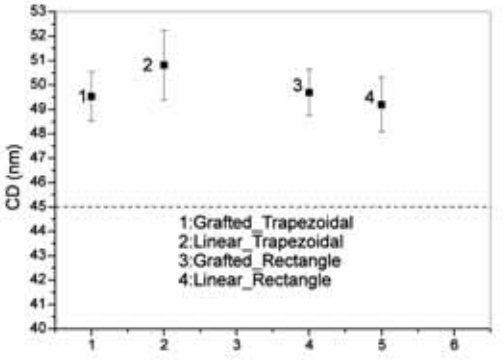


Fig. 4: E-beam Simulation with Trapezoidal and Rectangular Beam Shape. CD accuracy improves with increasing edge acuity (cases 3,4).

The e-beam lithography simulation approach described above was applied also for the simulation of Proton Beam Writing (PBW), a promising high resolution lithographic technology. For the PBW simulation, a complete model of proton energy transfer from a proton beam to a photoresist film was developed.

By applying the simulation software presented in the previous section, the PBW interaction with matter was explored. In Fig. 5 the energy deposition vs. sample's depth, due to point PB exposure, for 18μm PMMA film thickness is illustrated. The limited energy deposition dependence of the energy deposition with the resist depth (increased by 17% only) is one of the advantages of the PBW over the EBL for the patterning of thick films. In Fig. 6 the energy deposition vs. lateral dimension for various resist depths is presented. It is clear that the beam broadening is very small regardless the very high film thicknesses and certainly is considerably smaller compared to the broadening in EBL. This limited beam broadening is the second advantage of the PBW over the EBL for thick resist film patterning. These two advantages make the PBW the ideal

approach for mask-less patterning of high aspect ratio structures limited only by the initial proton beam diameter and the ability of the resist material to withstand high aspect ratio structures. In fig. 7 the energy deposited, cross-section, for a line exposure is illustrated, while in Fig.8 the actually negligible proximity effect is proven for a layout including a cross pattern. In the EBL case, the proximity would cause significant deviations of the resulted trenchwidth over the whole line length.

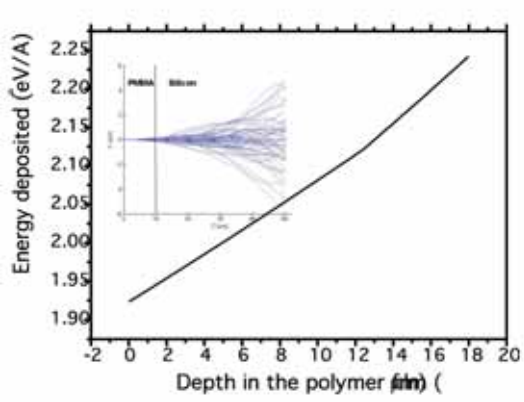


Fig. 5: The energy deposition vs. resist depth, using our Monte - Carlo simulations for 2 MeV protons impinging into 18μm PMMA film on Si substrate.

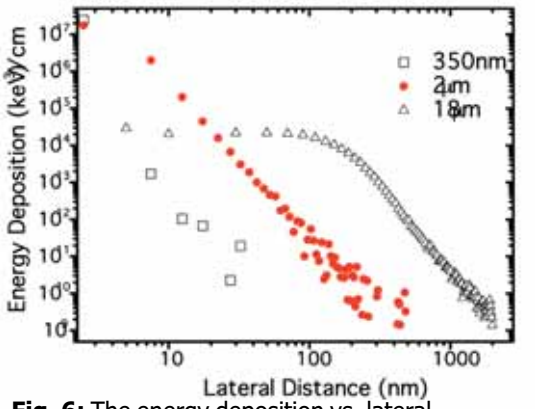


Fig. 6: The energy deposition vs. lateral dimension for various PMMA resist films (350nm, 2μm and 18μm) at the resist/Si interface. The beam broadening is very small regardless the very high film thicknesses.

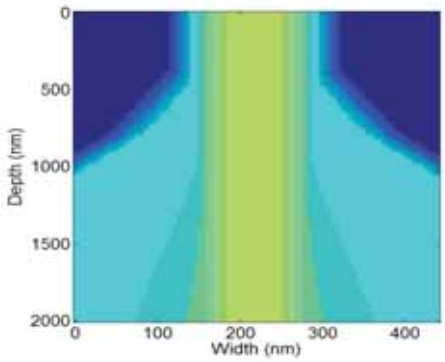


Fig. 7: Energy deposition profile (cross-section) for a 40nm wide line exposed with a beam of 100nm diameter.

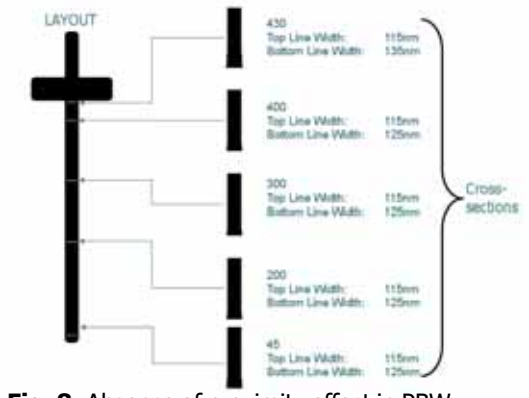


Fig. 8: Absence of proximity effect in PBW

Processing effects on the dissolution properties of thin chemically amplified photoresist films

Resist film thickness is anticipated to be 60 nm in the 22 nm technology node setting significant processing challenges due to resist non-bulk behavior. The changes in the dissolution rate of a commercial positive DUV polymer based chemically amplified resist platform due to various processing conditions such as film thickness, exposure dose, and thermal processing conditions, was experimentally investigated. It was quantified among others, the way an increase of PAB

temperature deteriorates dissolution rate at low exposure dose, while in higher exposure doses increasing PAB temperature enhances dissolution rate. Also, an analytic model for the dissolution rate was imported on a stochastic lithography simulator and first quantitative results for thin films are reported.

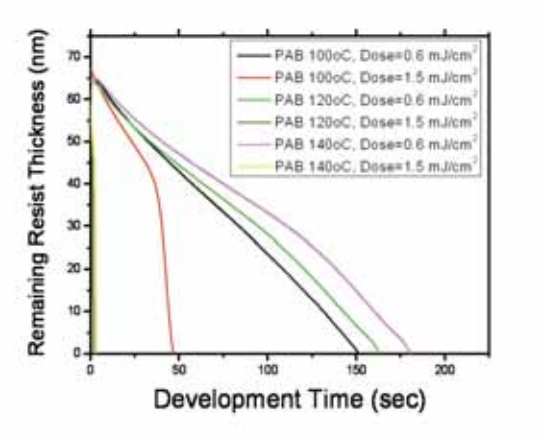


Fig.9: Film thickness evolution of 65nm thick AZ6270 films, processed at various PAB conditions, for two exposure doses (low and high)

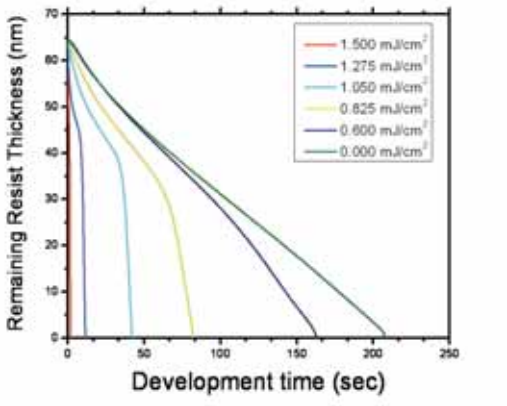


Fig. 10: Film thickness evolution of 65nm thick AZ6270 (AZ-EM) films for a wide exposure dose range. Unexposed films are dissolved smoothly with a low Dissolution Rate (DR). At high doses, two DR are observed.

A new imaging approach based on a thermally developable, etch resistant molecular material

A new imaging approach that is allowed by molecules with certain molecular structure characteristics as the 1,8 Naphthalenedimethanol (Fig.11) was introduced by our group. This molecule is soluble and can form films by spin coating, although it is also suitable for vacuum deposition. It was found that in the presence of a photoacid generator and after exposure in the 248 nm area (exposure at 193 nm is also possible) the sublimation temperature changes dramatically as shown in Fig. 12.

The proposed mechanism and the imaging principle are also shown in Fig. 11. In acidic environment 1,8 Naphthalan is created by the cyclization of 1,8 Naphthalenedimethanol [1]. The produced 1, 8 Naphthalan has lower sublimation temperature than the 1,8 Naphthalenedimethanol so that in the PEB step only the exposed area is developed. In figure 12, IR spectra for the 1,8 Naphthalenedimethanol without and with addition of PAG are presented. We can follow the sublimation of the initial diole by the dramatic reduction of all the peaks in the IR spectrum. In the left spectrum, this reduction occurs at ~ 150 °C but after the addition of PAG and exposure, the reduction occurs at ~ 60 °C. The produced chemical compound (ether) is indeed expected to have a distinctly lower sublimation temperature than the initial diole, due to the dramatic reduction of the intermolecular bonding.

1,8 Naphthalenedimethanol-based films showed very good etch resistance performance as expected by the high aromatic content of the compound. In this respect it seems that there is improvement in comparison with other thermally devolapable systems studied in the past. It should also be noticed the close structural resemblance of the studied molecule with the currently

investigated polyaromatic compounds in the field of organic electronics suggesting that this approach may find applications in patterning schemes for this area as well.

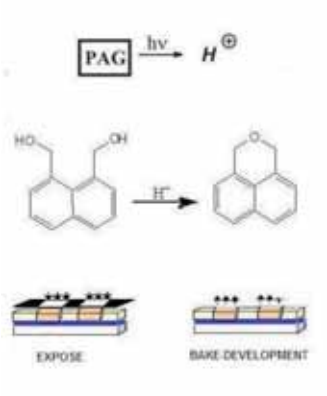


Fig. 11: Imaging Principle. The initial 1,8 Naphthalenedimethanol has distinctly higher sublimation temperature (~150 °C) compared with the produced 1,8 Naphthalan (~60 °C)

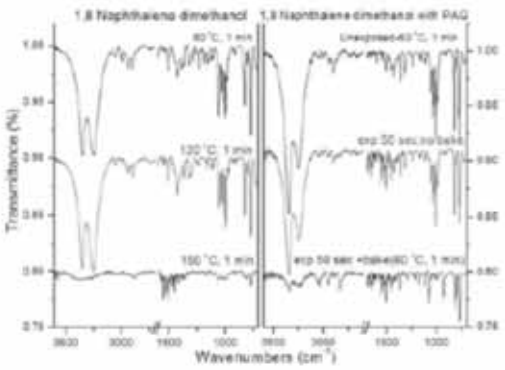


Fig. 12: IR spectra for several temperatures. Left: Films without PAG, Right: Films with PAG.

B. Lithographic materials and processes for micro-nano structure fabrication in MEMs and Nano-biotechnology

Photolithographic approaches in bio-surfaces functionalization

The chemical binding of biotin derivatives on patterned epoxy resist (EPR), which was first proposed by our group last year, has been further advanced. The epoxy resist used is a high resolution material that can be applied for the fabrication of submicron structures with deep UV exposure but has been also proved capable for sub 100 nm lithography if a suitable form of radiation, for instance e-beam, is used. The innovative aspect in this method relies in the fact that the epoxy resist is used for the creation of the micro structures and at the same time as substrate for covalent binding of biomolecules. The important factor of the proposed process is to tune the lithographic performance of the resist while keeping its chemical binding capacity in order to achieve the maximum resolution and the highest binding performance.

Unmodified biotin and biotin derivatives have been tested for binding on unexposed resist and on resist exposed at different doses. The best results were obtained the sulfo-NHS-LC-biotin, Using the lithographically sufficient dose, arrays of spots with diameter of 0.5 to 50 microns were created through covalent binding of sulfo-NHS-LC-biotin. The immobilized biotin was detected under a fluorescence microscope after reaction with AlexaFluor® 546 labeled streptavidin. As it shown in Fig. 6, spots with good morphology and intra-spot homogeneity were obtained for the whole range of spot diameters tested. The binding of biotin onto the microstructures created following the proposed method can be applied for the immobilization of any biotinylated protein onto the microstructures by exploiting the biotin streptavidin linkage. To confirm the chemical activity of the epoxy film, the fluorescence substance fluorescein was also immobilized onto an epoxy patterned surface using the reactive fluorescein isothiocyanate ester (FITC). As it is shown in Fig. 13, FITC was also immobilized very effectively onto the photolithographically defined epoxy micro structures. Conclusively any substance that can react with the epoxy resist can be patterned onto the surface and thus, the proposed method can be applied for a wide range of applications

beyond patterning of biomolecules. It must be noted that the size of the structures that can be created is limited only by the capacity of the exposure tool whereas at the same time photolithography offers unlimited freedom concerning the structure shape.

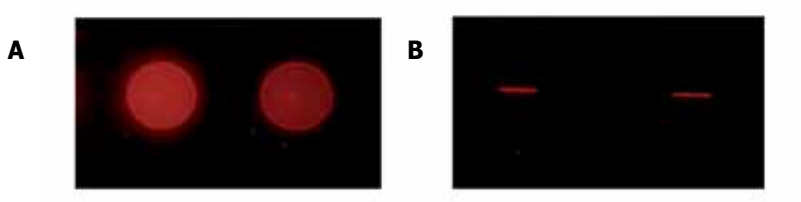


Fig. 13: Fluorescence images of (a) 50 μm biotin spots, (b) 0.5 μm biotin spots and (c) 5 μm FITC spots created to an epoxy patterned surface. The insert in (b) is a blow-up showing details of the spots.

New photoacid generation approach based on Dawson polyoxometallates

Polyoxometallates as potential molecular components of electronic devices

The capability of ammonium 18-molybdodiphosphate, $(NH4)_6P_2Mo_{18}O_{62}$, and ammonium 18-tungstodiphosphate, $(NH_4)_6P_2W_{18}O_{62}$, to generate acid photochemically within polymeric films with hydroxylic functional groups was demonstrated by our group. The polymer mainly investigated was the poly(2-hydroxyethyl methacrylate) (PHEMA). Upon UV irradiation both 2:18 polyoxometalates (POMs) investigated are reduced with concomitant oxidation of PHEMA and generation of acid, which subsequently catalyzes the crosslinking of PHEMA. The photoacid generation was monitored with an appropriate acid indicator (4-dimethylamino-4_-nitrostilbene, DANS) using UV spectroscopy. By comparing the efficiency of both POMs to induce acid-catalyzed crosslinking of PHEMA under similar conditions, the W based ion is found to be more efficient in photoacid generation than the Mo based ion. Imaging of the POM-containing PHEMA films through UV photolithographic processing was demonstrated. It should be emphasized that both POMs can be entirely leached during the development step by using pure water as developer, resulting to patterned PHEMA films (fig.14). This characteristic renders the investigated POMs attractive materials for applications especially in the area of biomaterials where removal of the photoacid generator from the film at the end of the process is desirable.

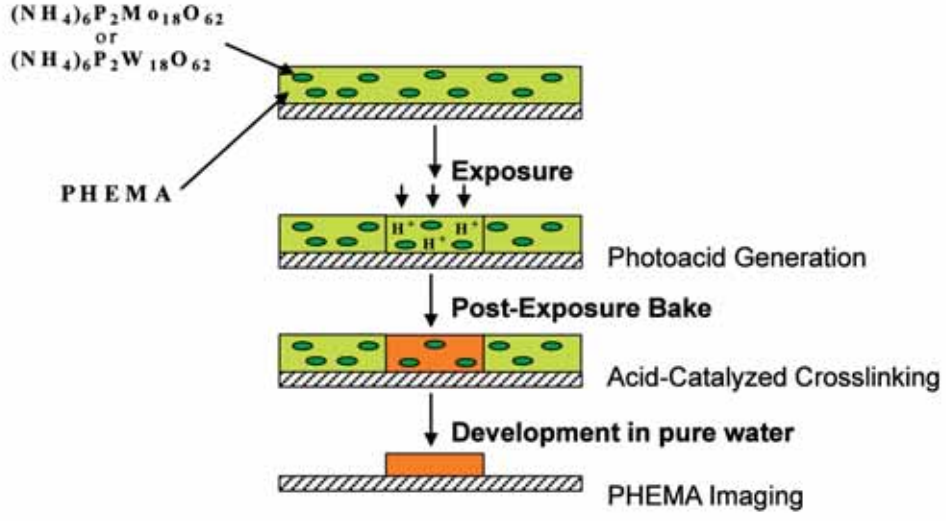


Fig. 14: Lithographic process based on photoacid generation by ammonium salts of Dawson polyoxometallates resulting to PHEMA imaging

Fabrication of [Co/Bi]n wire structures

[Co(1 nm)/Bi(2.5 nm)]n (n = 10 or 20) line structures on the Si(0 0 1)/SiNx substrate were fabricated by conventional patterning and deposition steps for the evaluation of the grain-boundary resistance's contribution to the magneto-transport properties. The fabrication involves 2 lithographic and 2 sputtering deposition steps, leading to 5 rectangular-shaped and parallel magnetic lines with thickness 60 nm and line width 2 μm. A rectangular magnetic pad is attached to each line. First, the layout for the magnetic wires is transferred on a photoresist film spin coated on a Si(100)/SiNx (100 nm) substrate. Then, the substrate is covered with a 60 nm thick magnetic film via sputtering and a lift-off process of the photoresist follows. The wafer with the magnetic wires is covered again with the photoresist and after a second lithography step, the layout of the electrodes appears. Finally, sputter deposition of a thin Cr (20nm) buffer layer and 350nm thick Au layer is followed by a lift-off process of the photoresist, resulting in well defined line structures with pad

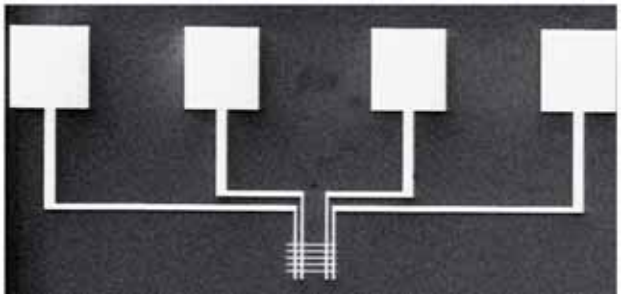


Fig. 15: SEM image of the fabricated device. Five [Co/Bi]n-lines are crossed by four Au electrodes.

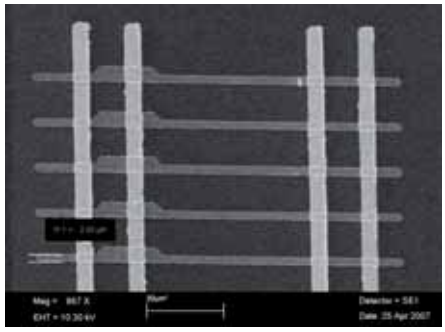


Fig. 16: Higher magnification of the structures, showing details of Au-electrodes crossing one magnetic pad and one magnetic line .

C. Materials for organic/molecular electronics

Polyoxometallates as potential molecular components of electronic devices

Polyoxometallates of Mo and W are investigated as potential molecular components of electrtronic devices and in particular memory devices based either on electron or on proton transport and storage. The relevant activities are carried out in collaboration with Project II.3 (Project Leader N. Glezos) and Project II.2 (Project Leader P. Normand) and the results are reported in the corresponding sections.

Hybrid polymer-inorganic light-emitting diodes with solution-processed polyoxometalates as electron transport layers

Improved performance single-layer polymer light-emitting diodes (PLEDs) based on polyfluorene derivatives were demonstrated. A thin solution processed hydrophilic tungstate polyoxometalates layer, such as $H_3PW_{12}O_{40}$, was introduced between the green emitting copolymer poly[(9,9-dioctylfluorenyl-2,7-diyl)-co-(1,4-benzo-{2,1',3}-thiadiazole)] (YE) and the cathode (Fig. 17) and its role was examined in the improvement of the device performance. Improved efficiencies by a factor of up to 1.5 (Fig. 17) were achieved as a result of the improved electron injection and

transport at the cathode/POM interface in PLEDs. Possible mechanisms for improved device performance in the context of energetic level alignment at the cathode/POM interface (Fig. 18) are investigated

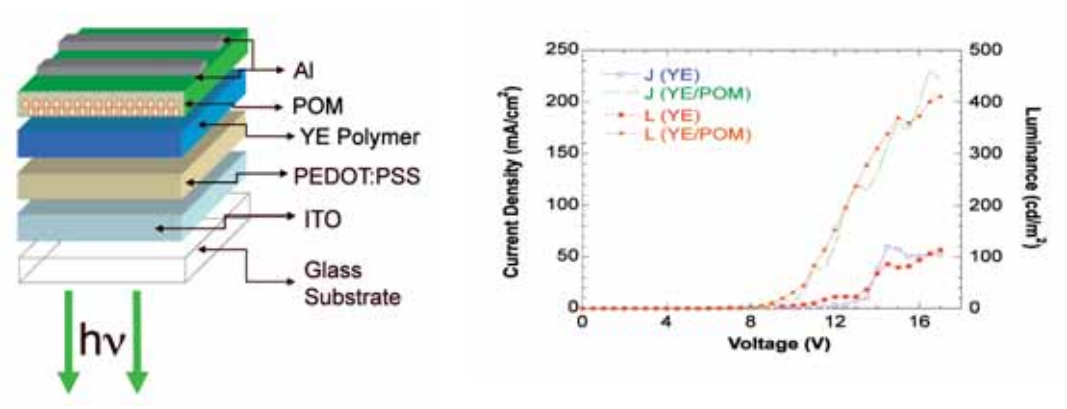


Fig. 17: Device structure (left) and J-V-L characteristics (right) of a YE PLED having a thin POM layer inserted between the cathode ant the active layer.

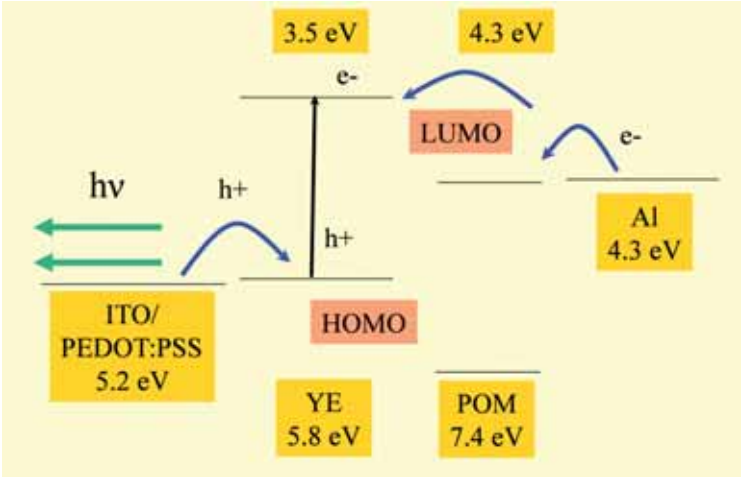


Fig. 18: Energy level diagram of a YE/POM LED

Hybrid polymer-inorganic solar cells with solution-processed polyoxometalates as exciton blocking/optical spacer

Improved performance bulk-heterojunction pphotovolta_cs (PVs) based on donor/acceptor polymer (regioregular poly(hexyl-thiophene)/fullerene ([6,6]-phenylC_{70}-butyric acid methyl ester) heterostructures upon inserting a thin layer of POM (Fig. 19) was demonstrated. It should be noticed that POMs represent a family of inorganic molecular oxides well known for their comparable with TiO_2 properties in the area of photocatalysis. In the case of PVs the improved performance upon the insertion of POM (Fig 19.) is attributed to the enhanced absorption as well as the exciton blocking ability of POM in PVs (Fig. 20).

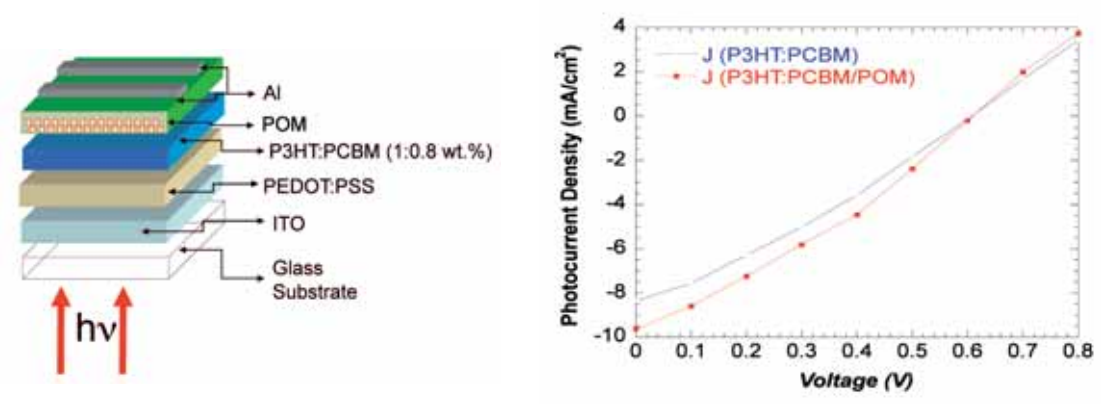


Fig. 19: PV device structure with POM layer **(left)** and J-V characteristics **(right)** where increased photocurrent suggests improved absorption in the P3HT:PCBM bulk.

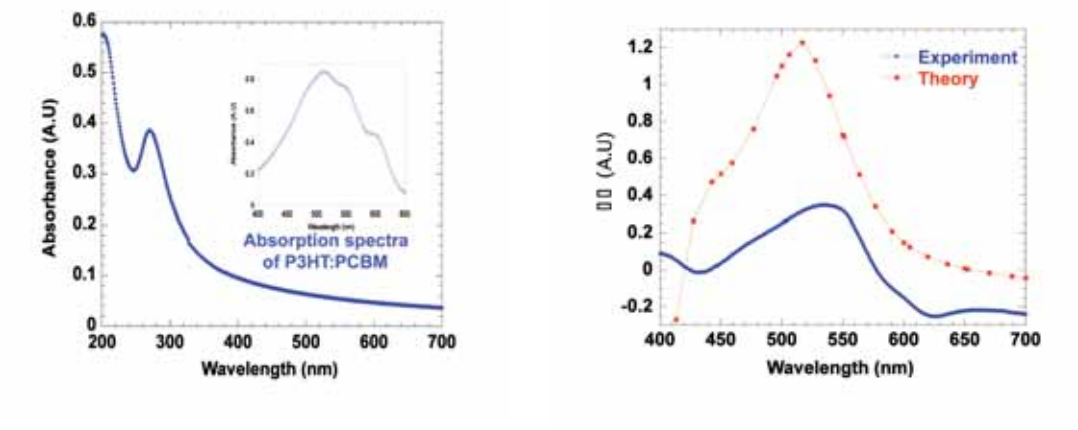


Fig. 20: Overall increased absorption in the spectral region where the P3HT:PCBM active layer absorbs when POM is used as an optical spacer.

Tuning the emitting colour of OLEDs: Towards device performance optimization and new applications

Continuing the research activity on the emission tuning of OLEDs following a photochemical route proposed by our group two years ago (M. Vasilopoulou et al., Adv. Funct. Mater. 2007), we worked towards the optimization of devices performance and the exploration of new possible applications of this technology in the area of all plastic microsystems.

It was first shown that the addition of photoacid generations (necessary in our emission tuning approach) inside the emissive layer of OLEDs can result to improved charge injection. Fig.21 (left). Although the luminance is in certain cases quenched, (eg when triphenyl sulfonium hexafluoroantimanate is used) the use of selected PAGs, such as the triphenyl sulfonium triflate, results to overall improvement of the device performance as shown in Fig. 21 (right).

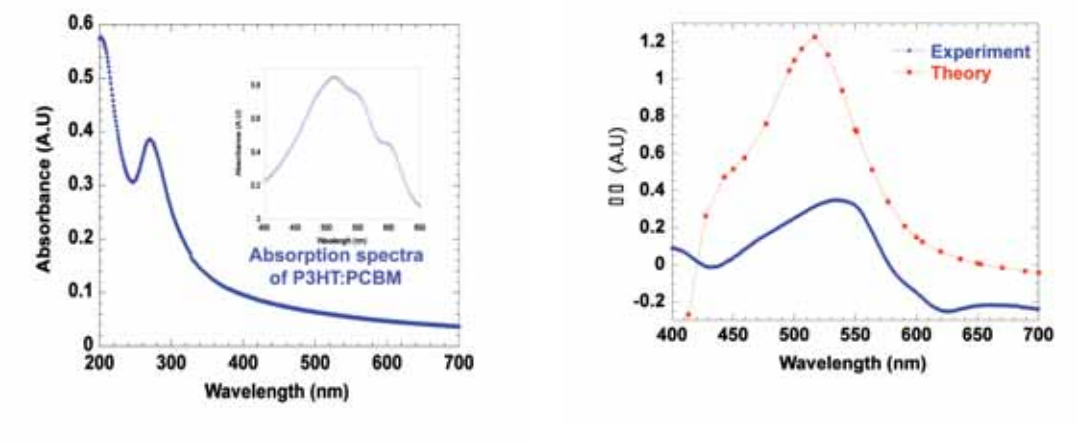


Fig. 20: Influence of the addition of photoacid generators in the emissive layer of OLEDs, using as host polymer the Poly[2-(6-cyano-6-methyl-heptyloxy)-1,4-phenylenederivative (commercial name BE 120).

On the other hand blue emitting flexible PLEDs based on either PVK or BE-120 were fabricated and an anti-rabbit IgG antibody, labeled with two different fluorescent dyes (ALEXA or PHYCO) was then adsorbed on the PET substrate. The blue light output of the PLED excited the fluorescent dye resulting in a red shift of the initial spectrum. The size of the shift depends strongly on the concentration of the fluorescent label. The quantum efficiency of the emitting polymers as well as the optimization of the PLED device characteristics play significant role to the sensitivity of this system. The ability to create patterned multi colour PLEDs onto the same substrate, which has been demonstrated by our group two years ago, can improve the selectivity upon different biomolecules present in the same sample by implementing a spectrally different fluorescent label for each biomolecule (Fig 22). The proposed solid-state PLED arrays are simple to construct, have low cost, low power consumption and are entirely flexible.

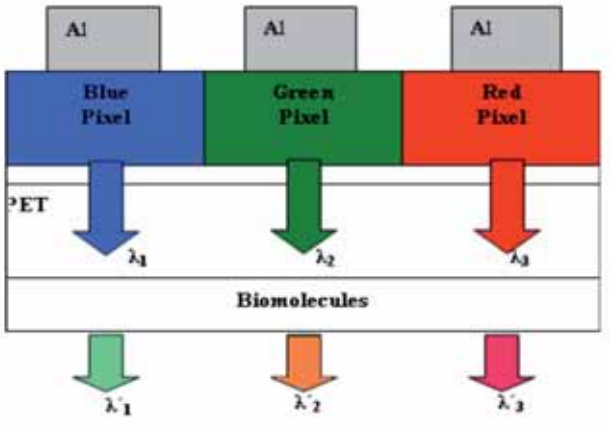


Fig. 21: Schematic representation of our approach towards a photopatterned 3-colour PLED device for the simultaneous detection of biomolecules labeled with different fluorescent dyes.

PROJECT OUTPUT IN 2008

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1. N. A. Stathopoulos, M. Vasilopoulou, L. C. Palilis, D. G. Georgiadou, and P. Argitis, "A combined experimental and simulation study on thickness dependence of the emission characteristics in multicolor single layer organic light-emitting diodes", **Appl. Phys. Lett. 93, 083310, 2008**
2. A.M. Douvas, E. Makarona, N. Glezos, P. Argitis, P. J.A. Mielczarski, E. Mielczrski, "Polyoxometalate-based layered structures for charge transport control in molecular devices", **ACS Nano 2(4), pp. 733-742, 2008**
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6. D.Drygiannakis, G.P.Patsis, K.vanWerden, A.Boudouvis, I.Raptis "Processing effects on the dissolution properties of thin chemically amplified photoresist films", **Microelectron. Eng. 85, 955, 2008**
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9. D.Drygiannakis, G.P.Patsis, N.Tsikrikas, G.Kokkoris, I.Raptis, A.Boudouvis, E.Gogolides, P.Argitis "Stochastic simulation studies of molecular resists for the 32nm technology node", **Microelectron. Eng. 85, 949, 2008**
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13. E.Valamontes, M.Chatzichristidi, N.Tsikrikas, D.Goustouridis, I.Raptis, C. Potiriadis, J.A.vanKan, F.Watt "Realization and simulation of high aspect ratio micro/nano structures by proton beam writing", **Jpn. J. Appl. Phys. 47, 8600, 2008**
14. D. Georgiadou, M. Vasilopoulou, G. Pistolis, D. Dimotikali and P. Argitis, "Energy transfer processes among emitters dispersed in a single polymer layer for colour tuning in OLEDs", P**hysica Status Solidi (A) Applications and Materials, 205 (11), pp. 2526-2531, 2008**
15. N. Stathopoulos, L. C. Palilis, M. Vasilopoulou, A. Botsialas, P. Falaras, and P. Argitis, "All-organic optocouplers based on polymer light-emitting diodes and photodetectors", **Physica Status Solidi (A) Applications and Materials, 205 (11), pp. 2522-2525, 2008**
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1. M. Vasilopoulou, P. Argitis, G. Aspiotis, G. Papadimitropoulos and D. Davazoglou « Flexible WO3 based electrochromic displays using proton conducting solid electrolytes", Physica Status Solidi (C) Current Topics in Solid State Physics 5 (12), 2008, pp. 3868-3871.
2. M. Vasilopoulou, L. C. Palilis, A. Botsialas, D. Georgiadou, , P. Bayiati, N. Vourdas, P. S. Petrou, G. Pistolis, N. Stathopoulos, and P. Argitis, «Flexible Organic Light Emitting Diodes (OLEDs) based on blue emitting polymers», Physica Status Solidi (C) Current Topics in Solid State Physics 5 (12), 2008, pp. 3658-3662.

Presentations in international Conferences

1. L.C. Palilis, M.Vasilopoulou, K.Kotsovos, A.Botsialas, E.Ntantoumis, P.Argitis, "Hybrid polymer-inorganic solar cells and light-emitting diodes with solution-processed polyoxometalates as exciton blocking/optical spacer and electron transport layers", European Materials Research Society (E-MRS) Conference 2008, Strasburg, France, 2008.
2. P.Dimitrakis, L.C.Palilis, M.Vasilopoulou, G.Papadimitropoulos, D.Davazoglou, P.Argitis, P.Normand, "Self-organization of Cu nanoparticles on polythiophene layers for bistable memory devices" European Materials Research Society (E-MRS) Conference 2008, Strasburg, France, 2008.
3. L.C.Palilis, M.Vasilopoulou, K.Kotsovos, D.G.Georgiadou, A.Botsialas, E.Ntantoumis, P.Argitis, "Hybrid polymer-inorganic solar cells and light-emitting diodes with polyoxometalates as dual-function optical spacer and electron injection layers", 1st International Symposium on Flexible Organic Electronics (IS-FOE), Halkidiki, Greece, 2008.
4. L.C.Palilis, M.Vasilopoulou, N.A.Stathopoulos, A.Botsialas, D.G.Georgiadou, G.Pistolis, D.Davazoglou, P.Falaras, P.Argitis, "Air-stable solution-processed polymer optocouplers", 1st International Symposium on Flexible Organic Electronics (IS-FOE), Halkidiki, Greece, 2008
5. M.Vasilopoulou, D.G.Georgiadou, L.C.Palilis, G.Pistolis, P.Argitis, "Photochemical study of organic dyes for color tuning in dye-doped OLEDs", 1st International Symposium on Flexible Organic Electronics (IS-FOE), Halkidiki, Greece, 2008.
6. N.A. Stathopoulos, M.Vasilopoulou, L.C.Palilis, D.G.Georgiadou, P.Argitis, "Thickness effects on the emitting properties of single layer polymer light-emitting diodes (PLEDs) - A combined experimental and theoretical study", 1st International Symposium on Flexible Organic Electronics (IS-FOE), Halkidiki, Greece, 2008.
7. D.G. Georgiadou, M.Vasilopoulou, L.C.Palilis, G.Pistolis, P.Argitis, "Improved charge injection in OLEDs via onium-salt addition inside polymer matrices", 1st International Symposium on Flexible Organic Electronics (IS-FOE), Halkidiki, Greece, 2008. Young Researcher's Award for the Best Poster Presentation.
8. D.G. Georgiadou, M. Vasilopoulou, L. Palilis, G.Pistolis, P.Argitis, "Photochemically Induced Emission tuning of fluorescent and phosphorescent emitters in full colour, single layer organic light emitting didodes", IV International Krutyn summer School, Masurian Lake District, Poland, 2008.
9. P. Pavli, P.S. Petrou, M. Chatzichristidi, A.M. Douvas, D. Niakoula, S.E. Kakabakos, D. Dimotikali, P. Argitis, "Photoresist-based lithographic process for biomolecules patterning through chemical binding on the substrate", 3rd International Workshop on Multianalyte Biosensing Devices 18-19/09/2008.
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11. M. Vasilopoulou, P. S. Petrou, S. E. Kakabakos, L. C. Palilis , D. Georgiadou, A. Botsialas , P. Argitis, "Photopatterned Polymer Light-Emitting Diode (PLED) arrays for biosensing applications", International conference on Micro- and Nano- Engineering (MNE), September 18-21 2008, Athens Greece.
12. M. Vasilopoulou, A. M. Douvas , L. C. Palilis, P. Bayiati, D. Alexandropoulos, N. A. Stathopoulos and P. Argitis, "Partially Fluorinated Methacrylate Polymers as Active and Cladding Components in Optical Waveguides", International conference on Micro- and Nano- Engineering (MNE), September 18-21 2008, Athens Greece.
13. T. Manouras, A.M Douvas, M.Chatzichristidi, N.Vourdas, E.Gogolides, P.Argitis. A new imaging approach based on a thermally developable, etch resistant molecular material. International conference on Micro- and Nano- Engineering (MNE), September 18-21 2008,
14. E. Kapetanakis, A. M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand, "Molecular proton memory", 34th International Conference on Micro- and Nano-Engineering (MNE), Athens, Greece, September 15-19, 2008.

Awards

Young Researcher's Award for the Best Poster Presentation to the graduate student **Dimitra G. Georgiadou** in the **1st International Symposium on Flexible Organic Electronics (IS-FOE), Halkidiki, Greece, July 2008**, for the paper:

D.G.Georgiadou, M.Vasilopoulou, L.C.Palilis, G.Pistolis, P.Argitis, "Improved charge injection in OLEDs via onium-salt addition inside polymer matrices

Patent Applications

"Memory devices using proton-conducting polymeric materials", E. Kapetanakis, A. M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand, Greek Patent Application No 20080100269, 18-04-2008.

LITHOGRAPHY and PLASMA PROCESSES for ELECTRONICS, MICROFLUIDCS, and SURFACE Nano-ENGINEERING

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Collaborating Researchers: K. Misiakos, I. Raptis, P. Argitis, C.Tsamis, S. Chatzandroulis

Permanent Researcher: V. Constantoudis

Researchers on Contract: G.P. Patsis, G. Kokkoris, N. Vourdas

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MSc Students: K. Kontakis, D. Papageorgiou, K. Ellinas, H. Christoyianni

Engineer: K. Kontakis

External collaborators: A. Boudouvis and M. Kalantzopoulou (NTUA, Greece), N. Hadjichristidis and E. Iatrou (UoA, Greece), S.Garbis and A. Vlahou (IIBEAA, Greece),

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Projects Running:

- IEU NMP NoE Nano2Life, Contract No 500057, 1/2/2004-31/1/2008
- EU NMP2 STREP Nanoplasma, Contract No 016424 , 1/4/2006-31/3/2009
- GSRT, PENED 03 ED 202, 1/12/2005-30/06/2009
- DHMOEREUNA-2005, 1/1/2007-30/9/2008
- MD3, IT 214948, 1/12/2007-30/11/2009

Objectives:

Lithography and plasma etching are used as enabling technologies not only for electronics and MEMs, but also for microfluidics and lab-on-a-chip fabrication and modification. We are developing deterministic and stochastic microfabrication processes for a broad range of applications including life sciences using top-down fabrication and plasma directed assembly. Process simulation is a key activity to understand and predict the phenomena explored experimentally:

- For nano-electronics our work focuses on Line Edge Roughness (LER) prediction using molecular simulation, LER noise-free measurement from SEM images, and LER transfer during plasma etching (see section A).
- For microfluidics we use Deep Plasma Etching, and plasma assisted bonding to fabricate PDMS, PMMA, PEEK and Si microfluidic devices, such as chromatography columns. We also demonstrate novel plasma-based micro array fabrication process (see section B).
- We have developed promising nano manufacturing processes for stochastic nano-texturing of polymers, and found that protein adsorption is greatly enhanced on such smart surfaces. In addition we have discovered that plasma directed assembly of periodic nanodots can take place during etching of polymers, thus paving the way to plasma based lithography-less nanofabrication. Finally we propose a fast in-situ method to measure surface roughness during etching using spectroscopic ellipsometry (see section C).
- In order to understand the phenomena induced from plasma processing we are also developing the components of a total multi scale plasma simulator, comprising gas phase kinetics, surface kinetics, microstructure etching, and nanoscale etching simulation. Gas phase kinetics of common gases (C4F8 and SF6) and profile simulation are modeled, as well as nanotexturing of porous films during etching (see section D).

EXAMPLES OF RESEARCH RESULTS IN 2008

A. Micro & Nanopatterning: Micro and Nano Lithography and Line Edge/ Line Width Roughness (LER, LWR)

A1 Molecular simulation of photoresists for double exposure 193nm Lithography

G. P. Patsis, D. Drigiannakis, I. Raptis

Increasingly smaller feature sizes emphasize the importance of the molecular properties of the materials comprising the resist film itself. The material size and architecture effects on LER need to be quantified for accurate LER control. The stochastic lithography simulator (SLS) developed by our group, provides mesoscopic models for the simulation of statistically important effects during the post exposure bake and development of the photoresist (Fig.1). This enables the simulation of line edge roughness related phenomena which become increasingly important in nanolithography.

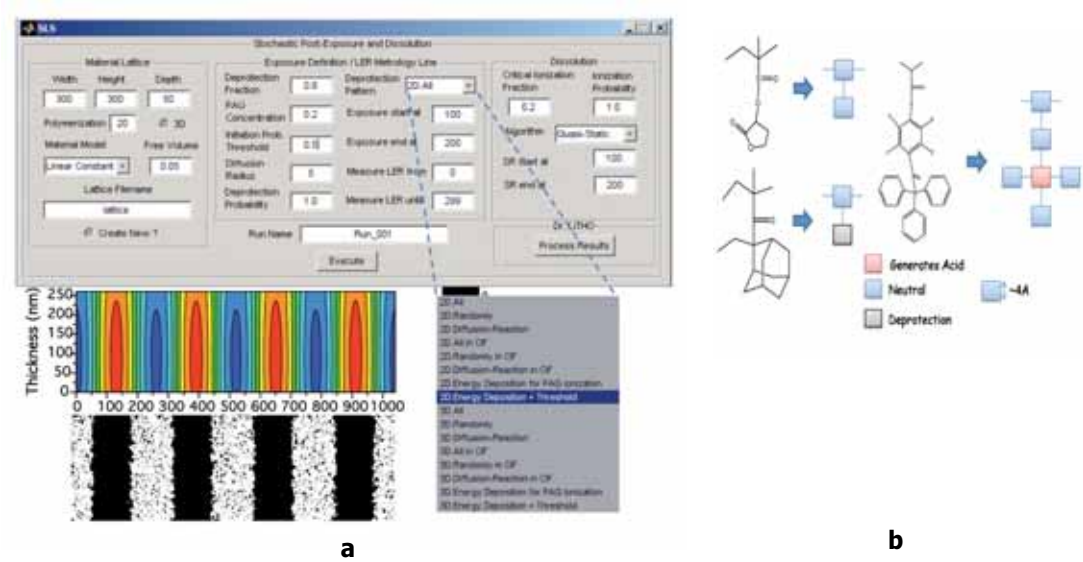


Fig. 1: (a) SLS interface. **(b)** Discrete representation of the molecular structures of typical 193nm resists in the SLS

Mesoscopic models of the resist film need to be highly detailed in order to capture and quantify the effects on LWR, and must consider polymer chain, PAG, and quencher molecule contribution to LER (Fig 1b). Such mesoscopic resist models specify the material in terms of the chemical groups contained in the molecule on an angstrom scale. The SLS can handle 3D lattices with resist, PAG, and quencher molecule descriptions and interaction in the same computational lattice.

C. T. Lee et al, (Proc. SPIE 6519 (2007) 65191E) proposed the use of polymer-bound and polymer-blend PAG chains, in order to minimize acid diffusion degradation of resist edge. Models of such molecular structures (Fig. 1b) were simulated with the 3D SLS for a typical 32nm exposure scenario. The resulting resist profiles were analysed with the off-line SEM-image-metrology software also developed by our group.

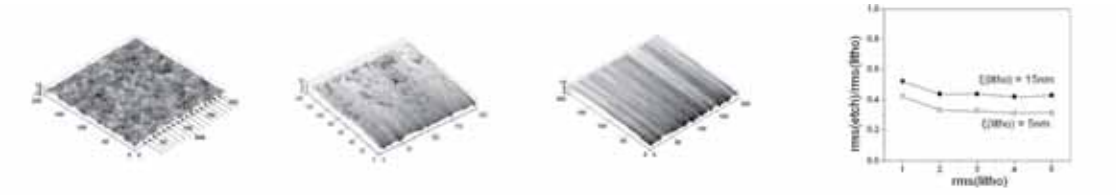
According to these simulations, the polymer - PAG-blend resist has a much higher LER than the resist with polymer bound PAGs. This is in good agreement with the experimental data. It also supports the intuitive explanation that a bounding of the PAG to the polymer chain allows for a high PAG concentration and therefore low acid diffusion and lower LWR.

A2 LER transfer during plasma etching

V. Constantoudis, G. Kokkoris, E. Gogolides

A lot of work has been devoted to the investigation of the material and process origins of Line Edge Roughness (see subtask A1). However, what actually affects device operation is not lithography induced resist LER, but the sidewall roughness of the final pattern transferred by etching to the layers (polySi, SiO_2...) beneath the resist film. We model LER transfer to underlayer taking into account the roughness of the resist sidewalls and assuming totally anisotropic etching. A 3D semi-analytical model is implemented, which mainly considers the effects of the shadowing of the anisotropic flux of incoming ions caused by resist roughness on underlayer LER.

Figure 2a,b,c shows the outcome of the model regarding sidewall morphology evolution. We can see that both resist (Fig. 2b) and underlayer sidewall (Fig. 2c) exhibit striations along ion direction, according to experimental results [e.g. D.L. Goldfarb et al., J. Vac. Sci. Technol. B 22 (2004) 647, X. Hua et al., J. Vac. Sci. Technol. B 24 (2006) 1850].



a Resist sidewall before etching

b Resist sidewall after etching

c Underlayer sidewall after etching

d

Fig. 2

The impact of resist LER on underlayer roughness parameters is displayed in Figure 2d, for two different initial resist correlation lengths (ξ(litho)=5 and 15nm). The model predicts that anisotropic etching significantly reduces the rms value of the underlayer sidewall (ratio of etch/litho less than one). Comparison of these predictions with experiments is the subject of ongoing work of our group.

A3 Noise free spatial LER/LWR metrology from top down SEM images

V. Constantoudis

The control and reduction of LER requires accurate measurement of LER. Up to now, despite the recent advances in scatterometry and CD-AFM techniques for LER/LWR measurement, the most widely used and mature method is based on the analysis of top-down CD-SEM images of line space structures. However, this method suffers from the presence of noise on CD-SEM images. Here we to focus on the noise free estimation of the spatial LER parameters. We showed that, by appropriately extending the methods of other groups [(see J. Villarubia and B. Bunday, SPIE 5752, 2005 and A. Yamaguchi et al. SPIE 6152, 2006)], we can obtain a) a formula for noise free calculation of the HHCF and b) an algorithm for noise free rms vs L curve using, in both cases, the measurements with image noise. The noise free spatial LER parameters of correlation length and roughness exponent can be straightforwardly extracted by these functions. Also, we tested the efficiency of these noise free estimations by using model edges and lines. Fig. 3a shows the HHCF of the true edge (blue solid line), of the measured edge including the image noise (green dashed line) and the corrected noise free HHCF (red line with full square symbols) provided by this work. One can easily notice the astonishing coincidence of the corrected HHCF with the true one. Fig.3b displays the same results but for the rms vs L curve. One can also observe the very good reproduction of rms vs L curve provided by the corrected result.

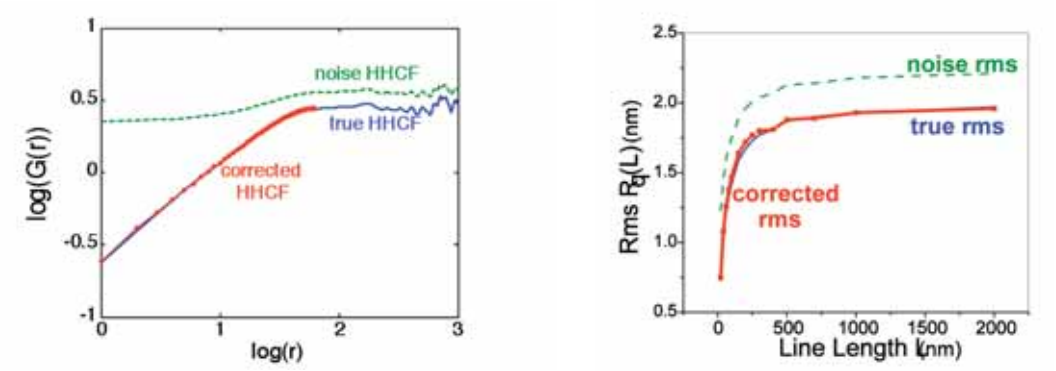


Fig. 3: Height-Height Correlation Function HHCF **(a)** and rms vs L curve **(b)** of the true edge points (blue solid line), of the measured edge points with the image noise (green dashed line) and the corrected estimation using our methodology (red line with full squares). Notice the very good reproduction of true curves by the corrected ones.

B. Microfluidic and Microarray Fabrication for Life Sciences
(see also project III.3)

B1 Plasma etching of PMMA and PEEK microfluidics

K. Tsougeni, K. Kontakis, N. Vourdas, D. Papageorgiou, E. Gogolides

We demonstrate a new mass production amenable technology for fabrication and surface modification of plastic disposable microfluidic devices, namely direct lithography on the plastic substrate followed by deep polymer etching. This year we applied plasma processing to fabricate polymeric microfluidics in Poly(methyl methacrylate) (PMMA) and Poly(ether ether ketone) (PEEK). Deep anisotropic O_2 plasma etching was utilized to etch (pattern) the polymeric substrate via an in situ - high etch resistant - Si-containing photoresist such as photosensitive Polydimethylsiloxane or inorganic-organic hybrid polymer (ORMOCER). Etch rates were optimized to minimize the process time and surface roughness was controllably adjusted from very rough (high aspect ratio nanocolumns) to smooth channels, by choosing appropriate plasma conditions (see below B2). After engraving the PMMA and the PEEK, a bonding step was done to seal the channels and provide their fourth wall. Fig. 4a demonstrates a PEEK plate, after the plasma treatment and after sealing with a pressure adhesive. Demonstration of a mixer was also done on PMMA (Fig. 4b).

a **b**

Fig. 4: (a) The microfluidic channel of PEEK and details in SEM of the cross section after the sealing. **(b)** Mixing of two liquids in PMMA plasma etched microfluidic mixer.

B2 Plasma etching of PDMS microfluidics

M.-E. Vlachopoulou, A. Tserepi

Plasma etching of PDMS by SF_6 plasma has been explored as a route for the fabrication of microfluidic devices made of PDMS with simultaneous control of surface properties (chemistry and topography). PDMS structures with vertical profile were obtained at high plasma powers and bias voltages, appropriate for high etching rates. We demonstrated control on the topography of the etched surfaces, depending on the etching conditions; either smooth surfaces or very rough columnar-like surfaces were obtained (Fig. 5 (a,b)). Further control of the surface topography can be achieved by treating the etched surfaces with wet etchants. Control of the wetting properties of PDMS surfaces has been also achieved, through tuning of the plasma conditions and plasma chemistry (Fig. 5 (c-f)).

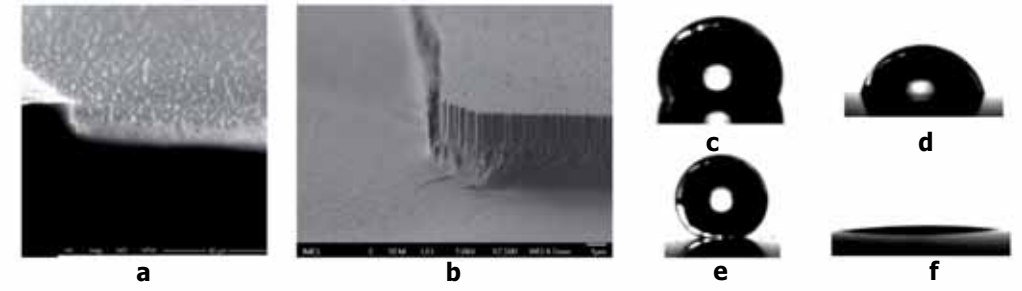


Fig.5: PDMS microchannels 10 μm deep etched for 15 minutes **(a)** under conditions appropriate for creation of high nanoroughness on the bottom, and **(b)** under conditions ensuring smooth etched surfaces. Water droplets on **(c)** an untreated PDMS surface (CA=110°), **(d)** a fresh SF6 treated PDMS surface (CA=75°), **(e)** a three-month aged 6-min SF_6 treated PDMS surface exhibiting superhydrophobicity (CA=145°) and **(f)** a 6-min SF_6 treated PDMS surface, after a subsequent O_2 plasma treatment for 1 min under mild conditions exhibiting superhydrophilicity (CA=5°).

B3 Plasma etching of silicon microfluidics

G. Boulousis, S. Garbis, A. Tserepi, E. Gogolides

We fabricated microfluidic devices in silicon substrates for chromatographic applications such as phosphopeptide separation. The stationary phase that we use is Titanium dioxide for affinity chromatography coupled with electrospray ionization mass spectrometry in collaboration with the Foundation of Biomedical Research of the Academy in Athens. Silicon [100] n-type substrates have been etched in an Alcatel helicon plasma reactor. The microfluidic devices have been etched with the gas chopping process (BOSCH process) (power 1800 Watt, pressure 5.25 Pa, -55 V bias, temperature 15 °C).Two different geometries were fabricated, one with 32 parallel channels and the other with posts as shown in figure 6 (a, c). After engraving the Si substrate, a bonding step with a pressure adhesive or with a PDMS film was done to seal the channels and provide their fourth wall. Fig. 1(b,d) demonstrates a Si microfluidic device after the plasma treatment in a tilted SEM view.

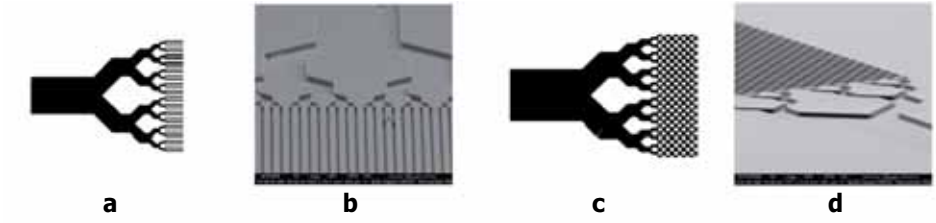


Fig. 6: Photos of the mask layout of the different geometries **(a)** the parallel channels and **(c)** the posts. The Silicon microfluidic devices, **(b)** the parallel channels and **(d)** the posts.

B4 Method for fabrication of protein microarrays through plasma treatment of patterned substrates

P. Bayiati, A. Malainou, A. Tserepi, P. S. Petrou, S. E. Kakabakos

Microarray technology has become an invaluable tool for large scale and high throughput bioanalytical applications. In the last year, the progress we have made concerns on one hand refinement of the already proposed method for protein patterning through plasma selective FC deposition on patterned SiO_2/Si substrates. The capability to immobilize two different proteins on such substrates was demonstrated (Fig. 7(a)), while the stability of protein binding on C_4F_8 plasma treated surfaces was also investigated and was found comparable to commercial PS microtitration plates. Therefore, with the proposed method, high density and high quality (signal to noise 25:1, Fig. 7(b)) protein microarrays can be fabricated exhibiting very good intra-spot homogeneity and inter-spot repeatability. On the other hand, progress achieved during the last year concerns the expansion of our method to low cost substrates, specifically on glass substrates patterned with a photoresist. We have demonstrated selective immobilization of proteins on glass areas surrounded by photoresist (AZ5214), after treatment of such substrates in O2 plasmas (Fig. 7(c)).

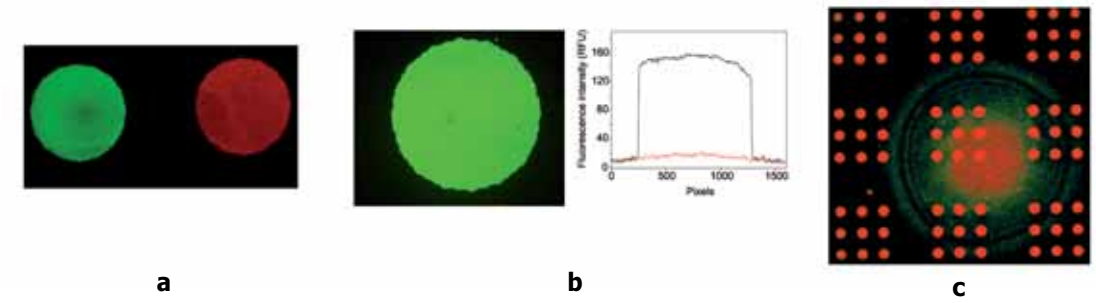


Fig. 7: (a) Fluorescence image of fluorocarbon modified Si substrate bearing SiO_2 spots after immobilization of two different proteins, gamma globulin IgG (green spot) and b-BSA (red spot), **(b)** high quality IgG spot on C_4F_8 plasma treated SiO_2/Si substrates, as demonstrated by the fluorescence intensity plot obtained across the image in (b), and **(c)** fluorescence image of a modified glass substrate patterned with AZ photoresist, demonstrating selective (10:1) protein adsorption on 100 μm glass spots after treatment in O_2 plasmas

C. Plasma nanotexturing and plasma-directed assembly on polymer surfaces: Fabrication, wetting and Bio applications

C1 Plasma nanotexturing of PMMA for increased protein adsorption

K. Tsougeni, P. S. Petrou, S. E. Kakabakos, E. Gogolides

We demonstrated fabrication of random columnar/filamented-like, low and high-aspect ratio micro or nano-structures based on O_2 plasma-induced roughening (nanotexturing) of poly(methyl methacrylate) (PMMA) (Fig. 8). The effect of topography and protein adsorption capacity was investigated. Conditions (plasma treatment, ageing) are sought for maximum and uniform protein adsorption on nanotextured PMMA surfaces. Specifically, adsorption of biotinylated-BSA was found to increase with plasma duration. A 2x to 4xtimes increase in protein adsorption (depending on the protein concentration) was observed on aged surfaces prepared following 5-60 min O_2 plasma treatment compared to untreated PMMA surfaces (Fig. 8b). Highly homogeneous bright protein microspots on such optimized plasma-nanostructured surfaces are also shown (Fig. 8c, d).

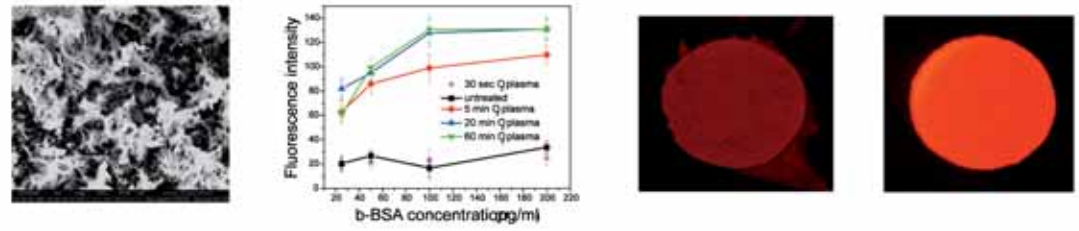


Fig. 8: (a) top down SEM images of PMMA surfaces after 25 min O_2 plasma etching. **(b)** Variation of fluorescence intensity after coating with biotinylated BSA and reaction with AF548 labeled streptavidin, on O_2 plasma treated surfaces, for different plasma exposure time. Fluorescence images of b-BSA spots on a **(c)** flat untreated, **(d)** 5-min O_2 plasma-treated PMMA surface.

C2 Plasma nanotexturing of PDMS for increased protein adsorption

M.-E. Vlachopoulou, P.S. Petrou, S.E. Kakabakos, A. Tserepi

Effect of SF_6 plasma induced nanotexturing on protein adsorption has been explored (Annual Report 2007), revealing increase in protein adsorption with plasma treatment time. This year, this work was continued by studying the effect of ageing of SF_6 treated surfaces on protein adsorption in detail and by using automated protein spotting (nanoplotter) and digital reading of fluorescence intensity by utilizing a scanner (Fig.9).

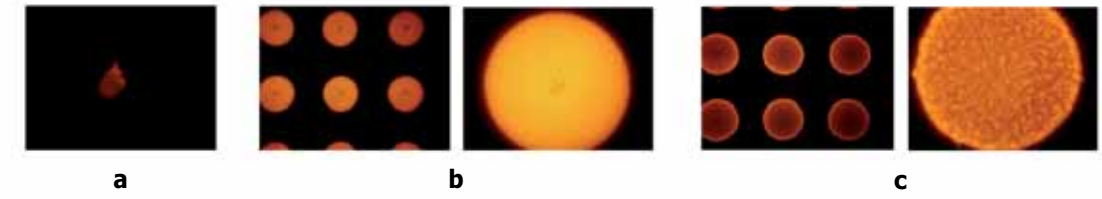


Fig. 9: Spotting of b-BSA on fresh SF_6 treated surfaces with a nanoplotter. Fluorescence images of spots of 200 μg/ml b-BSA **(a)** on an untreated PDMS surface, **(b)** on a 6 min SF_6 treated PDMS surface and **(c)** on a 20 min SF_6 treated PDMS surface.

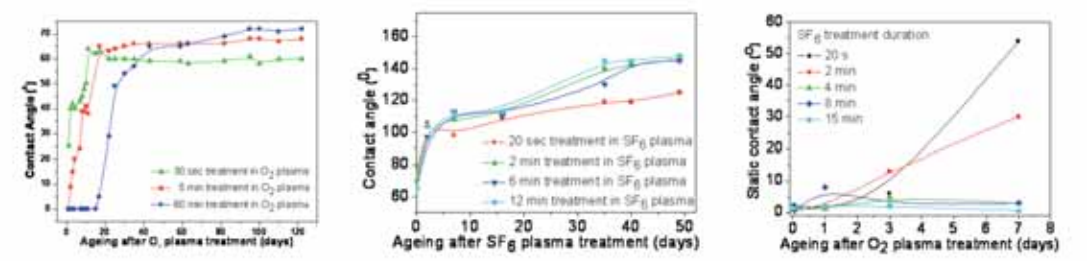
Furthermore, the effect of the subsequent O_2 plasma treatment under mild conditions and its ageing, on protein adsorption was explored. Fresh or aged SF_6 treated surfaces become super-hydrophilic after subsequent treatment with O_2 plasma. Ageing is necessary for spotting on such surfaces, in order to increase the deposited protein concentration. Thermal treatment of such surfaces at 120°C, after wash in deionised water, results in rapid hydrophobic recovery to 90°, without affecting surface topography. Such rapidly recovered hydrophobic surfaces resulted in increased protein adsorption capacity and spots with good homogeneity.

C3 Ageing properties of nanotextured PMMA and PDMS

M.-E. Vlachopoulou, K. Tsougeni, K.G. Beltsios, A. Tserepi, E. Gogolides

Design and control of wetting properties of PMMA and PDMS surfaces has been achieved (see Annual Report 2005, 2006, 2007) utilizing appropriate plasma treatment. This year, ageing of such plasma treated surfaces was studied in detail. Ageing of O_2 plasma treated PMMA surfaces is

presented in Fig.10(a), while ageing of SF_6 treated PDMS surfaces is shown in Fig.10(b), followed by the ageing of such surfaces after a subsequent O_2 plasma treatment under mild conditions in Fig.10(c). In all cases, plasma induced nanoroughness is revealed to delay hydrophobic recovery. Super-hydrophobic PDMS surfaces are obtained after appropriate ageing of SF_6 plasma treatment, while super-hydrophilic PDMS surfaces obtained after, the subsequent to SF_6 plasma, O_2 plasma treatment, are sufficiently stable when treated in SF_6 for at least 4 min.



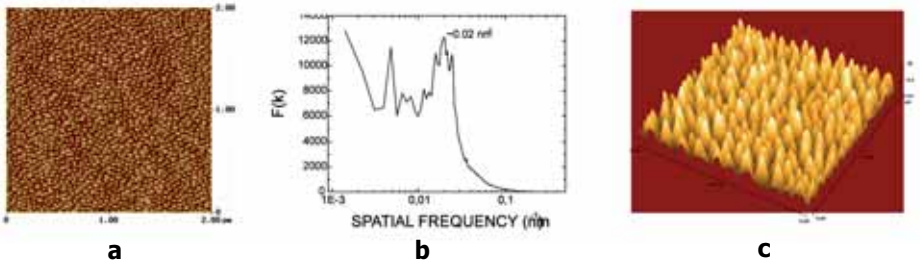
a b c

Fig. 10: Hydrophobic recovery of **(a)** O_2 plasma treated PMMA surfaces and **(b)** SF_6 treated PDMS surfaces depends on treatment time, as plasma induced nanoroughness delays their hydrophobic recovery. Similar conclusion has been obtained for the case of SF_6 treated PDMS surfaces after a subsequent O_2 plasma treatment under mild conditions **(c)**.

C4 Nanodot formation with plasma etching: Towards plasma directed assembly

N. Vourdas, D. Kontziampasis, E. Gogolides

Plasma etching is used to transfer a lithography pattern on to an underlayer (see B1-B4) or to nanotexture a surface as described in C1-C3. The first is a deterministic pattern-transfer process producing ordered structures with dimensions defined by lithography, while the second is stochastic process producing randomly placed and sized nanostructures. Can the plasma be used to produce lithography-less, and ordered nanostructures? Periodic, well-defined, features in the nano-scale are essential in several fields, such as photonics, optical applications, nanoelectronics, high-density information storage media, catalysis, bioanalytics, medicine etc. We discovered a new, fast, low ion energy, plasma-assisted method of fabricating periodic nano-structures with controlled geometrical characteristics on polymer/plastic materials under appropriate plasma conditions (patent application filed). Figure 11a is a 2x2 um^2 Atomic Force Microscopy (AFM) image, where the morphology of the plasma treated PMMA plate is unveiled; a mound-like surface of uniformly spaced and sized nanodots. The peak of F(k) function in Figure 11b at 0.02 nm^{-1} shows 1/0.02=50 nm periodicity. Figure 11c is a 3D AFM image of a PMMA film, unveiling the periodic nano-dots that are formed also on films.



a b c

Fig. 11: (a) 2x2 um^2 AFM image of PMMA plate surface after O_2 plasma treatment. RMS is 10.2 nm. (Nanoscope III AFM, tapping mode from Digital Instruments). **(b)** Circularly averaged fast Fourier transform of the AFM image (a). **(c)**. 2x2 um^2 AFM image of PMMA film surface after O_2 plasma etching down to Silicon substrate. RMS is 6.6 nm. (CP-II AFM, tapping mode, from Veeco)

C5 A method to measure plasma-induced surface roughness of polymeric films

N. Vourdas, G. Kokkoris, E. Gogolides

A method is proposed to measure the root mean square surface roughness (h_{rms}) of thin polymeric films on hard substrates during plasma etching. It utilizes in situ monitoring of the film thickness versus etching time by spectroscopic ellipsometry to extract the height distribution and h_{rms} at the corner point. The corner point is the time instant where etching rate starts to gradually drop; it depends on the initial film thickness, and denotes the gradual exposure of the hard substrate to the plasma due to the advancement of the rough etch front. The h_{rms} is found equal to approximately half of the remaining thickness at corner point. The method compares well with atomic force microscopy measurements.

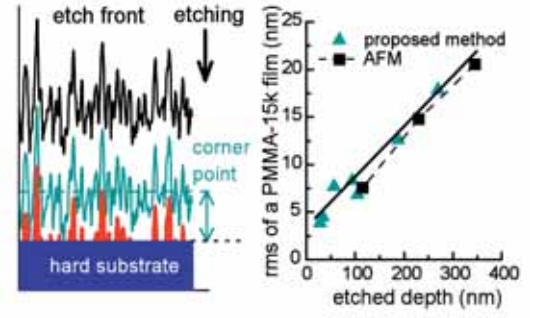


Fig. 12: The simulated evolution of an etch front under anisotropic etching at three time instances t0, tCP (corner point), and t>tCP. hrms versus etched depth according to the proposed method (empty triangles) and from AFM measurements (filled triangles). The material is PMMA-15k.

D. Plasma processes simulation

D1 Towards a complete multi-scale plasma simulator: Global plasma chemistry modules coupled to reactor kinetics for C4F8 and SF6 plasmas

G. Kokkoris, E. Gogolides

Revisited global models for C_4F_8 and SF_6 plasmas are formulated by coupling gas phase and wall surface reaction kinetics. The modules are part of our multi-scale plasma simulation effort. The contribution of this revisit is the inclusion of wall surface kinetics. In order to have a more detailed description of the plasma-wall interaction, a set of surface reactions, which follows experimental observations (e.g. production of CF_3 on the reactor wall during C_4F_8), is considered in the revisited global models. The rate coefficients of the surface reactions are adjustable parameters and are calculated by fitting the model to experimental data from an inductively coupled plasma reactor.

The major findings for C_4F_8 plasma are a) the vast dissociation of C_4F_8 and the dominancy of CF_4 even at low power conditions, and b) the net production of CF_3 and a net consumption of CF_2 at the reactor walls. Concerning SF_6 plasma, a loss mechanism for SFx radicals by deposition of a fluoro-sulfur film on the reactor walls is needed to predict the experimental data. (see fig. 13)

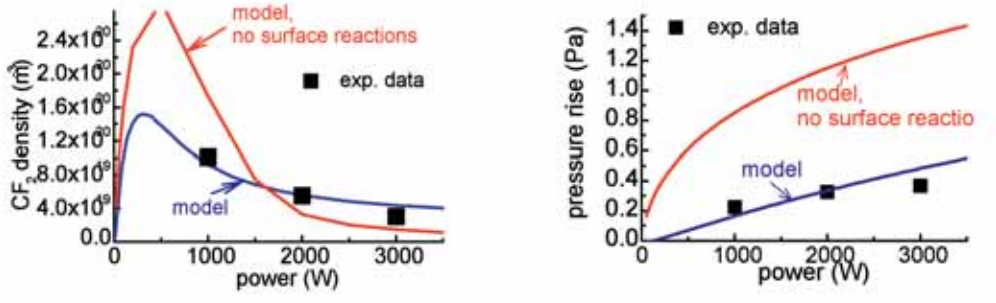


Fig. 13: C_4F_8 plasma (CF_2 density vs. power) and b) SF_6 plasma (pressure rise).

D2 Simulation of profile evolution during deep etching of Silicon nanostructures with neutral beams

G. Kokkoris, A. Tserepi, E. Gogolides

The potential of using hyperthermal neutral beams for etching high aspect ratio Si nanostructures is investigated through simulation. Advantageous aspects over the conventional plasma etching processes are predicted. Ultra high aspect ratio trenches with good anisotropy can be fabricated by neutral beam etching without (as necessary for conventional deep Si plasma etching) sidewall passivation. Sidewall bowing is a possible artifact. Inverse etching lag is predicted, and the neutral flux at the bottom of the structures, and consequently etching, can be sustained in structures with much higher aspect ratio compared with the case of conventional deep Si plasma etching.

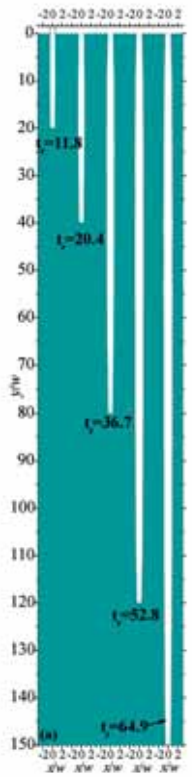


Fig. 14 : Simulated Si trench profiles versus time (tr) for the case of Neutral Beam Etching with a monoenergetic (5 eV) and fully collimated beam of F atoms.

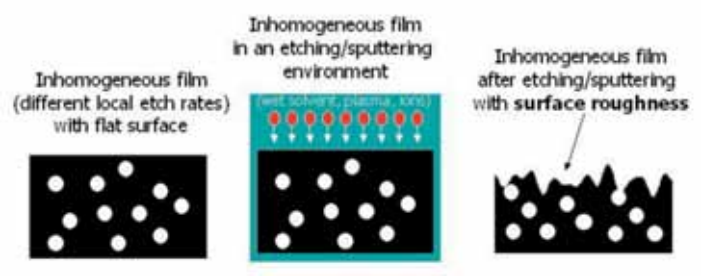
D3 Etching of inhomogeneous materials

V. Constantoudis, H. Christoyianni

During the recent years, films of inhomogeneous materials (porous or composite) are largely used in many areas of nano and microtechnology (e.g. as low-k dielectrics in semiconductor industry) due to their beneficial physicochemical properties. One of the major tools for patterning these films is etching, but experiments have shown that it induces noticeable surface roughness (much more important than that of homogeneous films) which obviously degrades their performance. We model the layer by layer (deterministic) etching of both porous and composite films in two and three dimensions and study the evolution of surface roughness and its dependence on pore and filler properties. A schematic representation of the roughness formation on an initially flat inhomogeneous film during etching is shown in Fig.15a.

We found that in both porous and composite films roughness evolution exhibits anomalous scaling behaviour indicated by the upward shift of the height-height correlation function with etching time

at all scales (see fig.15b). A new universality class is defined by the critical exponents of this evolution characterized by the constancy of correlations and the square root time increase of rms roughness. Finally, it was shown that the presence of even slight correlations between pores or fillers have drastic effects on the evolution of rms roughness (see fig. 15c). The latter finding may be exploited for the detection of correlations between pores or fillers using roughness evolution as a diagnostic tool.



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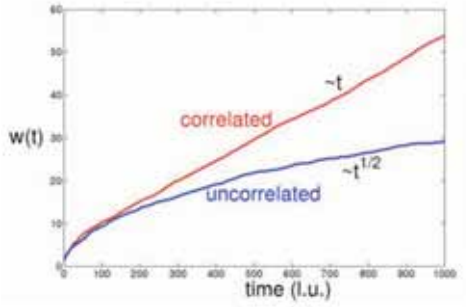

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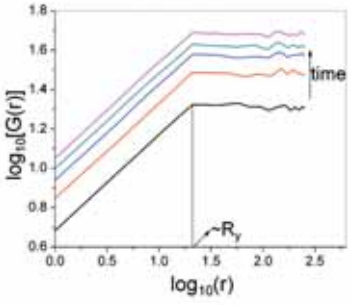

c

Fig. 15: **(a)** Schematic of plasma etching of inhomogeneous materials. **(b)** RMS roughness W vs. etching time for uncorrelated and correlated pores. **(c)** Height-height correlation functions of etched surfaces for various times showing anomalous scaling.

PROJECT OUTPUT in 2008

Publications in International Journals and Reviews

Microfluidics - Bioapplications

1. "Plasma processing for polymeric microfluidics fabrication and surface modification: Effect of super-hydrophobic walls on electroosmotic flow", N. Vourdas, A. Tserepi, A.G. Boudouvis, E. Gogolides, Microelectronic Engineering, 85 (5-6), pp. 1124-1127, (2008)
2. "High-aspect-ratio plasma-induced nanotextured poly(dimethylsiloxane) surfaces with enhanced protein adsorption capacity", Vlachopoulou, M.E., Petrou, P.S., Kakabakos, S.E., Tserepi, A., Gogolides, E., Journal of Vacuum Science and Technology B: Microelectronics and Nanometer Structures, 26 (6), pp. 2543-2548, (2008)
3. "Integration of microfluidics with a love wave sensor for the fabrication of a multisample analytical microdevice", Mitsakakis, K., Tserepi, A., Gizeli, E., Journal of Microelectromechanical Systems, 17 (4), pp. 1010-1019, (2008)
4. "Fabrication of a micro-column for gas separation using poly(dimethylsiloxane) as structural and functional material", A. Malainou, M. E. Vlachopoulou, R. Triantafyllopoulou, A. Tserepi and S. Chatzandroulis, J. Micromech. Microeng., 18, 105007 (2008)

Plasma Nanostructuring, Plasma Processing, Plasma Simulation

5. "Formation and metrology of dual scale nano-morphology on SF6 plasma etched silicon surfaces", G. Boulousis, V. Constantoudis, G. Kokkoris, E. Gogolides, Nanotechnology, 19 (25), art. no. 255301, (9pp), (2008)
6. "Oriented spontaneously formed nano-structures on poly(dimethylsiloxane) films and stamps treated in O2 plasmas", Tsougeni, K., Boulousis, G., Gogolides, E., Tserepi, A., Microelectronic Engineering, 85 (5-6), pp. 1233-1236, (2008)
7. "The potential of neutral beams for deep silicon nanostructure etching", Kokkoris, G., Tserepi, A., Gogolides, E., Journal of Physics D: Applied Physics, 41 (2), art. no. 024004 (2008)
8. "A global model for C4F8 plasmas coupling gas phase and wall surface reaction kinetics", Kokkoris, G., Goodyear, A., Cooke, M., Gogolides, E., Journal of Physics D: Applied Physics, 41 (19), art. no. 195211, (2008)
9. "High-density plasma silicon oxide thin films grown at room-temperature", Vlachopoulou, M.E., Dimitrakis, P., Tserepi, A., Vamvakas, V.Em., Koliopoulou, S., Normand, P., Gogolides, E., Tsoukalas, D., Microelectronic Engineering, 85 (5-6), pp. 1245-1247, (2008)

Lithography and Line Edge Roughness

10. "Stochastic simulation studies of molecular resists for the 32 nm technology node", Drygiannakis, D., Patsis, G.P., Tsikrikas, N., Kokkoris, G., Boudouvis, A., Raptis, I., Gogolides, E., Argitis, P., Microelectronic Engineering, 85 (5-6), pp. 949-954, (2008)
11. "Processing effects on the dissolution properties of thin chemically amplified photoresist films", Drygiannakis, D., Raptis, I., Patsis, G.P., Boudouvis, A., vanWerden, K., Microelectronic Engineering, 85 (5-6), pp. 955-958, (2008)
12. "Electron beam lithography simulation for the patterning of extreme ultraviolet masks", Tsikrikas, N., Patsis, G.P., Raptis, I., Gerardino, A., Quesnel, E., Japanese Journal of Applied Physics, 47 (6 PART 2), pp. 4909-4912, (2008)
13. "Modelling MOSFET gate length variability for future technology nodes", Patsis, G.P., Physica Status Solidi (A) Applications and Materials, 205 (11), pp. 2541-2543, (2008)

Other Collaborative Work

14. "Nonlinear classical model for the decay widths of isoscalar giant monopole resonances", Papachristou, P.K., Mavrommatis, E., Constantoudis, V., Diakonos, F.K., Wambach, J., Physical Review C - Nuclear Physics, 77 (4), art. no. 044305, (2008)
15. "Rare events and their impact on velocity diffusion in a stochastic Fermi-Ulam model", Karlis, A.K., Diakonos, F.K., Constantoudis, V., Schmelcher, P., Physical Review E - Statistical, Nonlinear, and Soft Matter Physics, 78 (4), art. no. 046213, (2008)
16. "Scattering off an oscillating target: Basic mechanisms and their impact on cross sections", Brouzos, I., Karlis, A.K., Chrysanthakopoulos, C.A., Diakonos, F.K., Constantoudis, V., Schmelcher, P., Benet, L., Physical Review E - Statistical, Nonlinear, and Soft Matter Physics, 78 (5), art. no. 056207, (2008)

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1. "Fractal dimension of line-width roughness and its effects on transistor performance" (oral), V. Constantoudis, E. Gogolides, Proceedings of SPIE - The International Society for Optical Engineering, San Jose, California, USA, 24 - 29 February 2008, 6922, art. no. 6922156, (2008)
2. "Electron-Beam-Patterning Simulation and Metrology of Complex Layouts on Si/Mo Multilayer Substrates" (poster), G. P. Patsis, D. Drygiannakis, N. Tsikrikas, I. Raptis, E. Gogolides, Proceedings

of SPIE - The International Society for Optical Engineering, San Jose, California, USA, 24 - 29 February 2008, 6922, art. No. 692287, (2008)

3. "High resolution patterning and simulation on Mo/Si multilayer for EUV masks", Tsikrikas, N., Patsis, G.P., Raptis, I., Gerardino, A., Proceedings of SPIE - The International Society for Optical Engineering, EMLC, Dresden, February 2008, 6792, art. no. 679216, (2008)
4. "An integrated microfluidics-on-SAW ("μF-on-SAW") setup for multi-sample sensing", Mitsakakis, K., Tserepi, A., Gizeli, E., 2008 IEEE International Frequency Control Symposium, FCS, art. no. 4623015, pp. 337-340

Conference Presentations

Invited talks

1. "Microfluidics and microarrays on smart, plasma processed, polymeric substrates", E.Gogolides, A. Tserepi, N. Vourdas, K. Tsougeni, M.E. Vlachopoulou, S. Kakabakos, P. Petrou, Nano2Life Annual Meeting, 25-27 June 2008, Heraklion, Crete, Greece
2. "Nano texturing / Patterning of Polymers with Plasmas: A Versatile Tool for Nanomanufacturing", E.Gogolides, A. Tserepi, N. Vourdas, K. Tsougeni, M.E. Vlachopoulou, G. Boulousis, 1st International Conference from Nanoparticles & Nanomaterials to Nanodevices & Nanosystems, 16-18 June 2008, Halkidiki, Greece
3. "Micro- and Nano- Structuring of Polymers Using Plasma Processes and Potential Manufacturing Applications", E. Gogolides, A. Tserepi, N. Vourdas, M. Vlachopoulou, K. Tsougeni, V. Constantoudis, G. Boulousis, D. Kontziampasis, 6th International Symposium on Nanomanufacturing, 12-14 November 2008, Vouliagmeni, Athens
4. "Polymer Nano-Texturing and Stochastic Nano-Patterning Using Plasma Processing", E. Gogolides, A. Tserepi, N. Vourdas, M.-E. Vlachopoulou, K. Tsougeni, and D. Kontziampasis, The AIChE Annual Meeting, 16-21 November 2008, Philadelphia, PA

Other presentations

Microfluidics - Bioapplications

1. "Plasma etching as a method for fabrication of polymeric microfluidics and micro arrays, and control of their properties" (poster), N. Vourdas, M.E. Vlachopoulou, K. Tsougeni, D. Papageorgiou, P. Petrou, S. Kakabakos, A. Tserepi, E. Gogolides, Lab-on-a-Chip World Congress, 7-8 May 2008, Barcelona, Spain
2. "High density protein patterning through selective plasma-induced fluorocarbon deposition on Si substrates" (poster), P. Bayiati, E. Matrozos, A. Tserepi, P. S. Petrou, S. E. Kakabakos, A. Malainou, E. Gogolides, 10th World Congress on Biosensors, 14-16 May 2008, Shanghai, China
3. "High-Aspect-Ratio Plasma Induced Nanotexturing of Polymers (PDMS, PMMA, PEEK,...) for protein adsorption applications" (poster), M.E.Vlachopoulou, K.Tsougeni, P.Petrou, S.Kakabakos, A.Tserepi, E.Gogolides, EIPBN (The Fifty Second International Conference on electron, ion and photon beam technology and nanofabrication): 27-29 May 2008, Portland
4. "High-Aspect-Ratio Plasma Induced Nanotexturing of Polymers (PDMS, PMMA, PEEK,...) for protein adsorption applications" (poster), M.E.Vlachopoulou, K.Tsougeni, P.Petrou, S.Kakabakos, A.Tserepi, E.Gogolides, Nanobio : 9-13 June 2008, Barcelona, Spain
5. "Microfluidics and microarrays on smart, plasma processed, polymeric substrates" (oral invited), E.Gogolides, A. Tserepi, N. Vourdas, K. Tsougeni, M.E. Vlachopoulou, S. Kakabakos, P. Petrou, Nano2Life Annual Meeting, 25-27 June 2008, Heraklion, Crete, Greece

6. "Plasma-Induced Nanotexturing of Polymers and application in protein adsorption" (oral), M.E.Vlachopoulou, K.Tsougeni, P.S.Petrou, S.E.Kakabakos, A.Tserepi, E.Gogolides, ISPPBA (1st International Symposium on Plasma Processing and Biomedical Applications), 27-29 August 2008, Milos Island, Greece
7. "Selective plasma modification of patterned Si and glass substrates for the fabrication of high-density biomolecular micro-arrays" (oral), P. Bayiati, A. Malainou, E. Matrozos, A. Tserepi, P. S. Petrou, S. E. Kakabakos, E. Gogolides, ISPPBA (1st International Symposium on Plasma Processing and Biomedical Applications), 27-29 August 2008, Milos Island, Greece
8. "A novel microfluidic integration technology for PCB-based devices: Application to microflow sensing" (poster), K. Kontakis, A. Petropoulos, G. Kaltsas, T. Speliotis, E. Gogolides, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
9. "Effect of surface nanostructuring of PDMS on wetting properties, hydrophobic recovery and protein adsorption" (poster), M.-E.Vlachopoulou, P.S.Petrou, S.E.Kakabakos, A.Tserepi, K.Beltsios, E.Gogolides, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
10. "Nanotexturing of polymeric surfaces using plasma processes and applications in wetting control and in protein adsorption" (oral), K. Tsougeni, P. S. Petrou, A. Tserepi, S. E. Kakabakos, E. Gogolides, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
11. "SAW device integrated with microfluidics for array-type biosensing" (poster), K. Mitsakakis, A. Tserepi, E. Gizeli, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
12. "Fabrication of Polymeric Microfluidic Devices and Control of their Surface Properties by Plasma Processing" (oral), K. Tsougeni, N. Vourdas, K. Kontakis, A. Tserepi and E. Gogolides, 6th International Symposium on Nanomanufacturing, 12-14 November 2008, Vouliagmeni, Athens
13. "Plasma-based fabrication of PDMS microfluidic devices of controlled surface roughness" (oral), M.E. Vlachopoulou, A. Tserepi, G. Boulousis, E. Gogolides, Microflu'08 (1st European Conference on Microfluidics) : December 10-12, 2008, Bologna, Italy
14. "Fabrication, Surface Modification and Characterization of Polymeric Microfluidic Devices UsingPlasma Etching and Plasma Processing Technology" (oral), K.Tsougeni, D. Papageorgiou, K. Kontakis, N. Vourdas, A. Tserepi, E. Gogolides, Microflu'08 (1st European Conference on Microfluidics) : December 10-12, 2008, Bologna, Italy
15. "Plasma-deposited fluorocarbon films as hydrophobic layers for electrowetting on dielectric based droplet transport" (oral), P. Bayiati, A. Tserepi, D. Goustouridis, K. Misiakos, E. Gogolides, Microflu'08 (1st European Conference on Microfluidics) : December 10-12, 2008, Bologna, Italy

Plasma Nanostructuring, Plasma Processing, Plasma Simulation

16. "Nano texturing / Patterning of Polymers with Plasmas: A Versatile Tool for Nanomanufacturing" (oral invited), E.Gogolides, A. Tserepi, N. Vourdas, K. Tsougeni, M.E. Vlachopoulou, G. Boulousis, 1st International Conference from Nanoparticles & Nanomaterials to Nanodevices & Nanosystems, 16-18 June 2008, Halkidiki, Greece
17. "Modeling of roughness evolution during the etching of inhomogeneous films : Material-induced anomalous scaling" (oral), V.Constantoudis, H. Christogianni, H. Zakka and E. Gogolides, International Conference in Statistical Physics SigmaPhi 2008, 14-18 July 2008, Kolympari - Chania, Greece
18. "Integrated plasma processing simulation framework, linking tool scale plasma models with 2D feature scale etch simulator", M. Hauguth, B.E. Volland, V. Ishchuk, D. Dreiler, T. Danz, I.W. Rangelow, G. Kokkoris, P. Geka, A. Panagiotopoulos, E. Gogolides, 34th International Conference on Micro and

Nano Engineering 2008, 15-18 September 2008 Athens, Greece

19. "Modeling of line edge roughness transfer during plasma etching", V. Constantoudis, G. Kokkoris, P. Xydi, G. P. Patsis, E. Gogolides, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
20. "Periodic nano-structuring of polymers using plasma processes: Towards plasma-directed polymer self-assembly?" (poster), N. Vourdas, D. Kontziampasis, G. Boulousis, V. Constantoudis, A. Tserepi, E. Gogolides, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
21. "Coupling Reaction Kinetics of Gas Phase, Reactor Wall, and Wafer Surface in C4F8 and SF6 Plasmas with Global Models" (oral), G. Kokkoris, E. Gogolides, A. Goodyear, M. Cooke, 2008 AVS 55th INTERNATIONAL SYMPOSIUM AND EXHIBITION, Boston, MA, 19-24 October, 2008
22. "Nano-Column Formation on Polymers Using Plasma Processes and Application in Wetting and Optical Properties Control" (oral), K. Tsougeni, M. E. Vlachopoulou, N. Vourdas, A. Tserepi, E. Gogolides, 6th International Symposium on Nanomanufacturing, 12-14 November 2008, Vouliagmeni, Athens
23. "Micro- and Nano- Structuring of Polymers Using Plasma Processes and Potential Manufacturing Applications" (oral invited), E. Gogolides, A. Tserepi, N. Vourdas, M. Vlachopoulou, K. Tsougeni, V. Constantoudis, G. Boulousis, D. Kontziampasis, 6th International Symposium on Nanomanufacturing, 12-14 November 2008, Vouliagmeni, Athens
24. "Polymer Nano-Texturing and Stochastic Nano-Patterning Using Plasma Processing" (oral invited), E. Gogolides, A. Tserepi, N. Vourdas, M.-E. Vlachopoulou, K. Tsougeni, and D. Kontziampasis, The AIChE Annual Meeting, 16-21 November 2008, Philadelphia, PA
25. "Coupling Gas Phase and Surface Reaction Kinetics In C4F8 and SF6 Plasmas Used for Si and SiO2 Etching" (oral), G. Kokkoris, E. Gogolides, A. Goodyear, and M. Cooke, The AIChE Annual Meeting, 16-21 November 2008, Philadelphia, PA

Lithography and Line Edge Roughness

26. "Fractal dimension of Line Width Roughness and its effects on transistor performance" (oral), V.Constantoudis and E. Gogolides, SPIE conference: Advanced Lithography 2008, 24-29 February 2008, San Jose, California, USA
27. "Advanced lithography models for strict process control in the 32nm technology node" (oral), G. P. Patsis, D. Drygiannakis, I. Raptis, E. Gogolides, A. Erdmann, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
28. "A new imaging approach based on a thermally developable, etch resistant molecular material" (poster), Th. Manouras, A. M. Douvas, N. Vourdas, E. Gogolides, P. Argitis, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece

Other Collaborative Work

29. "Partially fluorinated methacrylate polymers as active and cladding components in optical waveguides", M. Vasilopoulou, A. M. Douvas, L. C. Palilis, P. Bayiati, D. Alexandropoulos, N. A. Stathopoulos, P. Argitis, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece

Publications in Greek Conference Proceedings

1. "Monte Carlo modeling of micro and nano-roughness evolution during the etching of inhomogeneous films : Material origins of anomalous scaling behavior" (oral), V.Constantoudis, H. Christogianni, H. Zakka and E. Gogolides, XXIV Panhellenic Conference: Solid State Physics and Materials Science, 21-24 September 2008, Herakleion, Greece

2. "Wetting, Optical Property and Protein adsorption Control of Polymer Surfaces by Plasma Nanotexturing" (poster), K.Tsougeni, M.-E.Vlachopoulou, K.Kontakis, D.Papageorgiou, P.S.Petrou, S.E.Kakabakos, A.Tserepi, E.Gogolides, 7th Hellenic Polymer Conference : September 28 - October 1 2008, Ioannina, Greece
3. "Periodic nanodot formation on polymers with plasmas: Towards plasma-directed polymer self-assembly?" (poster), D. Kontziampasis, N. Vourdas, G. Boulousis, V. Constantoudis, A. Tserepi, E. Gogolides, 7th Hellenic Polymer Conference : September 28 - October 1 2008, Ioannina, Greece

Ph. D. thesis

Treatment and modification of polymeric materials for the fabrication and electrowetting actuation of microfluidic devices

Pinelopi Bayiati, Chemist, MSc, PhD
Thesis advisor-supervisor: Angeliki Tserepi
Co-advisors: Prof. Nikos Hadjichristidis, Ass.Prof. Hermis Iatrou
National and Kapodistrian University of Athens, Chemistry Dept.

M. Sc. thesis

Plasma etching of polymers for microfluidics fabrication and sealing

Konstantinos Kontakis, Electronics Engineer, MSc
Thesis Advisor-Supervisor: Evangelos Gogolides
Masters Programme in Microelectronics

Practical Training

Deep etching of polymers

Coralie Vissio
IUT Dept. of Chemistry, Grenoble
Research Supervisor: Angeliki Tserepi

Seminars and Courses

- "Microtechnology for the fabrication and liquid transport in microfluidic devices", A. Tserepi, University of Crete, Department of Materials Science and Technology, Colloquia 2007-2008, March 14, 2008
- During the advanced summer school "Methods in Micro-Nano Technology and Nanobiotechnology", June 30 - July 10, 2008 we tought the following labs:
  "Fabrication of microfluidic devices on plastic substrates by Soft lithography"
  (A. Tserepi, M.-E. Vlachopoulou)
  "Fabrication of plastic microfluidic devices by Lithography and deep polymer plasma etching techniques
  (E. Gogolides, K. Tsougeni, K. Kontakis)
  See video on Nano2Life Site: http://n2lvip.tau.ac.il/
- "A primer to top down micro and nano patterning of Materials for Lab on a Chip Applications", E.Gogolides, A. Tserepi, Nano2Life meeting Crete June 25-27, 2008
- "Microelectronics and Microsystems fabrication processes", (E. Gogolides, D. Davazoglou, A. Nassiopoulou), Postgraduate Programs on Microsystems and Nanodevices of the National Technical University of Athens and Micro and Nano Electronics of the National and Kapodistrian University of Athens
- "Plasma Processing for Micro and Nano Fabrication", (E. Gogolides, G. Kokkoris, V. Constantoudis, A. Tserepi), Postgraduate Program on Microelectronics of the National and Kapodistrian University of Athens

- "Simulation of Micro and Nano-Patterning", (E. Gogolides, G. Kokkoris, V. Constantoudis, A. Tserepi), Postgraduate Program on Mathematical Modelling in Modern Technologies and Financial Engineering of the National Technical University of Athens
- "Micro & Nano Fabrication", (S. Logothetidis, A. Nassiopoulou, E. Gogolides), Postgraduate Program on Nanosciences & Nanotechnologies of the Aristotle University of Thessaloniki
- "Fabrication of integrated circuits: Laboratory courses", (E. Tsoi, D. Kouvatsos, A. Tserepi), Postgraduate Program on Microelectronics of the National and Kapodistrian University of Athens
- "Microfluidic systems", (D. Mathioulakis, I. Anagnostopoulos, A. Tserepi), Postgraduate Program on Microsystems and Nanodevices of the National Technical University of Athens
- "Computational methods", (P. Trohidou, G. Kokkoris), Postgraduate Program on Microelectronics of the National and Kapodistrian University of Athens

New patent applications

- "Method for making a micro-array", A. Tserepi, E. Gogolides, P. Petrou, S. Kakambakos, P. Bayiati, E. Matrozos, PCT Request Filing No: PCT/GR08/00048
- "Method for the fabrication of periodic structures on polymers using plasma processes", E. Gogolides, A.Tserepi, V. Constantoudis, N. Vourdas, G. Boulousis, M.-E. Vlachopoulou, K. Tsougeni, D. Kontziampasis, Application No: 20080100404

Organization of Conferences, Workshops and Project meetings

- 3rd Nano2Life Summer School "Methods in Micro-Nano Technology and Nanobiotechnology", June 30 - July 10 2008, http://imel.demokritos.gr/SummerSchool2008/index.htm
- 34th Micro and Nano Engineering Conference MNE08, September 15 - 18 2008, http://www.mne08.org/

Products for possible licensing or other development

- Software for LER measurement and characterization from SEM images. Demo available on our web site http://www.imel.demokritos.gr/software.html
- Software for nanolithography simulation and LER prediction based on Monte Carlo methods. Demo in Preparation
- Software for topography evolution simulation during plasma processing. Demo released and tested in graduate class for Micro and Nano Fabrication for Electronics and MEMS. (free from www.phietch.org)

FRONT-END PROCESSES

Project Leader: C. Tsamis

Key Researchers: V. Ioannou-Sougleridis, C. Tsamis

PhD candidates: N. Kelaidis, N. Ioannou, V. Assimakopoulos

External Collaborators: D. Skarlatos (Univ. of Patras), C. Krontiras (Univ. of Patras), R. Georga (Univ. of Patras), C. Galiotis (FORTH/ICE-HT), Ph. Komninou (Univ. of Thessaloniki), B. Kellerman (MEMC, USA), M. Seacrist (MEMC, USA)

Projects Running:

- GSRT-PENED-03ED496, "Dopant diffusion and activation in Group-IV semiconductors (Strained Silicon and Germanium) for novel nanoelectronic devices"

Objectives

- Study of dopant diffusion/activation and point/extended defect kinetics in Group-IV semiconductors (Silicon, Strained Silicon, Germanium) for CMOS applications
- Thermal processes for ultra-thin gate dielectrics (oxides, oxynitrides) in Group-IV semiconductors for CMOS applications
- Process optimization for Nanodevices (Fabrication, Electrical Characterization)
- Continuum and atomistic simulation of processes and devices

RESEARCH ACTIVITIES AND MAIN RESULTS WITHIN 2008

Task I: Electrical characterization and Modeling of MOS capacitors on Strained-Silicon*

N. Kelaidis, V. Ioannou-Sougleridis and C. Tsamis

* In collaboration with Physics Dept., Univ. of Patras (D.Skarlatos, C. Krontiras, R. Georga), Physics Dept., Univ. of Thessaloniki (Ph. Komninou), FORTH/ICE-HT (C. Galiotis, J. Parthenios) and MEMC Electronic Materials Inc.(B. Kellerman, M. Seacrist)

Strained-Silicon on relaxed $Si_{1-x}Gex$ has been extensively investigated and implemented as a means to further increase the mobility of carriers thus improving device performance without decreasing device dimensions. Therefore, the study of the oxide and oxynitride formation on strained Silicon grown on Si_xGe_{1-x} substrates is of particular interest. However, excess thermal processing of s-Si can relax the s-Si epilayer and induce Ge diffusion towards the surface, deteriorating the integrity of the s-Si layer and of the two interfaces (s-Si/SiO_2 and the s-Si/SiGe). In the present work, a systematic study is performed on the thermal oxidation of s-Si at various oxidation conditions as well as nitrogen-enriched thermal oxides fabricated by (a) oxynitridation in N_2O (b) oxidation of $N2^+$ implanted s-Si and (c) dry oxidation. For this scope, electrical characterization, structural characterization and RAMAN spectroscopy has been implemented. Computer simulations have also been performed using Synopsys -Taurus software. A wide range of process temperatures has been studied including extreme thermal budget processing conditions, in order to examine the physical phenomena involved.

It has been shown that the electrical properties of the s-Si samples (Fig.1) are governed by the attributes of the two layers, s-Si and SiGe and their interfaces (SiO2/s-Si and s-Si/SiGe). Two

main factors influence the interfacial properties of the oxidized s-Si structures and consequently the electrical response of the MOS capacitors: (a) the extend of the s-Si layer oxidation, i.e. the remaining s-Si thickness and (b) the duration of the post-oxidation annealing in inert ambient. Due to the bandgap discontinuity in the s-Si/SiGe heterostructures, hole confinement effect exists and a characteristic hump in the C-V curves appears (Fig.2).

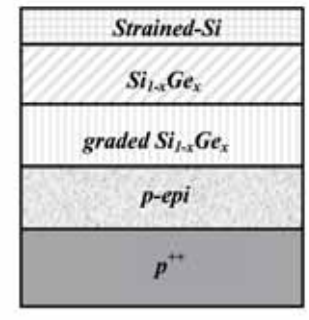

Fig. 1: Experimental structures.

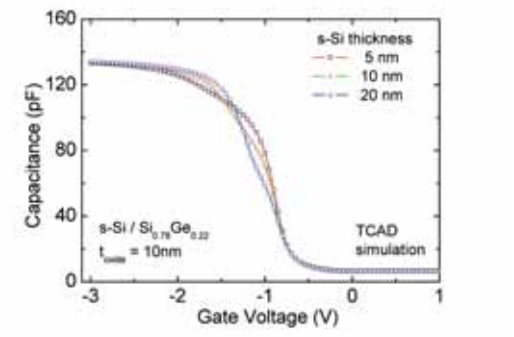

Fig. 2: The effect of s-Si thickness on C-V characteristics. TCAD simulation for a constant gate oxide thickness for S2 substrates: s-Si / $Si_{\neg 0.78}Ge_{0.22}$

When a significant part of the s-Si layer is consumed, the observer hump is completely masked by the interface trap behavior manifested by the strong frequency dispersion of the capacitance in this region. As the oxide thickness increases and the s-Si overlayer is consumed, the frequency dispersion and hump phenomena both become pronounced. This is evident even for lower strain S1 samples (s-Si/$Si0_{0.90}Ge_{0.10}$) where the s-Si layer is intentionally etched before oxidation process by an extended RCA treatment (Fig. 3). Instead, when using Piranha cleaning methods, in conjunction with Nitrogen-enriched oxidation processes, as the N_2O oxynitridation, the oxides demonstrate excellent characteristics (very low density of interface traps, i.e. ~ 1010 $ev^{-1}cm^{-2}$) for a variety of oxidation conditions and total thermal budget induced while no significant frequency dispersion is observed even for higher strain S2 samples (s-Si/$Si_{0.78}Ge_{0.22}$).

These results indicate that the observed frequency dispersion (and increased interface trap density) is related to the remaining s-Si thickness due to the formation of a defective transition layer zone at and/or near the s-Si/SiO_2 interface where the diffused Ge is accumulated. Longer post oxidation annealing may result to a much stronger Ge diffusion effect, and increased amount of Ge at the s-Si/SiGe interface which seems to annihilate interface traps and deform the s-Si/SiGe heterointerface. The elimination of the second interface (s-Si/SiGe) leads to a significantly smaller interface trap density and frequency dispersion effect. Thus, both interfaces contribute to the interface trap density when in close proximity, a result confirmed by TCAD simulation analysis. Additional parallel conductance measurements at various frequencies $G_p(\omega)$ and temperatures show the existence of two contributions to the conductance loss. The first one has activation energy of 0.55 eV, indicating generation-recombination phenomena, while the second has an activation energy of 0.4 eV. (Fig.4).

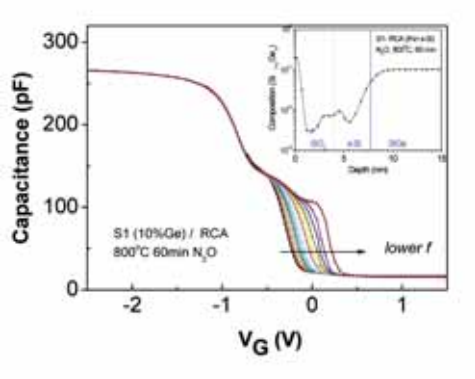

Fig. 3: . Intentionally thinned S1 sample oxidized at 800°C for 60 min and frequency dispersion effect. Inset: SIMS measurements and Ge diffusion

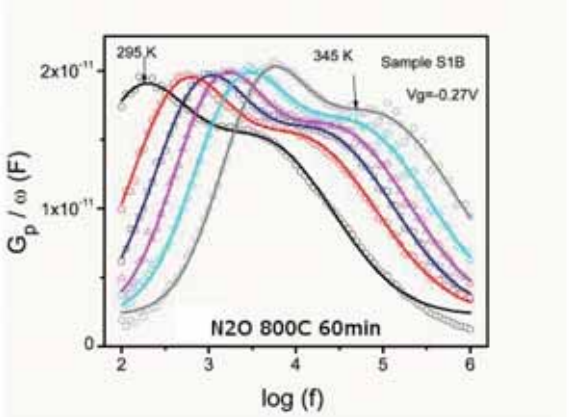

Fig. 4: Evolution of the conductance vs frequency characteristics with temperature of sample S1 at the depletion region. The characteristics were assumed to arise from two different loss mechanisms, and they were de-convoluted into two Gaussian contributions.

For more information please contact Dr. V. Ioannou-Sougleridis (e-mail: v.ioannou@imel.demokritos.gr)

N. Ioannou, V. Assimakopoulos and C. Tsamis

*In collaboration with Physics Dept., Univ. of Patras (D.Skarlatos, C. Krontiras, R. Georga) and Materials Dept., Imperial College, UK (A. Christofi, D.S. McPhail)

Over the last years Germanium has regained its importance for use in microelectronic applications and significant research efforts have focused in the understanding of the fundamental properties of germanium as well as of phenomena related to the technological processes needed for device fabrication. Unavoidably, dopant diffusion and defect kinetics are expected to play a dominant role in this new technology similar to the silicon technology. It is the aim of our work to study dopant diffusion in germanium and to develop models that can predict the phenomena involved.

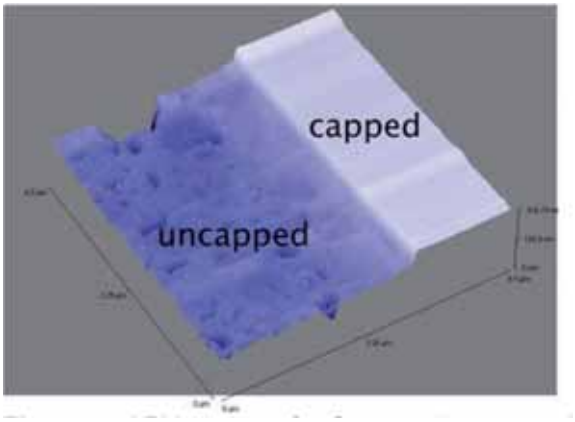

Fig. 5: AFM picture of a Ge sample annealed for 2 hrs at 500 °C showing a step between covered and uncovered area.

During this year we continued our investigation on Ge substrate evaporation and its influence on dopant diffusion. In order to study Ge substrate loss during annealing, patterned lines were formed, using lithography and wet etching, defining areas on the Ge surface that were either passivated or non-passivated. Subsequently samples were annealed at various temperatures (500-575 oC) and times (10 min-3 hrs). A height difference (step) between the passivated and non-passivated areas was observed and measured using stylus profilometry and Atomic Force Microscopy (AFM). This is a clear evidence of Ge substrate loss during annealing. Figure 5 is a typical AFM picture of a Ge sample showing a 116 nm step between passivated and non-passivated areas. The Ge substrate loss is extracted from the height difference between the protected and non-protected areas and is shown as a function of temperature in Figure 6. The data are well described by an Arrhenius law according to the relation:

$$R_{(100)} = 4.75x10^{12} \exp\left[\left(-2.03\ \text{eV}\right)/k_B T\right]\ \text{nm/min} \quad (1)$$

where R_{100} is the (100) Ge substrate loss rate, k_B is Boltzmann's constant and T(° K) the annealing temperature.

Figure 7 shows SIMS profiles of low dose P, at non-passivated Ge substrates after annealing at 500 °C for 1h and 5hrs. We observe a significant P dose loss (about 28% and 54% estimated for 1 hr and 5hrs annealing respectively) which is attributed to Ge substrate loss. Moreover, the dopant loss is accompanied by insignificant P diffusion indicating that the Ge loss mechanism does not induce defects into the substrate that could influence P diffusion. Simulations (shown also in Fig. 7), performed using SYNOPSYS Sentaurus process simulator using a concentration dependent Phosphorus diffusion model shows very good agreement with experimental results if the Ge loss rate given by equation (1) was taken into account.

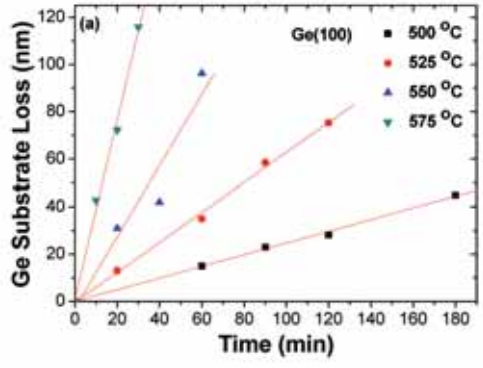

Fig. 6: Ge loss depth versus annealing temperature and time.

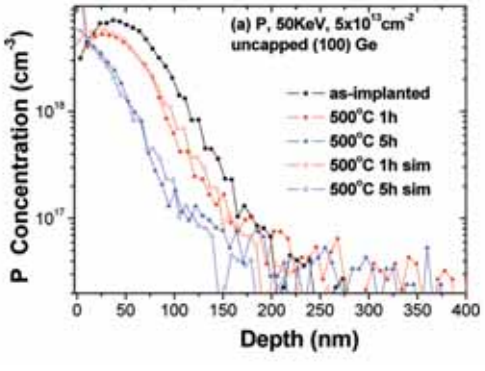

Fig. 7: Experimental and simulated P profiles for uncapped Ge sample s, implanted with a dose of $5x10^{13}$ cm^{-2} and energy 50 keV and after annealing at 500 °C.

For more information please contact Dr. C. Tsamis (e-mail: ctsamis@imel.demokritos.gr)

PROJECT OUTPUT IN 2008

Publications in International Journals and Reviews

1. "Influence of thermal processing on the electrical characteristics of MOS capacitors on strained-Silicon substrates", N. Kelaidis, V. Ioannou-Sougleridis, D. Skarlatos, C. Tsamis, C. A. Krontiras, S. N. Georga, B. Kellerman and M. Seacrist., Thin Solid Films, Volume 517, Issue 1, p. 350-352, November 2008
2. "Simulation of the electrical characteristics of MOS capacitors on strained-silicon substrates", N. Kelaidis, D. Skarlatos, and C. Tsamis, , Phys. Stat. Sol. (c) 5, No. 12, 3647-3650 (2008) / DOI 10.1002
3. "Germanium substrate loss during low temperature annealing and its influence on ion-implanted phosphorous dose loss", M. Ioannou, D. Skarlatos, C. Tsamis, C.A., Krontiras, S.N. Georga, A. Christofi, D.S McPhail, Applied Physics Letters 93 (10), art. no. 101910 (2008)

Conference Proceedings

1. "Thermally induced evaporation of germanium substrate and its influence on dopant diffusion", N. Ioannou, D. Skarlatos, A. Chroneos, C. Tsamis, C. Krontiras, S.N. Georga, M. Pisanias, A. Christofi, D.S. McPhail, , E-MRS 2008, 26-20 May, Strasbourg, France (Poster)

PhD Thesis

"Defect Processes in Germanium", A. Chroneos, Department of Materials, Imperial College of Science, Technology and Medicine, UK, January 2008, Supervisors : Dr C. Tsamis (NCSR"D") and Prof. R. Grimes (Imperial College)

Purchase of new equipmentt

Update of software for Process and Device modeling (Synopsys TCAD Tools 2008)

THIN FILMS by CHEMICAL VAPOR DEPOSITION (CVD)

Project leader: D. Davazoglou

PhD students: G. Papadimitropoulos

Master students: L. Zambelis (Master Programme: Microsystems)

Undergraduate students: M. Delihas, G. Aspiotis

Collaborating scientists:

Dr. M. Vasilopoulou, Dr. T. Speliotis, Dr. D, Kouvatsos, Dr. N. Vourdas

Collaboration with foreign Institutions:

Institute for Photonics and Nanotechnologies, CNR, Italy (Dr. R. Leoni, Mrs. S. Cibella)

Paul Sherrer Institute, Laboratory for Micro- and Nanotechnology, Switzerland, (Dr. V. Auzelyte, Dr. H. Solak)

Projects Running:

- Novel photovoltaic panels with vertical positioning of concentration Si cells, (FOCUS) (PAVET)
- Optical Smoke Detectors (OAKA) (PAVET)

Objectives:

The objectives of this group include research and development in the following:

a) Process and material development

b) Characterization of CVD films

c) Applications

MAIN RESULTS IN 2008

A. Fabrication of planar Copper electrodes by Selective Metal-Organic Chemical Vapor Deposition (SMOCVD)

G. Papadimitropoulos

Copper films were deposited on Si substrates covered with TiN and patterned with AZ3214™ photoresist to form planar interlacing electrodes as in Fig. 1. The deposition of Cu was made selectively on the exposed regions of the TiN layer only and not on the AZ3214™-covered regions (see Fig. 1, left). After Cu deposition the PMMA was removed in acetone under ultrasonic agitation (Fig. 1, right) and the fabrication sequence was finished by reactive ion etching the TiN using the Cu features as hard mask. A novel chemical vapor deposition reactor was used using as precursor hexafluoroacetylacetonate Cu(I) trimethylvinylsilane (CupraSelect®), which is liquid at room temperature and which was directly injected into the reactor with the aid of a direct-liquid injection system using N_2 as carrier gas.

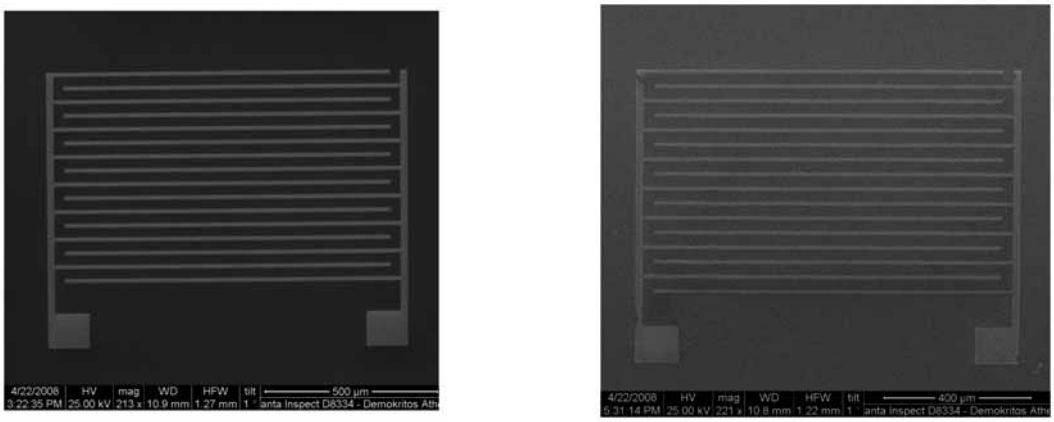

Fig. 1: TSEM micrographs of a couple of interlacing electrodes formed on a TiN covered Si substrate by patterning a AZ5214™ photo-resist layer followed by SCVD of Cu at 120 °C before **(left)** and after **(right)** photo-resist removal.

After the above initial results obtained using optical lithography and with the aim to decrease the dimensions of the obtained features, electron beam lithography was used. TiN covered Si substrates were covered with a 300 nm thick layer of poly-methyl-methacrylate (PMMA), which was patterned with e-beam lithography. After patterning Cu was again deposited selectively on the regions of the substrate that were uncovered by the PMMA. Depositions were carried out within the temperature range 100-150 °C and they were proved to be selective in all cases (see Fig. 2). After deposition the PMMA was removed in acetone and under ultrasonic agitation (Fig. 3). Cu lines with dimensions down to 100 nm and separated by gaps down to 300 nm were obtained as seen in Fig. 3. In all cases the adherence of the Cu layer on the TiN substrate was very good. The fabrication sequence was finishing by the removal of the TiN layer by reactive ion etching using the Cu as hard mask.

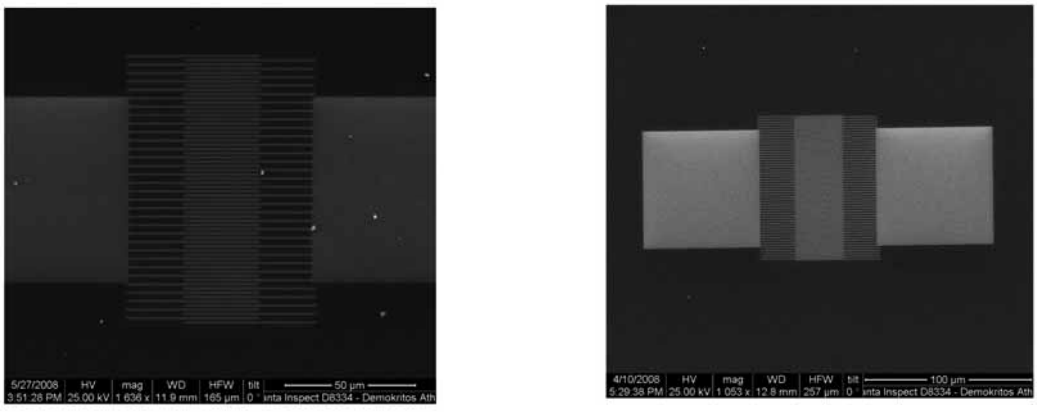

Fig. 2: SEM micrographs of interlacing electrodes formed on a TiN covered Si substrate by e-beam patterning a PMMA layer followed by SCVD of Cu at 100 **(left)**, 120 °C **(right)**. Micrographs were taken before removing the PMMA layer.

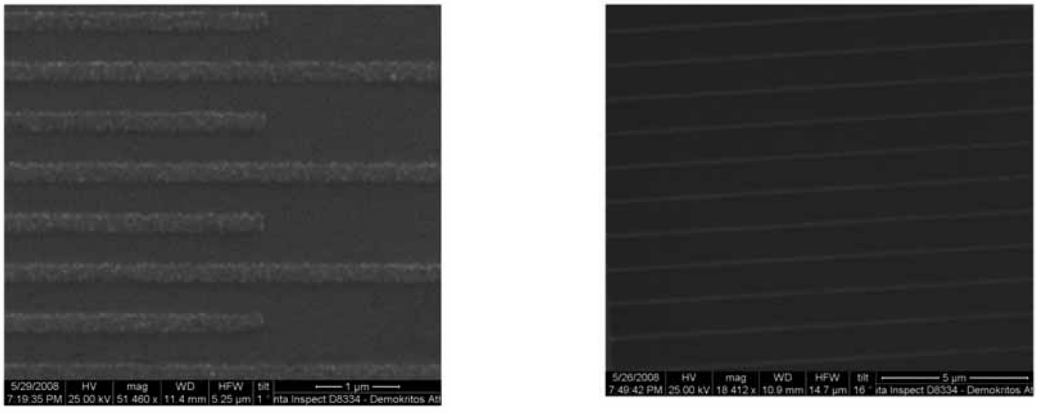

Fig. 3: SEM micrographs taken on electrodes fabricated by SCVD after PMMA removal. **(left)** Cu lines 200 nm wide separated by spaces of 300 nm, Cu deposited at 100 oC. **(right)** 100 nm Cu lines/1 μm spaces at 140 °C.

B. Fabrication of planar ultra-fine Copper lines with length to width ratio of the order of 10^5 by Selective Chemical Vapor Deposition

G. Papadimitropoulos

The advent of nano-technology has created new needs for interconnects with dimensions much longer than the active area of nano-devices. In an effort to obtain long Cu lines with widths in the nano-scal and also separated by fin gaps, we have used interference X-ray lithography. In Fig. 4 Cu lines as long as 1 mm are shown obtained by SCVD as described in the previous section. It an be observed that Cu lines are continuous with no defects and homogeneous.

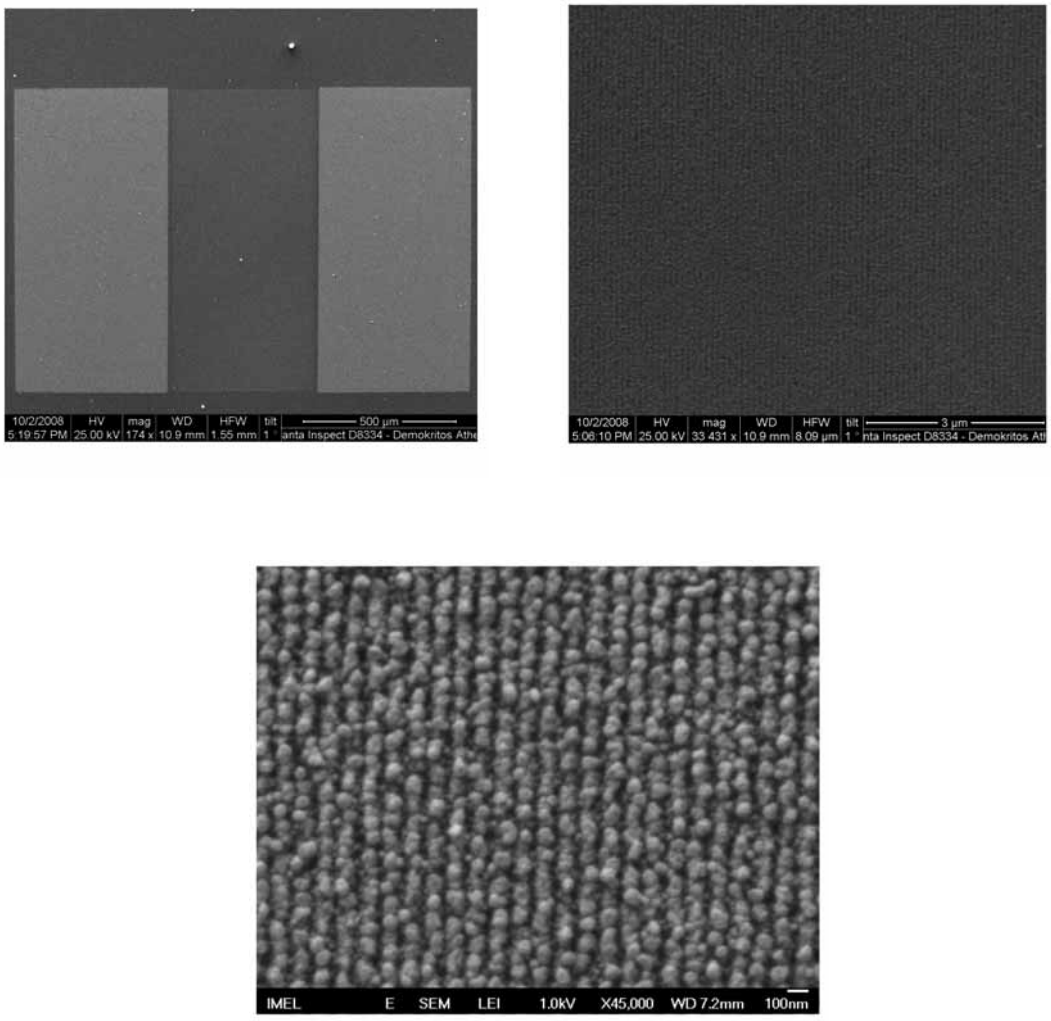

Fig. 4: 1 mm long Cu lines with width of the order of 50 nm obtained by X-ray inreference lithography and SCVD. A general view of the pattern is seen left. Two the lines are formed between the two pads seen left and right. A closer view is seen right and an even closer one down.

C. Silicon Solar Cells

L. Zambelis - G. Aspiotis

Within the frame of the project FOCUS concentration PV cells were fabricated (Fig. 5). These cells were made on floating zone, low resistivity, Si substrates and exhibited an efficiency of approximately 16% (Fig. 5).

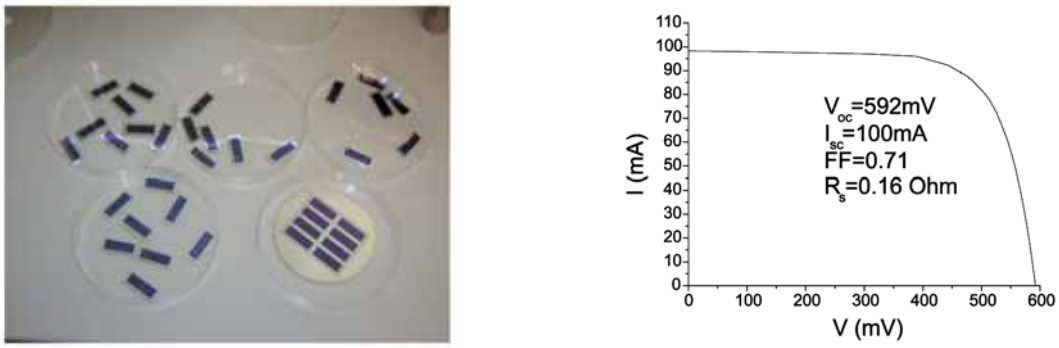

Fig. 5: A view of concentration PV cells made on Si **(left)** and a typical I-V characteristic taken on one such cell.

PV panels were fabricated by placing the above cells vertically as seen in Fig. 6 in an effort to minimize the space occupied by cells and, therefore increase the reliability by shortening the interconnects between cells, thus forming the FOCUS prototype.

Fig. 6: The FOCUS prototype just packed **(left)** and before positioning on the optical system for solar light concentration **(right)**.

The FOCUS prototype produced 30 W peak of electricity (3V, 10A) under illumination of 100 suns.

D. Non-imaging optics for the concentration of light on Si PV Cells

G. Aspiotis

Non-imaging lenses were designed for use in solar PV cells applications. Many configurations were designed and realized using poly-dimethyl siloxane (PDMS) as shown in Fig. 7. The effort was focusing on the realization of lenses with small focal length and being able to operate with high incident angle tolerances in order to minimize sun-tracking requirements.

Fig. 7: Various configurations of concentrating systems with small focal length fabricated with PDMS.

Small area (0,5 cm2) Si PV cells were fabricated and were interconnected as shown in Fig. 8. The operation under sun concentration proved to double the overall efficiency of the panel. It was demonstrated then that it is possible to decrease the consumption of single-crystalline silicon on solar panels, which sets the lower limit for the cost of the produced electricity.

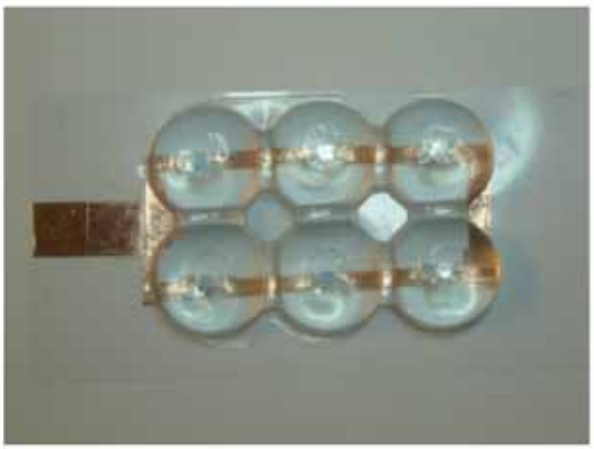

Fig. 8: A solar PV panel containing 6 small area (0,5 cm2) Si PV cells operating under illumination of 20 suns.

E. Optical smoke detectors

G. Aspiotis

Generally, optical smoke detectors contain a light source and a detector arranged in such a way that the light emitted by the former does not reach the latter directly. The presence of smoke particles in the ambient of the system causes light scattering so, in this case, the scattered light reaches the detector and an alarm signal is generated. Within the frame of the OAKA project many configurations operating as described above were designed using commercial software and the corresponding configurations were fabricated and tested using various materials such as poly-dimethyl siloxane (PDMS) as in Fig. 9.

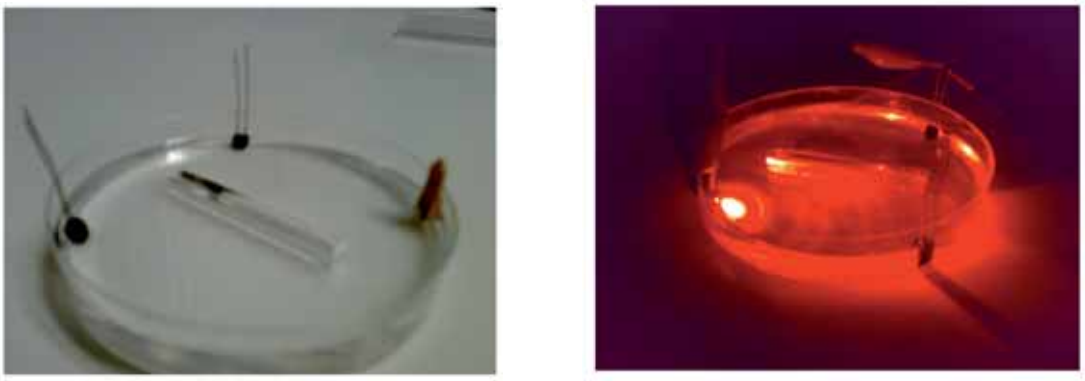

Fig. 9: An optical smoke detector containing one red light source and two detectors made of PDMS

Other configurations tested were based on the guiding of IR irradiation through optical fibers from the IR source to the detector(s) through the smoke detection chamber (see Fig. 10). Various materials were tested such as PDMS (Fig. 10, left) and poly-amide (Fig. 10, right). In all cases the fabricated devices were operating properly with power consumptions of the order of 1 mW.

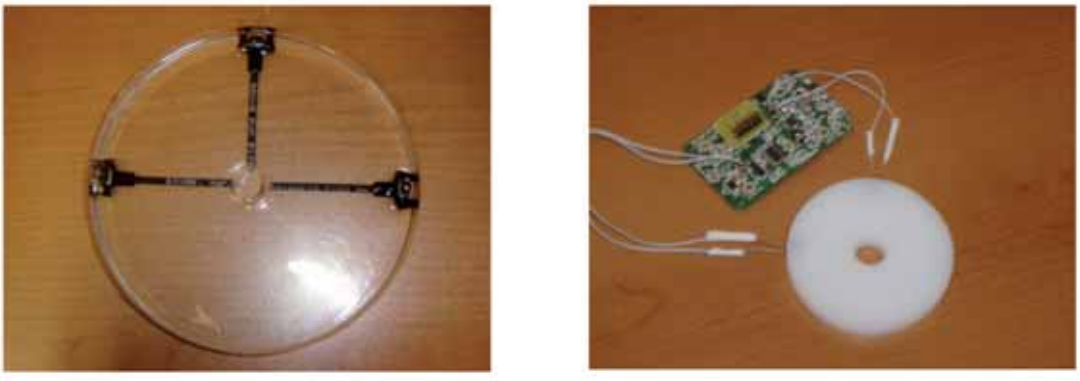

Fig. 10: Optical smoke detectors operating with light guiding from the source to the detectors through the smoke detection chamber. Two detectors are used **(left)** for the device made of PDMS while one detector is used on the device on poly-amide seen on the **right.**

PROJECT OUTPUT in 2008

Publications in International Journals and Reviews

1. Flexible WO3 based electrochromic displays using proton conducting solid electrolytes, M. Vasilopoulou, P. Argitis, G. Aspiotis, G. Papadimitropoulos and D. Davazoglou Physica Status Solidi (C) Current Topics in Solid State Physics 5 (12), 2008, pp. 3868-3871.
2. Hot-wire CVD of copper films on self-assembled-monolayers of MPTMS G. Papadimitropoulos, A. Arapoyanni and D. Davazoglou Physica Status Solidi (A) Applications and Materials 205 (11), 2008, pp. 2607-2610

Conference Presentations

1. Initial stages of thermal and hot-wire assisted CVD Copper growth on SiLK® and LTO activated with Mercaptopropyl triethoxysilane self-assembled monolayers G. Papadimitropoulos, T. Speliotis, A. Arapoyianni and D. Davazoglou, MAM 2008 -- Materials for Advanced Metallization Conference, Dresden (Germany), 2-5 March 2008
2. Selective CVD of Copper on TiN Substrates versus electron beam patterned PMMA by DLI of CupraSelect® G. Papadimitropoulos, S. Cibella, T. Speliotis, R. Leoni, D. Davazoglou, Micro- and Nano-Engineering (MNE) Conference, Athens (Greece), Sept. 15-18, 2008

Conference Participation

1. MAM 2008 -- Materials for Advanced Metallization Conference, Dresden (Germany), 2-5 March 2008
2. Micro- and Nano-Engineering (MNE) Conference, Athens (Greece), Sept. 15-18, 2008

NANOSTRUCTURES FOR NANOELECTRONICS, PHOTONICS AND SENSORS

Project leader: A. G. Nassiopoulou

Other key researchers: H. Contopanagos, S. Gardelis, M. Huffman and N. Papanikolaou

Post-doctoral: M. Theodoropoulou

Phd students: V. Gianneta, F. Zacharatos, A. Petropoulos, M. Kokonou, E. Almpanis

Collaborations: I. Tsiaoussis, N. Lioutas and N. Frangis (University of Thessaloniki), A. Othonos (University of Cyprus), S. Kennou (University of Patras, Chemical Engineering Department), S. Georga and C. A. Krontiras (Univeristy of Patras, Physics Department), M. Fakis, P. Persefonis and V. Giannetas (University of Patras, Physics Department), M. A. Reading and J. A. Van Den Berg (University of Salford, UK), S. Jaziri (Faculté des Sciences de Bizerte, Tunisie), I. Kleps (IMT-Bucharest, Romania), C. Terkezis, G. Gantzounis and N. Stefanou (University of Athens)

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- EU IST I_3 ANNA, 1/12/2006 - 1/12/2010, Contract No: 026134
- FP7-IST-NoE NANOSIL, 1/1/2008-1/1/2011 - Contract No: 216171
- GSRT- PENED-03ED579, 15/7/2005-14/7/2008
- Bilateral project (Greece-Romania), 1/2/2006-31/3/2008
- Bilateral project NON-EU-99 (Greece-Tunisia), 19/7/2006- 19/7/2008

Research orientation:

- Semiconductor nanostructures: Growth, characterization (electrical, optical, structural), applications
- Porous Si technology for sensors
- Porous anodic alumina thin films for masking and templating applications
- On-chip RF passives using porous silicon microplate technology
- Self-assembly of dots and nanowires
- Theory (Ballistic transport in nanostructures, Surface plasmons in thin metallic films, classical molecular dynamics and nanoscale heat transport)

a) Nanostructure growth, characterization and applications

The activity on semiconductor nanostructures started at IMEL at the early nineties and it was conducted within different EU projects, in collaboration with other European groups (Esprit-EOLIS, contract No 7228 (1992-95) Esprit FET SMILE contract No 28741 (1998-2000), IST FORUM FIB contract No 29573 (2001-2004), IST-FP6 NoE SINANO contract No 506844 etc). Worldwide original results were produced, including fabrication of light emitting silicon nanopillars by lithography and anisotropic etching and investigation of their optical and electrical properties, growth of Si nanocrystal superlattices by LPCVD and high temperature oxidation/annealing, with interesting optical properties, fabrication and characterization of LEDs based on Si nanopillars and nanodots, fabrication of Si and Ge nanocrystals embedded in SiO_2 and fabrication and investigation of the corresponding memory structure.

The present focus of research is on self-assembly and ordering of nanostructures and their different applications in nanoelectronics, photonics and sensors. Porous alumina template and masking technology are also developed. Porous alumina ultra-thin films are grown on silicon by electrochemistry. By appropriately choosing the electrochemical conditions used, pore size and density are monitored. Through-pore silicon nanostucturing follows the pore size and density. Arrays of SiO_2 nanodots on Si are fabricated and characterized. Dot size varies from few nm up to few hundreds of nm.

Another technology under development is the growth of ultra thin porous silicon films by electrochemical dissolution of silicon in the transition regime between porosification and electropolishing. Under appropriate conditions, the obtained films are amorphous with embedded Si nanocrystals of various sizes. Under other conditions, the films are nanocrystalline. Their properties are investigated in view of different applications in nanoelectronics and photovoltaics.

The theoretical group focuses on the investigation of ballistic transport in nanostructures, surface plasmons in thin metallic films, classical molecular dynamics and nanoscale heat transport.

b) Porous silicon technology for sensors

An important effort has been devoted the last years within the group in developing materials and enabling technologies for application in sensors. One such material platform with important potential for applications in different sensor devices, microfluidics, lab-on-chip, integration of passives on silicon etc, is porous silicon technology.

Either mesoporous or nanoporous/macroporous silicon are grown. Mesoporous silicon is nanostructured and appropriate for use as micro-plate for local thermal or electrical (dc, RF) isolation on a silicon substrate. Nanoporous Si is also used in the above, after further treatment. Macroporous silicon is developed for use in via technology, in device cooling and in particle filtering.

Different technologies based on porous silicon are available at IMEL, including:

- Proprietary micromachining techniques based on the use of porous silicon as a sacrificial layer for the fabrication of free standing membranes, bridges and cantilevers on a silicon substrate
- Technologies using porous silicon for local thermal or for RF isolation on a silicon wafer, or using porous silicon as a matrix for the deposition of catalytic materials for use in chemical sensors

c) RF isolation by porous silicon micro-plates on a silicon substrate
The overall objective of this research is:

- to explore and extend porous silicon technology into the domain of CMOS-compatible integrated RF components and
- to improve the performance of currently integrated analog CMOS components by above technology, and related optimization of design methodologies.

EXAMPLES OF RESEARCH RESULTS IN 2008

Highly ordered hexagonally arranged nanostructures on silicon through a self-assembled silicon-integrated porous anodic alumina masking layer

Filimon Zacharatos, Violetta Gianneta and Androula G Nassiopoulou

A combined process of electrochemical formation of self-assembled porous anodic alumina thin films on a Si substrate and Si etching through the pores was used to fabricate ideally ordered nanostructures on the silicon surface with a long-range, two-dimensional arrangement in a hexagonal close-packed lattice. Pore arrangement in the alumina film was achieved without any pre-patterning of the film surface before anodization. Perfect pattern transfer was achieved by an initial dry etching step, followed by wet or electrochemical etching of Si at the pore bottoms.

Anisotropic wet etching using tetramethyl ammonium hydroxide (TMAH) solution resulted in pits in the form of inverted pyramids, while electrochemical etching using a hydrofluoric acid (HF) solution resulted in concave nanopits in the form of semi-spheres. Nanopatterns with lateral size in the range 12-200 nm, depth in the range 50-300 nm and periodicity in the range 30-200 nm were achieved either on large Si areas or on pre-selected confined areas on the Si substrate. The pore size and periodicity were tuned by changing the electrolyte for porous anodic alumina formation and the alumina pore widening time. This parallel large-area nanopatterning technique shows significant potential for use in Si technology and devices.

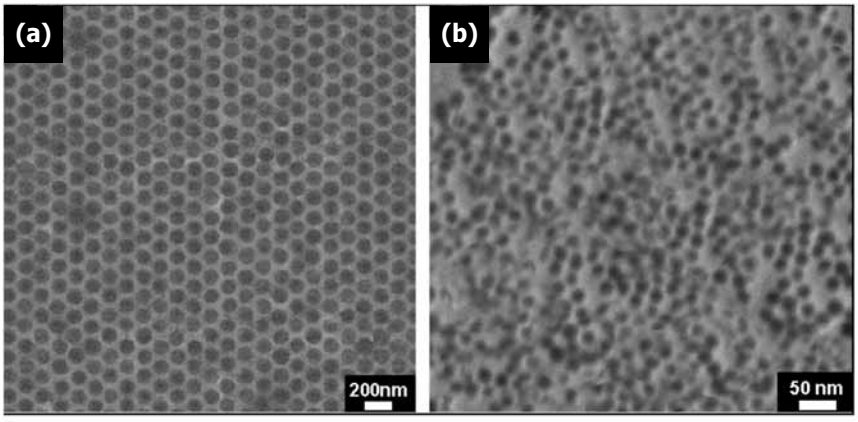


Fig. 1: SEM images of hexagonally arranged arrays of nanoconcave pits on Si, fabricated by electrochemical etching in IPA:HF:H2O 10:3:6 solution at 15 mA cm-2 for 60 s. **(a)** The PAA film was anodized in oxalic acid. The mean diameter of the concave pits is 120 nm, the lattice constant being 200 nm. **(b)** The PAA film was anodized in sulfuric acid and the diameter of the concave pits is 12 nm.

Highly ordered hexagonally arranged sub-200 nm diameter vertical cylindrical pores on p-type Si using non-lithographic pre-patterning of the Si substrate

Filimon Zacharatos, Violetta Gianneta, and Androula G. Nassiopoulou

Anodically etched two-dimensional (2-D) arrays of highly ordered sub-200 nm in diameter vertical cylindrical pores were fabricated on p-type Si wafers, with a resistivity of 6-8 Ω cm, by non-lithographic pre-patterning of the silicon substrate through a self-assembled porous anodic

alumina (PAA) thin film, directly grown on the Si wafer. The PAA film was grown by electrochemical oxidation of a thin Al film in an oxalic acid aqueous solution electrolyte. Through the PAA pores, concave etch pits were formed on Si by chemical etching, that were then used as pore initiation sites for electrochemical macroporous silicon formation. The so formed vertical cylindrical pore arrays showed perfect hexagonal arrangement on the Si surface. A pore diameter down to 180 nm and a pore height up to ~1 μm were achieved for the first time on p-type Si. The developed technology is particularly interesting for photonic crystals and sensors applications.

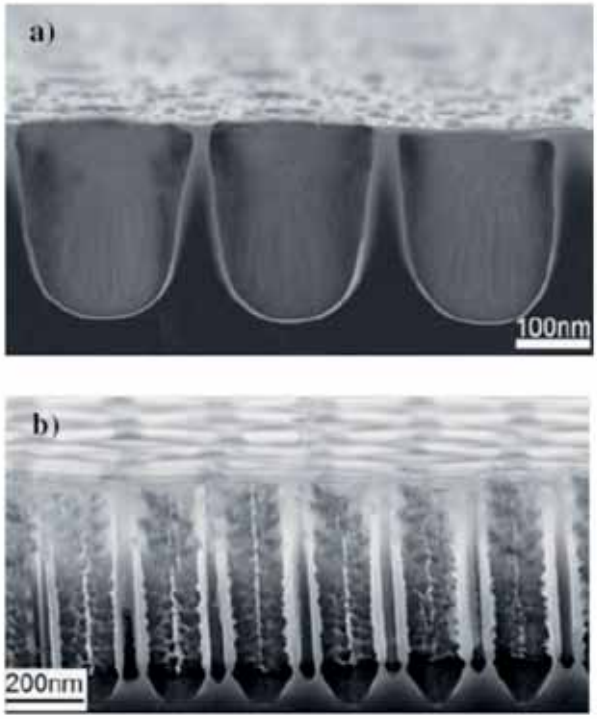


Fig. 2: a) Cross sectional view of the pits formed electrochemically through the PAA mask. **b)** SEM cross sectional view of the hexagonally arranged vertical pores. Pore depth is ~1 μm. The macroporeformation is initiated in the predefined areas.

Self-assembled hexagonal ordering of Si nanocrystals embedded in SiO_2 nanodots

A. G. Nassiopoulou, V. V. Gianneta, M. Huffman, M. A. Reading, J. A. Van Den Berg, I. Tsiaoussis and N. Frangis

Highly dense hexagonally ordered two-dimensional arrays of Si nanocrystals embedded in SiO_2 nanodots were fabricated on a silicon substrate by using a self-assembled porous anodic alumina thin film as a masking layer through which electrochemical oxidation of the Si substrate and ultralow energy Si implantation took place. After removal of the alumina film and high temperature annealing of the samples, hexagonally ordered Si nanocrystals embedded within SiO_2 nanodots were obtained, having sizes in the few tens of nanometers range. The fabricated ordered structures show significant potential for applications either in basic physics experiments or as building blocks for nanoelectronic and nanophotonic devices.

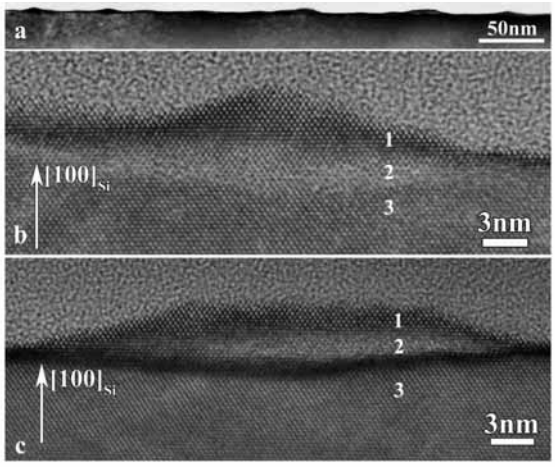


Fig. 3: TEM images of the samples after ion beam synthesis. In **(a)** we see a bright field image showing the presence of undulations on the Si surface. In **(b)** we see an HRTEM image presenting a Si nanocrystal with dome-like shape. **(c)** shows a HRTEM image presenting a truncated-shape Si nanocrystal. Note in both high-resolution images the epitaxial growth of the Si nanocrystals (area 1) in relation to the Si substrate (area 3), with an amorphous material (SiO_2) at the interface between the nanocrystals and the Si substrate (area 2).

Photoluminescence in the blue spectral region from fluorine molecules embedded in porous anodic alumina thin films on silicon

M. Fakis, V. Gianneta, P. Persephonis, V. Giannetas, A.G. Nassiopoulou

The photoluminescence (PL) in the blue spectral region from fluorene molecules embedded in the pores of anodic alumina thin films on silicon was investigated in detail. It was found that the PL was strongly dependent on the diameter and depth of the pores, as well as on the solvent used to dissolve the fluorene molecules. A photoluminescence blue shift with a maximum value of 30nm was observed when the fluorenes were embedded into 40nm pores of the alumina film compared to the corresponding spectrum in solution. The results have shown that the penetration of the molecules into the pores, as well as the formation of nanosize aggregates are favored when the molecules are dissolved in aromatic solvent.

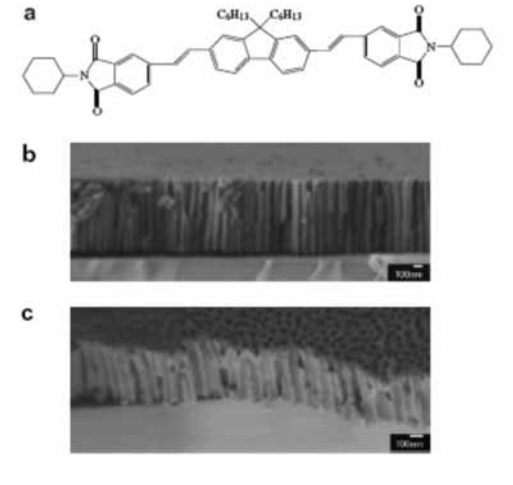


Fig. 4: (a) The chemical structure of the fluorene molecule, **(b)** and **(c)** SEM images of the porous alumina before and after the impregnation of the fluorene molecules respectively. In (b) and (c) the PAA thickness is 750nm and the pore diameter is 40nm.

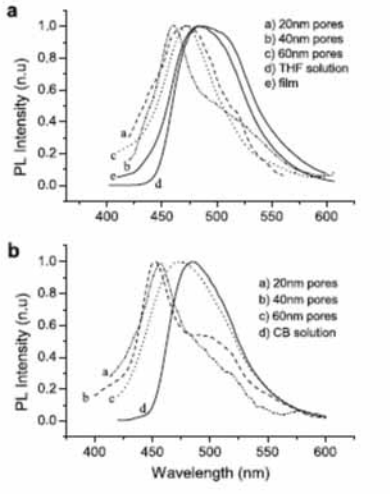


Fig. 5: The PL spectra of **(a)** F-PHT/PAA/THF composites (750nm thickness) and **(b)** F-PHT/PAA/CB composites (750nm thickness) with different pore diameters together with the spectra of F-PHT i n solution and film. All spectra were taken after the rinsing procedure.

Porous anodic alumina thin films on Si: Interface characterization

V. Gianneta, and A.G. Nassiopoulou, C. A. Krontiras, and S. N. Georga

Porous anodic alumina (PAA) thin films (thickness~50nm) were fabricated on Si by anodization of thin Al films under constant voltage of 20V in sulphuric acid aqueous solution. The films exhibit cylindrical vertical pores of diameter~13-15nm, arranged in hexagonal close packed structure. Electrochemical oxidation of the Si substrate through PAA, used as masking layer with openings in the pores, resulted in the for-films of SiO_2 dots at each pore tips.

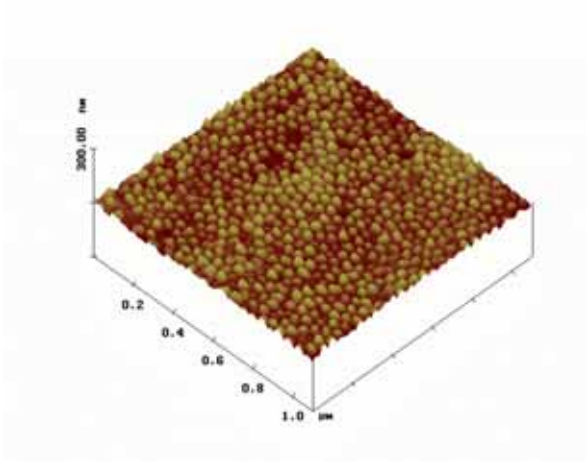


Fig. 5: AFM image of arrays of SiO_2 dots, fabricated through anodic porous alumina masking layer.

Two different kinds of films, namely with or without SiO_2 dots at pore tips, were fabricated, In order to characterize the electrical quality of the interface of PAA thin films with Si, C-V and G-V measurements were performed on Metal-Insulator-Semiconductor (MIS) structures with Al metallization. The measurements were carried out in the voltage range +1.0V to -3.0V in steps of 0.05V and in the frequency range 1MHz to 100Hz. The typical form of C-V and G-V curves of a MIS structure was obtained. In order to determine the interface trap density D_{it}, C-f and G-f measurements were performed as a function of the applied gate voltage in the depletion region. Dit was evaluated following the Conductance Method (E. H. Nicollian, and J. R. Brews, MOS Physics and Technology (J. Wiley & Sons, New York, 1982), p.222 [1]). Both types of samples exhibit values of D_{it} in the order of $10^{11}eV^{-1}cm^{-2}$.

Copper-filled macroporous Si and cavity underneath for microchannel heat sink technology

F. Zacharatos and A. G. Nassiopoulou

Thermal management in ICs becomes essential as integration density and total power consumption increase. The use of microchannels in high power density electronics cooling is a well-known technique for heat transfer. In this work we developed Cu-filled macroporous Si channels with a Cu-filled cavity underneath, which may be used as heat sinks in high power density electronics cooling. Macroporous Si is formed by electrochemical dissolution of bulk Si, while pore filling with copper is achieved by electro-deposition. Using appropriate design, the resulting composite

material may be fabricated on selected areas on the silicon substrate for use as heat sink on Si. The surface area is defined by patterning. The macroporous Si structure is composed of either randomly distributed pores or pores arranged in two-dimensional (2-D) arrays, fabricated by pre-patterning the Si surface before anodization so as to form pore initiation pits. The pore size in this work was 5μm, while the porous layer and the cavity underneath had both a thickness of 40 μm. Copper deposition proceeds first by filling the micro-cavity underneath the porous layer. This is achieved by linearly increasing the applied potential during electro-deposition. After full Cu-filling of the cavity, pore filling starts from the bottom of each pore and proceeds laterally, while no nucleation takes place on pore wall. In this way, homogeneous copper wires within pores may be fabricated. The Cu/Si composite material is appropriate for forming channels with improved heat transfer within the Si wafer.

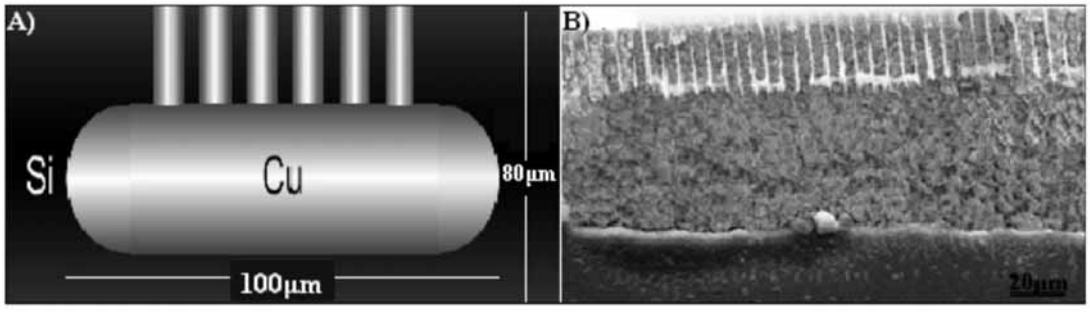


Fig. 6: A) Schematic representation of the fabricated device. The copper-filled microcavity is interconnected with the surface through the copper cylinders. The cavity is 40 μm deep and the metallic cylinders 40 μm long. **B)** Cross-sectional SEM image of the resulting structure after complete pore and cavity filling with Cu. The duration of the electrochemical deposition was 60 min under variable bias voltage as in Fig. 4a. Three areas are discerned from top to bottom: Macropores filled with Cu, Cu filled cavity and the Si substrate.

Electrical characterization of HfO_2 and $HfSiO_x$ MOS capacitors

M. Theodoropoulou and A. G. Nassiopoulou

A series of samples containing HfO_2 or $HfSiO_x$ dielectrics, fabricated at IMEC were characterized electrically at IMEL as part of the ANNA project. The goal of this effort was to better understand the parameters that affect the electrical characteristics of these two high-k dielectrics. MOS capacitors with Al metallization were fabricated at IMEL and electrical measurements were performed on several devices (room temperature), using standard techniques for MOS characterization. The obtained results suggest that, in general, plasma nitridation (DPN) and post nitridation annealing produce films of slightly better quality (lower leakage currents). Strong frequency dispersion in both depletion and accumulation is observed for all the samples (Fig N8). The density of interface states is in the order of $10^{12}/cm^2$, as calculated from data plots such as Fig. N9. This is relatively high but it does agree with literature values. These characteristics could be improved by further processing of the samples such as annealing and more careful method of making electrical contact.

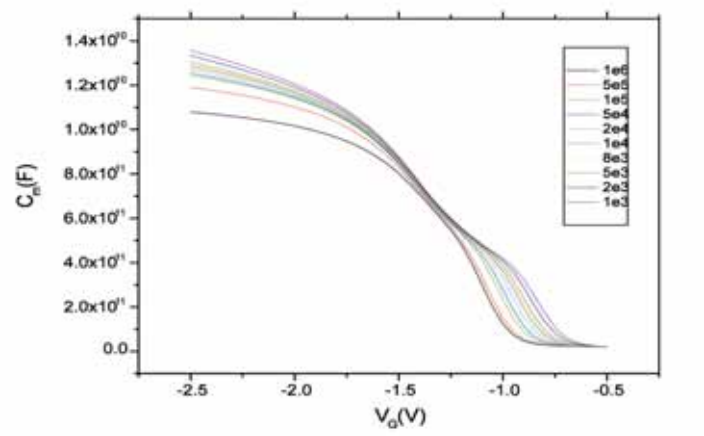


Fig. 8: C-V measurements in the high frequency region for sample DO4.

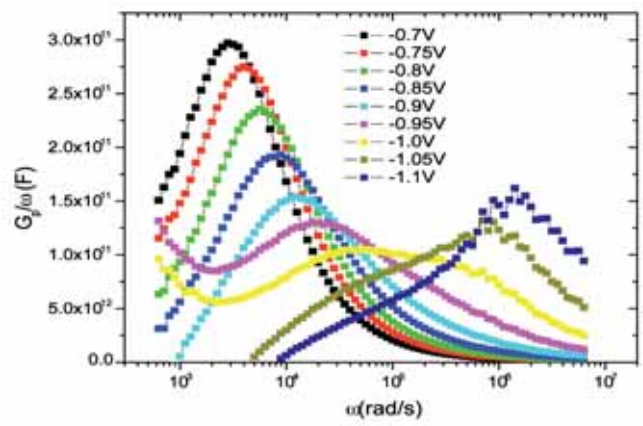


Fig. 9: Experimental Gp/ω vs ω curves for sample DO6.

High-frequency characterization of mesoporous Si: RF-shielding properties and complex permittivity extraction through on-chip co-planar waveguide measurements

H. Contopanagos, F. Zacharatos and A. G. Nassiopoulou

The objective of this work is to use the technology of porous Si for RF circuits integrated on-chip in CMOS-compatible processes, operating at frequency bands of interest, namely 1GHz-6GHz where current wireless telephony operates, as well as for the 60-GHz band, where future analog RFIC's will work. The major hurdle in the operation of these devices are the Si-substrate losses as well as associated cross-coupling between closely spaced analog stages of the devices. In this work, we use porous Si as a CMOS-compatible technology that grows local microplates of specified layouts underneath the passive components, with the purpose of dramatically reducing RF losses as well as cross-coupling between adjacent devices. We have grown mesoporous Si microplates of various thicknesses, on a bare p-type Si die of N = 8 Ω.cm, used in standard CMOS. The measuring platform we have used is shown in Fig. N10 and consists of an on-chip Aluminum Coplanar Waveguide (CPW) fabricated on a fixed-thickness Si die using Al metallization.

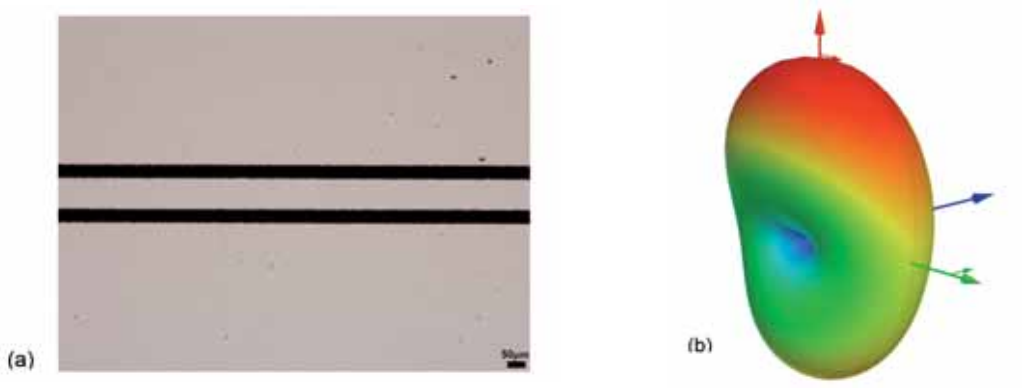


Fig. 10: a) On-chip CPW platform on the X-Y plane, with the line along Y. **b)** Total 3D radiative gain at 5 GHz.

Regarding losses, we use energy conservation to quantify the power lost within the CPW through the formula $PL = 1 - |S_{11}|^2 - |S_{21}|^2$. Associating this power loss with material losses only, assumes the CPW is a non-radiating transmission line. This is certainly valid in our case, due to the dimensions chosen, as illustrated in Fig. N11a, where we show the 3-dimensional total radiative gain of the CPW which is completely negligible, reaching a maximum (red region) of $4x10^{-7}$. For comparison, a half-wave dipole antenna matched to a 50 Ω-port similarly has a maximum gain of about 1.5.

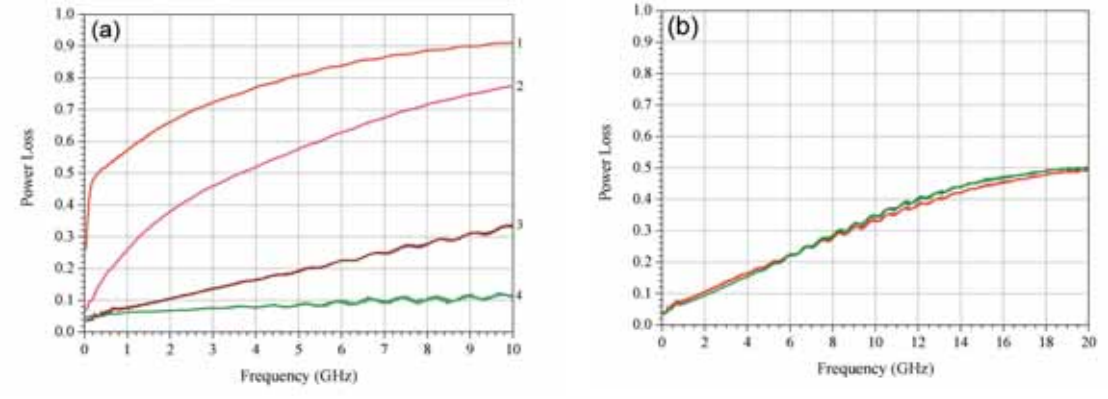


Fig. 11: a) Measured power loss for 4 different dies: 1 no porous 2 μ 25μm-thick layer of mesoporous Si 3 a 50 μm-thick layer and 4 a low-loss dielectric of tanδ<10^{-3}. **b)** Measured power loss of a 50-μm-thick (red) and 100-μm-thick (green) porous Si microplate.

In fig. N11a we present the measured power loss of 3 identical CPW's fabricated on 3 different dies, all of the same total thickness, as well as the same CPW on a low-loss RF substrate. The bare Si die consumes a lot of power, but a 50μm-thick porous microplate substantially reduces the RF losses to 1/6-1/4 of these values. Therefore, this material is excellent for CMOS-compatible

integration of passive RF devices. For comparison, the low-loss RF laminate (4) of Fig. N11a presents at 5 GHz a loss not less than half of that of the line on the 50Φm-thick porous Si. An important issue for ease of fabrication, regards the minimum porous Si layer thickness necessary to saturate the RF isolation effects. In Fig. N11b, we show that the measured power loss on dies containing 50 and 100-micron-thick microplates turns out to be identical, hence 50 microns of porous Si effectively saturate the RF-isolation effects for the form-factors of the CPW's used.

We have used the measured S-parameters as inputs and compared them to the simulation results obtained through HFSS simulations of the same structure, each time varying the quantities Re{B} and Im{B}, until the best fit is obtained. The agreement is explored between several functions of frequency, therefore the fits are highly non-trivial. In Fig. N12a we show the result of the agreement, for the extracted value of the complex permittivity. The extracted constant value of the complex permittivity of the mesoporous Si grown is $\varepsilon_{PS} = 3.85(1 + i0.11)$. In Fig. N12b we show the corresponding comparison between measured and theoretical normalized power loss and we see again excellent agreement. An issue we are currently pursuing actively is lowering the loss tangent even further by appropriate alterations of the fabricating electrochemical conditions and the post anodization processing steps.

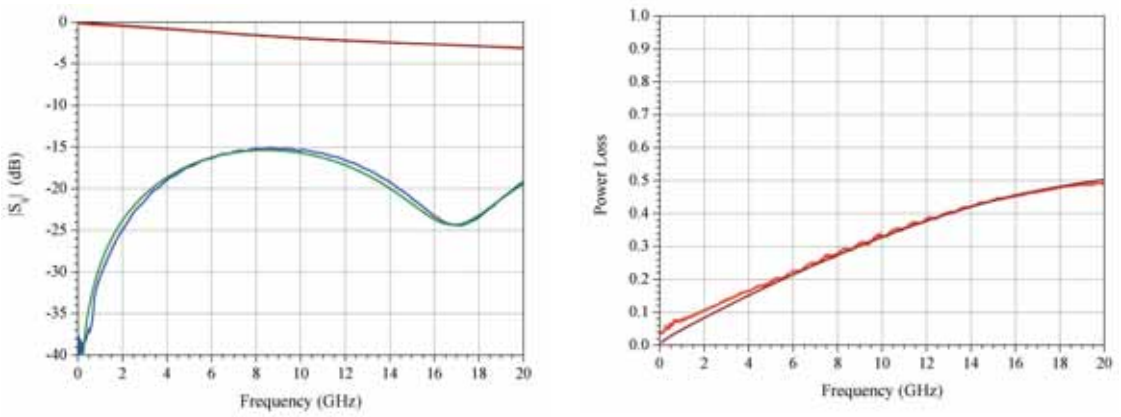


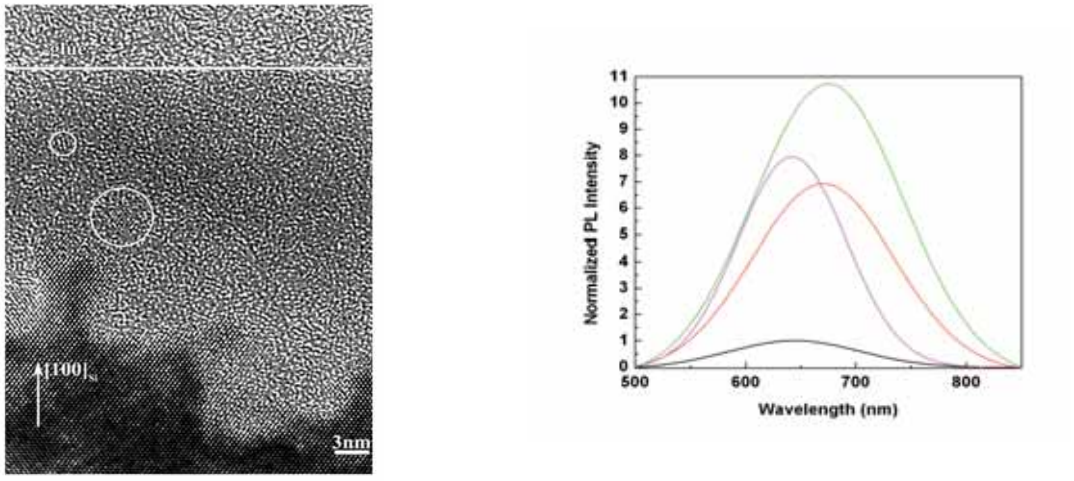
Fig. 12: a) Measured vs. theoretical S-parameters of the CPW on a composite die with a 50-μm-thick porous Si microplate on Si: Blue (|S11|) & Red (|S21|) = Measurements; Green (|S11|) & Brown (|S21|) = Simulations. **b)** Measured (red) vs. simulated (brown) power loss.

Enhancement and red shift of photoluminescence (PL) of fresh porous Si under prolonged laser irradiation or ageing: Role of surface vibration modes

S. Gardelis and A. G. Nassiopoulou

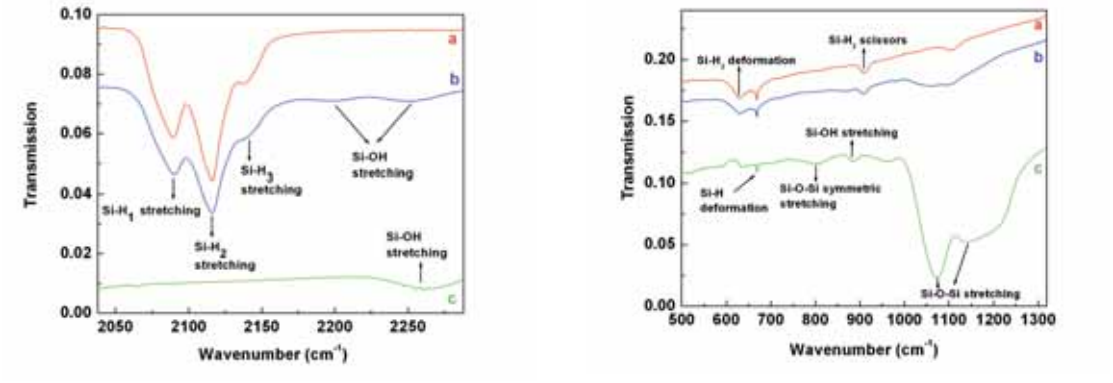
We investigated the effect of a red shift and a considerable enhancement of photoluminescence (PL) intensity from a freshly etched porous Si thin film after prolonged laser irradiation or after aging in atmosphere (Fig. N13b). Both effects coincide with the appearance of Si-OH and Si-O-Si vibration modes in the Fourier Transform Infra Red (FTIR) absorption spectra (Fig. N14). The red shift is attributed to a pinning of the band gap of the light emitting Si nanocrystals due to the

formation of Si-OH and Si-O-Si bonds. Using theoretical calculations, we estimated the electron and hole energy shifts caused by the interaction of the electronic states of the Si NCs with the surface vibrations, and correlated the observed PL enhancement with resonant coupling between the quantized valence sub-levels in the Si NCs and surface vibration modes (Fig. N15a, N15b).



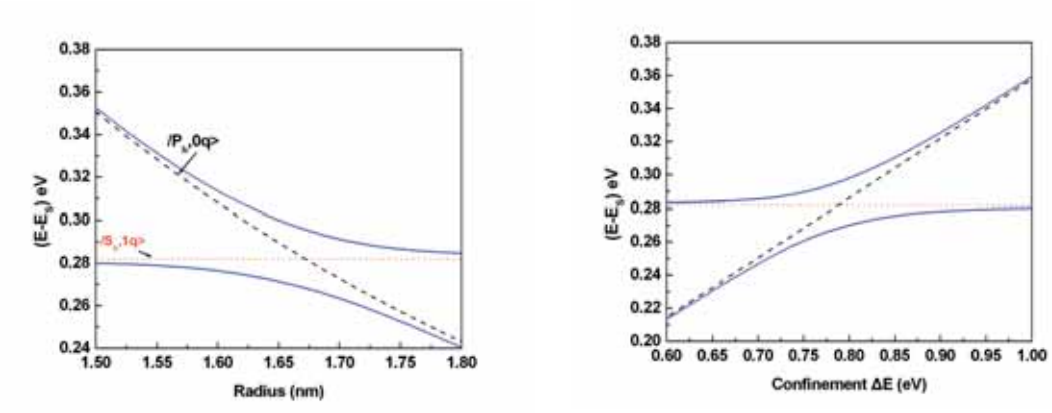
a **b**

Fig. 13: (a) A typical High Resolution Transmission Electron Micrograph (HRTEM) obtained from the anodic films, showing Si nanocrystals of sizes between 1.5 to 7 nm. **(b)** Photoluminescence (PL) spectra obtained from the as-grown anodic film (black), after prolonged laser irradiation (orange), after aging (green) and after immersion in hydrofluoric acid (HF).



a **b**

Fig. 14: FTIR absorption spectrum obtained from: **(a)** the as-grown fresh porous Si film, **(b)** after prolonged laser irradiation and (c) after aging in air.



a **b**

Fig. 15: (a) Resonant coupling between Si-OH stretching vibration modes at 282 meV and valence inter-sub-levels occurs for Si NCs with radius of about 1.7 nm. **(b)** Calculated energy separation of valence inter-sub-levels (VISL). The dotted line corresponds to the energy of the Si-OH stretching mode at 282 meV. The dashed line indicates the prediction of the quantum confinement model for VISL. The crossing of the two lines occurs at ΔE=0.78 eV.

S. Gardelis, A.G. Nassiopoulou, M. Mahdouani, R. Bourguiga, S. Jaziri, Physica E,
http://dx.doi.org/10.1016/j.physe.2008.08.021

PHOTONICS, SURFACE PLASMONS, METAMATERIALS (Acvtivity of N. Papanikolaou)

Diploma student: P. Theodoni
PhD student: E. Almpanis

Surface plasmons, metamaterials

C. Terkezis, G. Gantzounis, N. Stefanou, N. Papanikolaou

The interaction of light with periodic, metallic or dielectric structures has revealed a plethora of fascinating new phenomena and novel ways to tailor light. In the case of metamaterials the structure determines the optical properties with unique consequences like negative refraction and cloaking and a big potential for applications. To facilitate progress in the field, reliable and efficient simulation methods are required. We are currently developing a method based on multiple scattering theory. The method was used to analyze periodic arrays of metal/dielectric/metal nanosandwiches and we have retrieved the effective permittivity and permeability of the structure (Fig N16). Depending on the particular geometry, this system shows negative magnetic permeability as high as -2 at optical frequencies, which is a basic ingredient towards negative refractive index metamaterials.

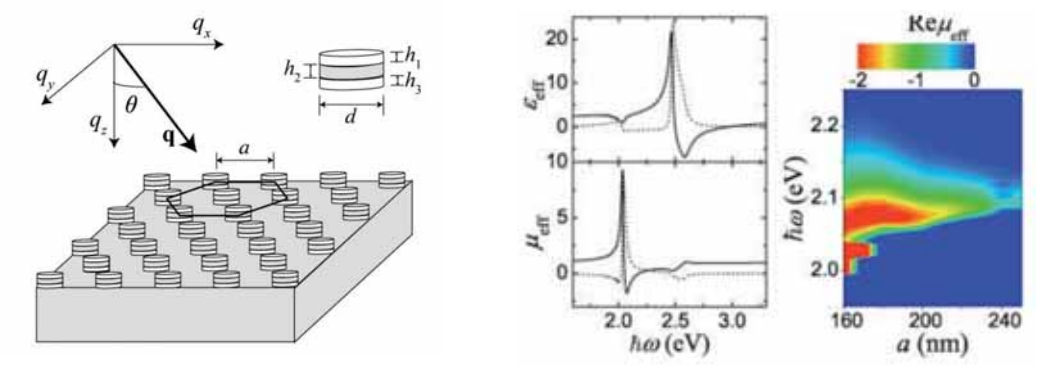


Fig. 16: Left: Metal/dielectric/metal nanosandwich arrays on a substrate. The lattice constant (a) ranges from 160 to 250nm and the diameter of the nanodisks is 100nm the heights of metal and dielectric nanodisks are 20 nm. **Right:** Effective electric permittivity ε and magnetic permeability μ of the structure for a=200nm. The colour plot shows the variation of μ with the lattice constant. Close packed nanosandwiches show high negative μ close to -2.

Efficient IR emitters

P. Bayiati, M. Chatzichristidi, Th. Speliotis, V. Em. Vamvakas, I. Raptis, N. Papanikolaou

Patterned metallodielectric structures have interesting optical properties. We have fabricated arrays of holes on a thin (100 nm) film on a Si substrate and transferred the hole pattern using plasma etching into the Si. The final structure is shown in Fig N17 where the diameter of the holes is around 2.5 μm. This structure shows a narrow absorption band in the infrared (~5μm) at wavelengths close to the lattice constant. Strong narrow band absorption means efficient, narrow band IR emission which is shown Fig N17 for different temperatures. Such structures could find applications in thermophotovoltaics where heat is converted to electricity.

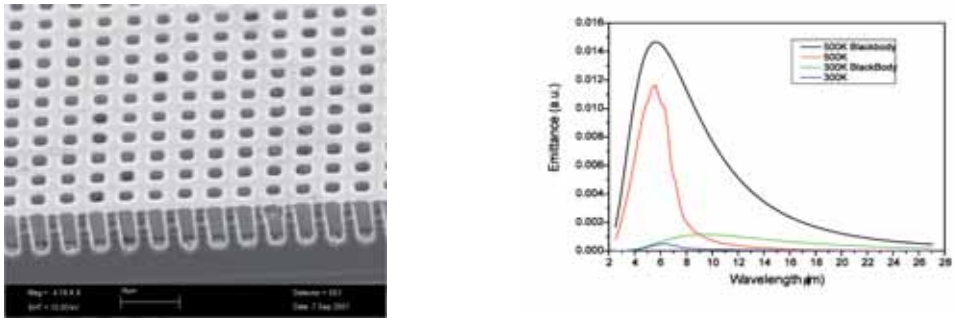


Fig. 17: SEM micrograph **(left)** of periodic arrays of 2-3 μm sized holes on Si covered with a thin (100nm) Au film. Fabricated using optical lithography. The structure was measured to have strong, IR absorption in a narrow band, and is expected to have efficient, narrow band, IR emittion shown on the **right**.

Fluorescence enhancement

A.M. Gerardino, P. Petrou, S. Kakabakos, I. Raptis, N. Papanikolaou

Patterned metallodielectric structures have interesting optical properties. We have fabricated arrays of holes on a thin (100 nm) film on a Si substrate and transferred the hole pattern using plasma etching into the Si. The final structure is shown in Fig N17 where the diameter of the holes is around 2.5 μm. This structure shows a narrow absorption band in the infrared (~5μm) at wavelengths close to the lattice constant. Strong narrow band absorption means efficient, narrow band IR emission which is shown Fig N17 for different temperatures. Such structures could find applications in thermophotovoltaics where heat is converted to electricity.

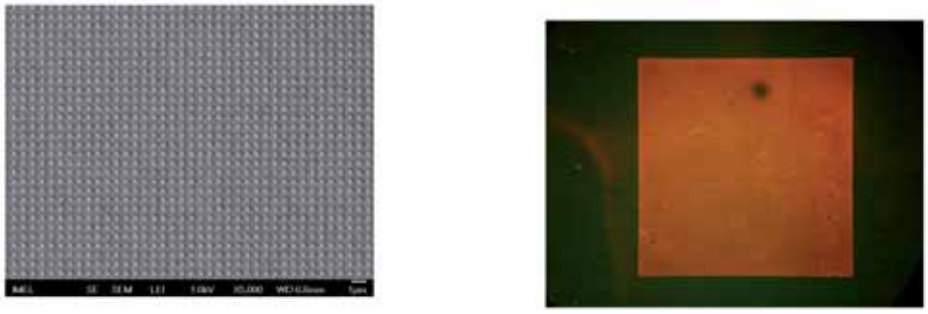


Fig. 18: SEM micrograph **(left)** of periodic arrays of metallic nanoparticles fabricated using e-beam lithography. The nanoparticles size is 150-200 nm in a lattice with lattice constant 300-500 nm. The whole sample was covered with AntiRabit IgG antibody with fluorescent labels alexafluor 546. The incident light was at 546 nm while the outgoing light was monitored around 575 nm. The patterned region shows much higher fluorescence **(right)** compared to the unpatterned one

Thermal transport in nanowires

N. Papanikolaou

Managing heat in todays nanoelectronics industry is a major issue which cannot be neglected in the design of electronic components. It is well known that the thermal properties change upon nanostructuring a material since the dimensions become smaller than the bulk thermal mean free path. In order to investigate such effects we developed a classical molecular dynamics simulation computer code mainly for semiconductor materials, and studied SiC nanowires. Our approach was able to show some features on the dependence of the lattice thermal conductivity on the geometric parameters of the wires, and generally predict a big decrease of the thermal conductivity of the nanowires compared to the bulk.

RESEARCH PAPERS 2008

PUBLICATIONS IN REFEREED JOURNALS

1. "RF characterization and isolation properties of mesoporous Si by on-chip coplanar waveguide measurements", Contopanagos, H., Zacharatos, F., Nassiopoulou, A.G., Solid-State Electr., 52 (11), pp. 1730-1734 (2008)
2. "Self-assembled hexagonal ordering of Si nanocrystals embedded in SiO2 nanodots", A. G. Nassiopoulou, V. Gianneta, M. Huffman, M. A. Reading, J. A. Van Den Berg, I. Tsiaoussis, N. Frangis, Nanotechnology 19, 495605 (2008)
3. "Highly ordered hexagonally arranged nanostructures on silicon through a self-assembled silicon-integrated porous anodic alumina masking layer", F. Zacharatos, V. Gianneta and A. G. Nassiopoulou, Nanotechnology 19, 495306 (2008)
4. "Growth and electrical characterization of thin conductive Au nanoparticle chains on oxidized Si substrates between electrodes for sensor applications", Zoy, A., Nassiopoulou, A.G., Phys. Stat. S. (a) Applications and Materials, 205 (11), pp. 2621-2624 (2008)
5. "Auger recombination in silicon nanocrystals embedded in SiO2 wide band-gap lattice", Mahdouani, M., Bourguiga, R., Jaziri, S., Gardelis, S., Nassiopoulou, A.G., Phys. Stat. Sol. (a) Applications and Materials, 205 (11), pp. 2630-2634 (2008)
6. "Broadband electrical characterization of macroporous silicon at microwave frequencies", Contopanagos, H., Pagonis, D.N., Nassiopoulou, A.G., Phys. Stat. S. (a) Applications and Materials, 205 (11), pp. 2548-2551 (2008)
7. "Columnar growth of ultra-thin nanocrystalline Si films on quartz by Low Pressure Chemical Vapor Deposition: Accurate control of vertical size", Lioutas, Ch.B., Vouroutzis, N., Tsiaoussis, I., Frangis, N., Gardelis, S., Nassiopoulou, A.G., Phys. Stat. S. (a) Applications and Materials, 205 (11), pp. 2615-2620 (2008)
8. "A thermal vacuum sensor fabricated on plastic substrate - Study in various operation modes", Petropoulos, A., Kaltsas, G., Nassiopoulou, A.G., Phys. Stat. Solidi (a) Applications and Materials, 205 (11), pp. 2639-2642 (2008)
9. "Copper-filled macroporous Si and cavity underneath for microchannel heat sink technology", Zacharatos, F., Nassiopoulou, A.G., Phys. Stat. S. (A) Applications and Materials, 205 (11), pp. 2513-2517 (2008)
10. "Ultrafast time-resolved spectroscopy of Si nanocrystals embedded in SiO2 matrix", Lioudakis, E., Emporas, A., Othonos, A., Nassiopoulou, A.G., J. of Alloys and Compounds, doi:10.1016/j.jallcom.2008.07.193, Article in Press (2008)
11. "Enhancement and red shift of photoluminescence (PL) of fresh porous Si under prolonged laser irradiation or ageing: Role of surface vibration modes", Gardelis, S., Nassiopoulou, A.G., Mahdouani, M., Bourguiga, R., Jaziri, S., Physica E: Low-Dimensional Systems and Nanostructures, doi:10.1016/j.physe.2008.08.021, Phys. Stat. Sol. (a), No 11, 2630 (2008)
12. "Morphology, structure, chemical composition, and light emitting properties of very thin anodic silicon films fabricated using short single pulses of current", Gardelis, S., Nassiopoulou, A.G., Petraki, F., Kennou, S., Tsiaoussis, I., Frangis, N., J. of Appl. Phys., 103 (10), art. no. 103536 (2008)
13. "Surface-related states in oxidized silicon nanocrystals enhance carrier relaxation and inhibit auger recombination", Othonos, A., Lioudakis, E., Nassiopoulou, A.G., Nanoscale Research Letters, 3 (9), pp. 315-320 (2008) and selected for open-access presentation to the OAtube Nanotechnology 1 (2008) 903 (HUhttp://www.oatube.org/2008/09/aothonos.htmlUH)
14. "Determination of critical points on silicon nanofilms: surface and quantum confinement effects", E. Lioudakis, A. Othonos and A. G. Nassiopoulou, Phys. Stat. Sol. (c), 5, 3776 (2008)
15. "Multilevel charge storage in Si nanocrystals arranged in double-dot-layers within SiO2", Theodoropoulou, M., Nassiopoulou, A.G., Microelectronic Engineering 85 (12), pp. 2362-2365 (2008)

Publications in Conference Proceedings

1. "Ultrafast phenomena in ultrathin polycrystalline silicon films", E. Lioudakis, L. Loumakos, A. G. Nassiopoulou and A. Othonos, XXII Panhellenic Solid State and Material Science conference, University of Patra -Greece, Proceedings conf. (2006).
2. "Determination of critical points on silicon nanofilms: surface and quantum confinement effects", Emmanouil Lioudakis, Andreas Othonos, A. G. Nassiopoulou, Physica status solidi (c), Volume 5, Issue 12, December 2008, pp. 3776-3779
3. "Dielectric characterization of macroporous thick silicon films in the frequency range 1 Hz-1 MHz", M. Theodoropoulou, D. N. Pagonis, A. G. Nassiopoulou, C. A. Krontiras, S. N. Georga, Physica status solidi (c), Vol. 5, Issue 12, December 2008, pp. 3597-3600
4. "Porous anodic alumina thin films on Si: interface characterization", V. Gianneta, A. G. Nassiopoulou, C. A. Krontiras, S. N. Georga, Physica status solidi (c), Volume 5, Issue 12, December 2008, pp. 3686-3689
5. "Evaluation of a gas flow sensor implemented on organic substrate", A. Petropoulos, G. Kaltsas, T. Speliotis, A.G. Nassiopoulou, Physica status solidi (c), Volume 5, Issue 12, December 2008, pp.3839-3842
6. "On-chip RF-shielding by mesoporous Si microplate measured through an integrated coplanar waveguide", H. Contopanagos, F. Zacharatos and A. G. Nassiopoulou, Materials of the 6th International Conf. on Porous Semiconductors - Science and Technology, Mallorca, Spain, pp. 80-81 (10-14 March 2006).

Presentations in Conferences

1. "Nanoelectronics, Micro and Nanosystems", A. G. Nassiopoulou, Information and Brokerage Event, Moscow, 21-23 October 2008
2. "Electronics and micromachining using porous silicon", A. G. Nassiopoulou, Porous Semiconductors - Science & Technology, PSST - 2008, March 10-14 2008, Mallorca
3. "Beyond Moore flexible platform at EU level for Nanoelectronics and MEMS/NEMS", A. G. Nassiopoulou, 14th Micromachine Summit, Daejeon, Korea, April 30 - May 3, 2008
4. "Micro&Nanoelectronics: Present status and perspectives", A. G. Nassiopoulou, 14.4.2008, NCSR Demokritos, Athens, Greece
5. "Surface-related states in oxidized silicon nanocrystals enhance carrier relaxation and inhibit Auger recombination", A. Othonos, E. Lioudakis, A. G. Nassiopoulou, 2008 Virtual Conference on Nanoscale Science and Technology VC-NST, July 24-29, 2008 Fayetteville, Arkansas 72701, USA.
6. "CMOS-integrated low-loss porous Si technology for on-chip RF inductors", F. Zacharatos, H. Contopanagos, and A. G. Nassiopoulou, 38th European Solid-State Device Research Conf. (ESSDERC2008), 15-19 Sept. 2008, Edinburgh, Scotland, U.K.
7. "Structural, chemical and light emission properties of very thin anodic silicon films fabricated by short single pulses", S. Gardelis, A.G. Nassiopoulou, F. Petraki, S. Kennou, I. Tsiaoussis, N. Frangis, XXIV Panhellenic Conference on Solid State Physics and Materials Science, Heraklion, Crete, 2008, Invited
8. "Enhancement and red shift of photoluminescence (PL) of fresh porous Si under prolonged laser irradiation or ageing: Role of surface vibration modes", S. Gardelis, A.G. Nassiopoulou, M. Mahdouani, R. Bourguiga, S. Jaziri, EMRS Spring Meeting, Strasbourg, France, 2008

Edition of a special issue of Physica Status Solidi containing the Proceeding of Micro&Nano 2007 International Conference: phys. stat. sol. (a) 205, No 11, 2505-2656 (2008) and phys. stat. sol. (c) 5, No 12, 3571-3878 (2008). Guest editors : A. G. Nasiopoulou, P. Argitis and N. Papanikolaou

Invited talks

1. "De la Micro- à la Nanoélectronique et les Microsystèmes", A. G. Nassiopoulou, International Workshop on Research, Innovation, Enterprises in Communication Technologies, 4 November 2008, Pôle Elgazala, Tunisie

2. "Electronics and micromachining using porous silicon", A. G. Nassiopoulou, International Conference PSST 2008, March 10-14 2008, Mallorca, Spain
3. "Porous anodic alumina thin films on Si as masking layers for silicon surface nanostructuring and as templates for nanostructure growth", A. G. Nassiopoulou, V. Gianneta, F. Zacharatos, M. Kokonou, M. Hauffman, 1st International Conference from Nanoparticles and Nanomaterials to Nanodevices and Nanosystems, Halkidiki, Greece, 16-18 June 2008
4. "The Greek micro-nanotechnology and MEMs landscape", A. G. Nassiopoulou, 14th Micromachine Summit, Daejeon, Korea, April 30 - May 3, 2008
5. "Electronics and micromachining using porous silicon", A. G. Nassiopoulou, 2nd International Summer School on "Nanosciences & Nanotechnologies" (SS-NN08), Thessaloniki, Greece, 12-18 July 2008
6. "Nanoelectronics at the Center of high technologies", A. G. Nassiopoulou, 8th Scientific Symposium on High Technologies in Physical Sciences, 3-5 October, Aegion, Greece
7. "Silicon nanocrystals in SiO2 thin layers: Growth, ordering and light emitting properties", A. G. Nassiopoulou, S. Gardelis, V. Gianneta, E. Lioudakis and A. Othonos, 2008 Virtual International Conference on Nanoscale Science and Technology VC-NST, July 24-29, 2008 Fayetteville, Arkansas 72701, USA
8. "Structural, chemical and light emission properties of very thin anodic silicon films fabricated by short single pulses", S. Gardelis, A.G. Nassiopoulou, F. Petraki, S. Kennou, I. Tsiaoussis, N. Frangis, XXIV Panhellenic Conference on Solid State Physics and Materials Science, Heraklion, Crete, September 2008

Courses taught

1. "Introduction to CMOS devices and processes", A. G. Nassiopoulou, course within the MSc and PhD programme on Nanosciences and Nanotechnologies, Univeristy of Thessaloniki, 2nd semester 2008
2. "Introduction to CMOS technology", course within the MSc programmes on Microelectronics (University of Athens) and Nanoelectronic devices and MEMs (National Technical University of Athens), 1st semester 2008-2009
3. "Introduction to Sensors and MEMs", S. Gardelis, course within the MSc programme on "Microelectronics" of the University of Athens, 1st semester 2008

Courses and Seminars

1. "From Micro- to Nanoelectronics: Challenges and Perspectives", A. G. Nassiopoulou, Seminar, Summer School, NCSR Demokritos, 14th July 2008
2. "Current trends in Nanoelectronics and MEMS", A. G. Nassiopoulou, 8.7.2008, NCSR Demokritos, Athens, Greece
3. "Electronics and micromachining using porous silicon", 2nd International Summer School on "Nanosciences & Nanotechnologies" (SS-NN08), Thessaloniki, 2008

Organization of Conferences, Symposia, Workshops

1. 6th International Biennial Conference on Porous Semiconductors Science and Technology (PSST 2008). The Conference was held in Mallorca, Spain in the period 10-14 March 2008. Chairpersons of the Conference and Scientific Editors of the Proceedings were: Prof. Leigh T. Canham (pSiMedica Ltd., UK), Dr. Androula Nassiopoulou (IMEL/NCSR "Demokritos", Greece), Prof. Michael Sailor (University of California at San Diego, USA), Prof. Patrik Schmuki (University of Erlangen-Nuremberg, Germany). The Conference was attended by 280 people from 43 countries and 220 papers were presented in oral or poster sessions. The Conference Proceedings were published in a special issue of Physica Status Solidi. Available on line at www.interscience.com

PhD theses

1. "Porous anodic alumina thin films on Si: Fabrication, properties, applications", M. Kokonou, PhD thesis, Thesis Advisor-Supervisor: Androula G. Nassiopoulou. Thesis defended at the National Technical Univeristy of Athens (2008)

Patents

1. Title: "Integrated gas flow sensor based on porous silicon micromachining"
   Application date: 7/5/97
   Greek Patent number: OBI 1003010
   International patent number PCT/GR 97/00040, Published by WIPO: 12/11/98 European patent number EP979133469, 7/11/99
   Applicants: NCSR Demokritos, A.G. Nassiopoulou
   Inventors: A.G. Nassiopoulou and G. Kaltsas

2. Title: "Thermoelectric power generator based on an integrated thermopile"
   Application date: 30/7/1999
   Greek Patent number: OBI 100260
   International patent number PCT/GB00/02936 -WO 01/09964 A1, 8/2/2001
   Applicants: NCSR Demokritos, and A.G.Nassiopoulou
   Inventors: A.G. Nassiopoulou and S. Panaghe

3. Title: "Method for the fabrication of suspended Porous Silicon microstructures and application in gas sensors",
   Application date: 31/7/2001
   Greek Patent number: OBI 1004040
   International patent number: PCT/GR02/00008 - WO 03/011747A1
   Applicants: IMEL/NCSR "Demokritos", C. Tsamis, A.G. Nassiopoulou
   Inventors: C. Tsamis, A. Tserepi and A.G. Nassiopoulou

4. Title "Low Power Silicon Thermal Flow Sensors and Microfluidic Devices Using Porous Silicon Sealed Air Cavity or Microchannels"
   Application date: 24/1/2002
   Greek patent number: OBI 1004106
   International Patent number: PCT GR03 0003/16.1.2003
   Applicants: IMEL/NCSR "Demokritos", A.G. Nassiopoulou
   Inventors: A.G. Nassiopoulou, G. Kaltsas and D. Pagonis

5. Title: "Gas Flow Meter and Specially Designed Housing For Use in Medical Equipment for Respiratory Control"
   Application date: 06/03/2002
   Greek patent number: OBI 100127
   Applicants: IMEL/NCSR "Demokritos", A.Nassiopoulou
   Inventors: A. G. Nassiopoulou and G. Kaltsas

MATERIALS AND DEVICES FOR MEMORY APPLICATIONS

Project leader: P.Normand

Key researchers:V. Ioannou-Sougleridis, P. Dimitrakis

Collaborating Researchers: P. Argitis, N. Glezos, A.M. Douvas

Post-doctorals: E. Kapetanakis*, E. Makarona, D. Velessiotis

PhD candidate: P. Goupidenis

*From June 2008: Assistant Professor at the Department of Electronics, TEI Crete

Objectives:

- Development of functional dielectrics and nanostructured materials for inorganic/organic memory applications.
- Study of the structural and electrical properties of the generated materials and demonstration of material functionality enabling the development of low-voltage memory devices.
- Realization and testing of memory devices and manufacturability assessment of the developed fabrication routes in an industrial environment.

Funding

- Bilateral French-Greek Project, Si-Nanocrystal Synthesis by Plasma-Immersion Ion-Implantation for Non-Volatile Memory Applications, EPAN. M.4.3.6.1E.
- III-Nitrides quantum dots-resonant tunneling diodes as tunable wavelength UV-VIS phototodetectors, European Space Agency (ESA), RFQ No. 3-12083

Activities:

Our research activities in materials and structures for memory applications started in 1996 with the development of the low-energy ion-beam-synthesis (LE-IBS) technique in collaboration with Salford University (UK). Two-dimensional arrays of Si nanocrystals in thin gate dielectrics were demonstrated and further exploited in the fabrication of nanocrystal memories (NCMs). This activity was first supported by the EU project, FASEM (1997-2000). LE-IBS development with target the realization of non-volatile NCMs in an industrial environment has been conducted further within the framework of the EU project, NEON (2001-2004), in collaboration with the US implanter manufacturer, Axcelis.

In addition to our LE-IBS-NCM activities, major efforts have been devoted the last few years to novel NCMs alternatives including: (a) Memory devices by Si+ irradiation through poly-Si/SiO2 gate stack (Collaborators -CLRs-: FZR and ZMD AG both sited in Dresden (DE)), (b) Memory devices using Ge-NCs produced by MBE (CLR: Aarhus Univ. (DK)), (c) hybrid silicon-organic and SiGe-organic memories (CLR: Durham Univ. (UK)); this last activity was conducted within the framework of the EU project, FRACTURE (2001-2003), (d) formation of LE-IBS Ge-NCs in high-k dielectrics (CLRs: CEMES/CNRS (FR), FZR Dresden and Cambridge NanoTech (USA)), (e) Formation of Si NCs in thin SiO2 layers by Plasma Immersion (CLRs: CEMES/CNRS & Ion-Beam-Services (IBS, FR)), (f) Wet oxidation of silicon nitride implanted with low-energy Si ions for ONO memory stacks (CLRs: CEMES/CNRS and MDM-INFM (IT)), (g) MOS structures with low-energy Ge-implanted thin gate oxides (CLR: LETI/CEA (FR)), (h) Proton radiation tolerance of nanocrystal memories (CLR: NTUA (GR)), (i) Fabrication and characterization of SiO2 films with Si NCs obtained by stencil-masked LE-IBS (CLR: CEMES/CNRS and INSA Toulouse (FR)).

In 2008, our main activities focused on the following tasks: (A) Molecular storage elements for proton memory devices (CLRs: IMEL's projects I.2 & II.3), (B) Fluorene-based cross-bar organic memory device (CLRs: NTUA and Durham Univ.), (C) High-k dielectrics stacks for advanced non-volatile memory devices (CLRs: Helsinki Univ. (FI) & IMS/NCSR'D' (GR)), (D) III-Nitrides quantum dots-resonant tunneling diodes as tunable wavelength UV-VIS phototodetectors (CLR: MRG/FORTH (GR)), (E) Fabrication and characterization of Ge diodes (CLR: IMS/NCSR'D').

A. Molecular storage elements for proton memory devices

E. Kapetanakis, A.M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand

With the increasing challenge in flash memory scaling, various information storage elements based on novel gate materials and physical storage principles have been proposed. Significant efforts have been devoted to storage elements exploiting: a) charge injection and trapping in dielectrics or nanoparticles, ferroelectric polarization of dielectrics, and c) the motion and trapping of protons in dielectrics (proton memory).

Apart from the benefits of using a single-transistor memory architecture and of being radiation tolerant, the proton memories also have the advantage of being able to be programmed at very low voltages, thus offering an attractive alternative for low-power low-voltage non-volatile data storage. While promising device results have been obtained, the conventional methods of forming proton memories still face critical issues towards the development of commercial products. For example, all existing methods utilize proton generating techniques (high-temperature processing and ion implantation) that can seriously affect the logic structures on the chip and cannot control the number of generated protons, thereby introducing large variations in device-to-device performance. In addition, the current fabrication methods of proton memory devices are not compatible with the emerging memory technologies of "all-polymer" ICs. Therefore, it is highly desirable to find a simple and low-cost method able to produce proton-based storage elements that can be reliably incorporated into the gate of inorganic and/or organic transistors.

Towards this goal, we recently reported the use of storage elements based on mobile protons that naturally exist in a solution-processed proton-conducting polymeric material. Such an approach does not involve a processing step for introducing protons inside the storage element, a trait that reduces complexity and cost in device fabrication. Moreover, a solution-based fabrication method can offer the capability for manipulating the storage elements' properties simply via formulation of the solution or/and chemical synthesis; a feature which is necessary for the modulation and optimization of the device overall memory performance. In addition, solution-processed elements provide compatibility with mechanically flexible substrates, low-cost manufacturing and large-area integration, and thereby, may be exploited for producing "all-polymer" single-transistor memories.

Realization of non-volatile memory devices is achieved using a stacked structure consisted of a proton-conducting polymeric layer (PCL) based on a tungsten heteropolyacid and poly(methyl methacrylate) (PMMA), and a proton-trapping polymeric layer (PTL) based on PMMA containing amine proton trapping sites, as depicted in figure 1 in the case of a MIS-type capacitor. Application of a positive voltage to the gate electrode with the substrate connected to ground ("Write" operation) allows for the dissociation of neutral (n) sites of the PCL into anions (-) and protons (+), motion and trapping of protons in the PTL. This induces a negative flat-band voltage shift of the capacitor C-V characteristics. A subsequent negative voltage moves back the trapped protons leading to the reformation of neutral sites within the PCL ("Erase" operation).

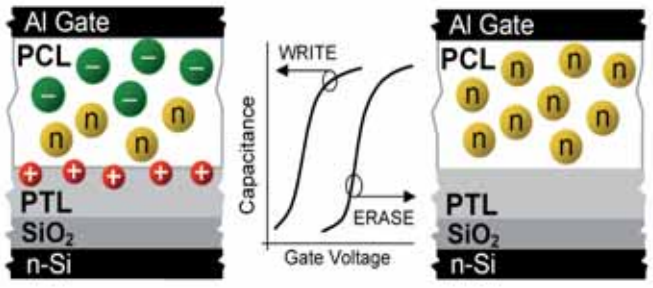


Fig. 1: Schematic illustrating the structure and the operation principle of a non-volatile bistable MIS memory device with a molecular-based proton storage element consisting of a proton-conducting polymeric layer (PCL) and a proton-trapping polymeric layer (PTL) bi-layer stacked structure.

B. Fluorene-based cross-bar organic memory device

P. Dimitrakis, P. Normand, D. Tsoukalas*, Ch. Pearson, J. H. Ahn**, M. F Mabrook**, D. A Zeze**, M. C. Petty****

*School of Applied Sciences, National Technical University of Athens (GR)
**Centre for Molecular and Nanoscale Electronics, Durham University (UK)

Organic and polymer materials are promising candidates for future molecular-scale electronic applications. Their attractive features include good processability, scalability and the possibility for molecular design through chemical synthesis. As an emerging area in organic electronics, polymer memories have become an active research topic in recent years. They are likely to be a promising alternative to the conventional memory technologies facing the challenges in miniaturizing from microscale to nanoscale. The last two decades various memory concepts and molecular materials have been examined with particular emphasis on the metal/organic/metal bistable two terminal devices. For such devices, application of appropriate voltage pulses switches the resistance of the organic material from a high state to a low state and vice versa. Each resistance state corresponds to a memory state or in other words represents a bit of information. A stringent challenge is here to synthesize an organic material exhibiting resistance switching using unipolar pulses.

In this context, our group in collaboration with Durham University focused on molecules containing the fluorene-group. We previously demonstrated (APL, 91(2007), 123506) that 7-{4-[5-(4-tert-butylphenyl)-1,3,4-oxadiazol-2-yl]phenyl}-9,9-dihexyl-N,N-diphenyl-fluoren-2-amine exhibit switching and negative differential resistance (NDR) measurements. Further, we examined the switching and NDR mechanisms and how the top-metal layer (Al) formation conditions affect the device operation. For these studies two different measurement protocols have been developed based on I-V measurements utilizing (1) single-directional voltage sweep and (2) bi-directional voltage sweep in combination with high and low electrode reversing. In most cases, a "forming" process, in which a large positive voltage is applied to the top Al electrode, was required before the NDR and resistance switching be observed. Three different electrical conductivity regimes have been identified: Poole-Frenkel conductivity in unformed structures, linear I-V characteristics for the low resistance state in formed devices, and superlinear I-V behavior for the high resistance state in formed devices.

Models based on metallic filaments or on the injection and storage of charge cannot explain all our experimental observations. Instead, our results suggest the formation of nanocrystalline regions that locally modify the polymer film resistivity. In addition, we found that polymer+0.5% of Au nanoparticles blends improve the switching phenomena and enhance device reliability. The devices can be used as two-terminal memory cells operating with unipolar voltage pulses in the regime of 1s. Low resistivity state can be achieved utilizing +3V pulses (i.e., peak voltage of the NDR region) on top-electrode independently on the thickness of the organic layer (Fig.2). High resistivity state is achieved using +5V, +6V and +8V (i.e., valley voltage of the NDR region) for devices with layers 40nm, 50nm and 70nm respectively (Fig.3). The current difference at a certain voltage between these states defines the memory window which is around two orders of magnitude.

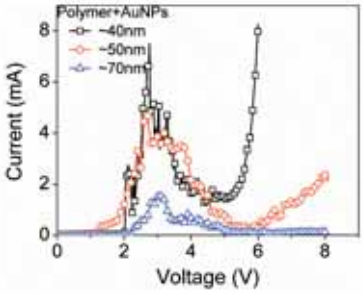


Fig. 2: I-V characteristics exhibiting strong NDR regions for different organic layer thicknesses

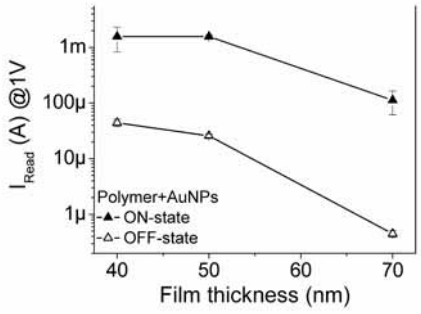


Fig. 3: Current level differences between the low (ON) and the high (OFF) resistivity states as function of organic layer thickness.

C. High-k dielectrics stacks for advanced non-volatile memory devices

V. Ioannou-Sougleridis, P. Dimitrakis, P. Normand, K. Kukli [*], J. Niinisto[*], M. Ritala[*], M. Leskela[*]

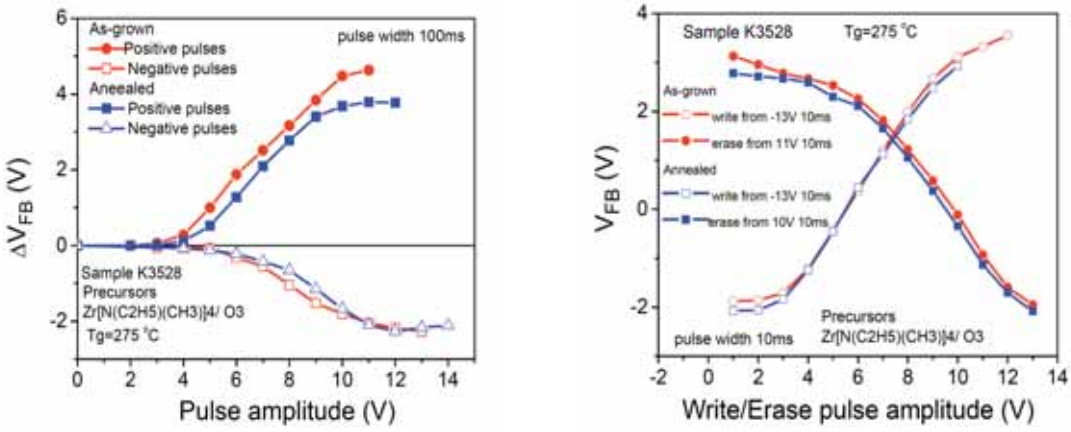
[*] Chemical Department of Helsinki University (FI)

The overall objective of this project is to explore advanced atomic-layer-deposition (ALD) precursor chemistry of high-k dielectrics used as tunnel or control insulators of nitride-based memory structures in order to improve the functionality and performance of SONOS-type devices. This project is conducted in close collaboration with the University of Helsinki.

Silicon nitride memory technology has significant advantages that could alleviate the scaling restrictions of the conventional flash technology. Silicon nitride technology employs ONO (oxide-nitride-oxide) dielectric stacks and utilizes traps that exist in the nitride layer as individual charge storage nodes. Despite the inherent advantages of the nitride technology it suffers from a number of drawbacks with most important the notorious "erase-saturation" effect. These problems can be bypassed using a number of approaches that include the replacement of the control and bottom oxides by single or multi-layer dielectric stacks composed of high-k insulators and also the replacement of the polysilicon gate electrode by a high work function metal electrode. These modifications provide a material based engineering solution of the erase-saturation effect. The use of high-k insulators increases the total EOT of the structure, allowing the use of a thicker

control oxide. Additionally, the use of such dielectric stacks provides a significant number of parameters such as energy gaps, band offsets, dielectric constants and thicknesses of the stack layers, as well as stack layer ordering (i.e. low-k/high-k or high-k/low-k) that under proper consideration may lead to advanced and scalable non-volatile memory cells.

ALD precursor chemistry is becomes gradually the critical factor which determines the physical, chemical and electrical properties of the deposited high-k insulators. This year we examined Al_2O_3, HfO_2 and ZrO_2 materials synthesized by different precursor chemistries such as $Al(CH_3)_3$-H_2O, (Al_2O_3), $Zr[N(C_2H_5)(CH_3)]4$-O_3, (ZrO_2), $(CpMe)_2Zr(OMe)Me$-O_3, (ZrO_2), $Hf[N(C_2H_5)(CH_3)]_4$-O_3, (HfO_2) and $(CpMe)_2Hf(OMe)Me$-O_3 (HfO_2). These materials were evaluated through structural studies and electrical characterization of oxide-nitride-high-k dielectrics stacks. Fig.4a shows the charging characteristics (flat-band voltage shift) of the as-grown oxide-nitride-ZrO_2 ($Zr[N(C_2H_5)(CH_3)]_4$-O_3) dielectric stack after consecutive pulses of 100 ms, and Fig. 4b shows the dynamic response of the same dielectric stack under varying height write-erase pulses.



a **b**

Fig. 4: Write/Erase characteristics of Oxide-Nitride-ZrO2 stacks. **(a)** Flat-band voltage shift as a function of the 100ms applied pulse amplitude and **(b)** flat-band voltage as a function of 10ms write/erase pulses for 10ms/-13V and 10ms/11V starting memory states.

D. III-Nitrides quantum dots-resonant tunneling diodes as tunable wavelength UV-VIS photodetectors

P. Dimitrakis, E. Iliopoulos*, G. Deligiorgis*, P. Normand, G. Konstantinidis*, A. Georgakilas*

* Department of Physics & MRG/FORTH (GR)

The objective of these activities is to design, fabricate and evaluate the performance of a novel solid-state photodetector device with spectroscopic capability, operating in the ultraviolet-visible part of the electromagnetic spectrum. The proposed device principle combines the broad spectrum responsivity of a layer containing non-uniform size distribution of (In)GaN quantum dots (QDs) with energy selective read-out mechanism based on AlGaN/GaN asymmetric double quantum-well resonant tunneling diode (RTD) structure (Fig.5).

Theoretical modeling (MRG/FORTH) of the structure was first realized allowing for the calculation of the RTD tuning range as a function of the composition of the quantum-wells (QWs), i.e., the

AlN mole fraction. The effect of the geometrical characteristics of the NPs and their density were taken into account for the calculation of the RTD tuning range. Meanwhile, self-consistent calculations of the Schrodinger-Poisson equations considering analytical expressions for the calculation of piezoelectric fields were performed using the code developed by MRG allowing for the precise estimation of the energy band diagram under different external applied bias conditions. Towards, the development of insulating dielectric materials of the proposed structures, IMEL provided TEOS layers deposited by LPCVD and characterized different layers (e.g. PE-CVD SiN) and processes. After dielectric optimization, MRG fabricated RTD structures of various configurations (e.g. single-well, double-well, various thicknesses of the layers, various AlN mole fractions) which are under testing at IMEL. Typical I-V curves of the fabricated diodes exhibiting a clear NDR region are reported in figure 6. The hysteresis behavior detected after forward and backward voltage sweeps is probably due to the charge trapping that occurs at the lateral surface of the vertical multilayer stack of the diode in combination with the presence of strong piezoelectric fields. This undesirable hysteresis effect was also reported by other groups and its elimination constitutes a difficult task to overcome.

In addition, different MBE growth conditions have been tested to examine the growth mechanisms of the GaN QDs. Comprehensive AFM studies reveal that the required height-to-diameter ratio for our application can be achieved by applying a two-step growth process. In order to investigate the electrical properties of the QDs, special diode structures have been fabricated and tested using C-V and I-V measurements. Finally, according to the device architecture, the top electrode should be a transparent electrode. Different transparent metal oxide conductors (e.g. ITO) are under investigation at IMEL in collaboration with the IMS/NCSR'D' (A. Speliotis).

Fig. 5: Optical Microscope image of a 100μm diameter two-terminal diode.

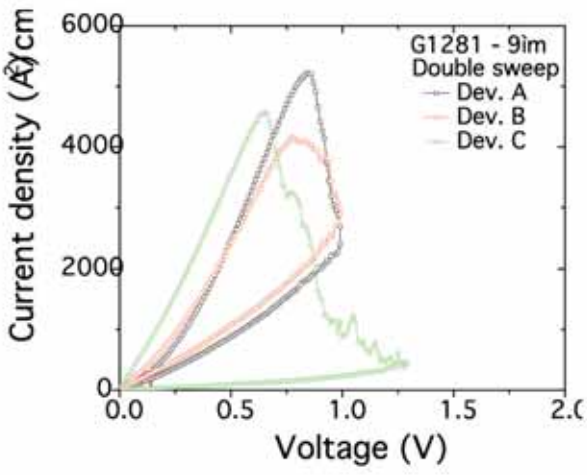


Fig. 6: -V characteristics of three different RTD diodes exhibiting hysteresis

E. Fabrication and characterization of Ge diodes

V. Ioannou-Sougleridis, P. Dimitrakis, P. Normand, A. Speliotis*, A. Dimoulas*

* Institute of Materials Science NCSR 'D'

The objective of this research activity is the fabrication and assessment of junction diodes on Ge substrates. Germanium was recently suggested as an alternative substrate that could alleviate the significant scaling limitations of the conventional Si MOSFET. Ge has a number of attractive properties which may lead to the development of nanoscale transistor structures. The lower effective masses and the resulting higher mobility of both type of charge carriers (two times higher than Si for electrons and four times for holes) in Ge, makes this material ideally suited as channel material for high-performance logic applications. However, the substitution of silicon by Ge substrates is not technological a straightforward task. The study will examine the dependence of the diode electrical characteristics (such as the reverse current, ideality factor and surface states effects) upon the main fabrication parameters (implantation and annealing) and the different surface passivation materials such as GeOx, Si/HfO2, La2O3,/HfO2, GeO2/HfO2, GeOx/HfO2, GeOx/ZrO2. This activity takes place in collaboration with the Institute of Materials Science NCSR "D" within the framework of FP7-ICT project DUALLOGIC.

PROJECT OUTPUT in 2009

Publications in International Journals

1. "Molecular storage elements for proton memory devices", E. Kapetanakis, A.M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand, Advanced Materials 20, 4568-4574 (2008).
2. "Electrical behavior of memory devices based on fluorene-containing organic thin films", P. Dimitrakis, P. Normand, D. Tsoukalas, C. Pearson, J.H. Ahn, M.F. Mabrook, D.A. Zeze, M.C. Petty, K.T. Kamtekar, C. Wang, M.R. Bryce, M. Green, Journal of Applied Physics 104, art. no. 044510 (2008).
3. "KFM detection of charges injected by AFM into a thin SiO2 layer containing Si nanocrystals", C. Dumas, L. Ressier, J. Grisolia, A. Arbouet, V. Paillard, G. BenAssayag, S. Schamm, P. Normand, Microelectronic Engineering 85, 2358-2361 (2008).
4. "Electrical properties of metal-oxide-semiconductor structures with low-energy Ge-implanted and annealed thin gate oxides", E. Kapetanakis, P. Normand, P. Holliger, Journal of Applied Physics 103, art. no. 064515 (2008).
5. "Study of charge storage characteristics of memory devices embedded with metallic nanoparticles", Ch. Sargentis, K. Giannakopoulos, A. Travlos, P. Normand, D. Tsamakis, Superlattices and Microstructures 44, 483-488 (2008).
6. "Silicon nanoparticles synthesized in SiO2 pockets by stencil-masked low energy ion implantation and thermal annealing", J. Grisolia, C. Dumas, G. Ben Assayag, C. Bonafos, S. Schamm, A. Arbouet, V. Paillard, M.A.F. van den Boogaart, J. Brugger, P. Normand, Superlattices and Microstructures 44, 395-401 (2008).
7. "High-density plasma silicon oxide thin films grown at room-temperature", M.E. Vlachopoulou, P. Dimitrakis, A. Tserepi, V.Em. Vamvakas, V.Em., S. Koliopoulou, P. Normand, E. Gogolides, D. Tsoukalas, Microelectronic Engineering 85, 1245-1247 (2008).

Publications in International Conference Proceedings

1. "Low-energy ion-beam-synthesis of semiconductor nanocrystals in very thin high-k layers for memory applications", C Bonafos, S Schamm, A Mouti, P Dimitrakis, V Ioannou-Sougleridis, G Ben Assayag, B Schmidt, J Becker, P Normand, in Microscopy of Semiconducting Materials 2007, A. G. Cullis and P. A. Midgley Editors, Springer Proceedings in Physics V.120, 321-324 (2008).

2. D.C. Moschou, E. Verrelli, D.N. Kouvatsos, P. Normand, D. Tsoukalas, A. Speliotis, P. Bayiati, D. Niarchos, Investigation of top gate electrode options for high-k gate dielectric MOS capacitors, Physica Status Solidi (C) 5, 3626-3629 (2008).

Chapter in Book

1. "Silicon nanocrystal memories", P. Dimitrakis, P. Normand, D. Tsoukalas, in Silicon Nanophotonics, L. Khriachtchev Editor, Pan Stanford Publishing, Chap. 8, 211-244, 2008.

Conference Presentations

1. 15th International Biennial Conference on Insulating Films on Semiconductors, INFOS 2007, Glyfada, Athens, Greece, June 20-23, 2007 (HYPERLINK "http://www.infos2007.gr" http://www.infos2007.gr). This conference was organized by the Institute of Materials Science (IMS) and the Institute of Microelectronics (IMEL) from NCSR Demokritos, the National Technical University of Athens and the University of Ioannina. The 134 papers (119 contributed and 15 invited) presented at the conference are published in A. Dimoulas and P. Normand (Eds), Microelectronic Engineering 84 (9-10), 2007.

Patent

1. "Hybrid organic-inorganic materials for molecular proton memory", E. Kapetanakis, A. M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand, Presented at: 34th International Conference on Micro- and Nano-Engineering, MNE 2008, Athens, Greece, September 15-19, 2008.
2. "Nanostructured ZnO-based layers deposited by non reactive rf magnetron sputtering on ultra-thin SiO2/Si through a stencil mask", A. Barnabé, M. Lalanne, L. Presmanes, Ph. Tailhades, C. Dumas, J. Grisolia, M. Naceur, A. Arbouet, V. Paillard, G. BenAssayag, M.A.F. van den Boogaart, J. Brugger, P. Normand, Presented at: 2nd International Symposium on Transparent Conductive Oxides, Hersonissos, Crete, Greece, October 22-26 2008.,
3. "Self-organization of Cu nanoparticles on polythiophene layers for bistable memory devices", P. Dimitrakis, M. Vassilopoulou, L.C. Palilis, G.Papadimitropoulos, D. Davazoglou, P. Argitis, P. Normand, E-MRS 2008 Spring Meeting, Symposium Q, Strasbourg, France, June 2008.

Invited Talks

1. "Des alternatives pour les mémoires non-volatiles à grille flottante", P. Normand, IMEP, MINATEC, Grenoble, France, 24 June 2008.

Master theses

1. "Study of dynamic charging phenomena of silicon nanocrystals in ONO dielectric stacks", N. Nikolaou, M.Sc. thesis held at IMEL/NCSR Demokritos (Supervisor: V. Ioannou-Sougleridis). Defended at the Department of Informatics and Telecommunications, National and Kapodistrian University of Athens (7/2008)

Conference Organisation

1. 34th International Conference on Micro- and Nano-Engineering, MNE 2008, Athens, Greece, September 15-19, 2008. (www.mne08.org). This conference was organized by the Institute of Microelectronics (IMEL) from NCSR Demokritos. Organizing Committee: E. Gogolides (Conference Chair), A. Tserepi (Conference Co-Chair), I. Raptis (Program Chair), P. Normand (Program Co-Chair), P. Argitis, N. Glezos, K. Misiakos, M. Hatzakis (Honorary Member).

Patent

1. Greek Patent Application, No 20080100269, Publication date: 18-04-2008, Memory devices using proton-conducting polymeric materials, Inventors: E. Kapetanakis, A.M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand.

MOLECULAR MATERIALS AS COMPONENTS OF ELECTRONIC DEVICES

Project leader: N. Glezos

Key researchers: P.Argitis P.Normand

Post Doctorals: D.Velessiotis, A.Douvas, E.Makarona, E. Kapetanakis

Collaborating Researchers: D. Yannakopoulou and E. Mavridi (Institute of Physical Chemistry, NCSR "D"), P.Petrou (Institute of Radioisotopes and Radioprotection, NCSR "D") , S. Kennou (Department of Chemical Engineering, University of Patras), G.Papavasiliou (National Hellenic Research Foundation), Z.Pikramenou (University of Birmingham), T.Gotszalk (University of Wroclaw), M.Woszczyna (University of Wroclaw), F.Saurenbach (SIS GmbH)

Funding:

• NMP STREP TASNANO, 1/1/2005-30/7/2008, Contract No 516865

Research orientation:

- To investigate the potential of molecular materials to be used as active components in molecular devices e.g. as switching or memory elements.
- to develop consistent evaluation methods based on the electronic transport properties at the nano-level for the characterization of single layered and few-layered systems.
- to produce physical parameters (film thickness, surface molecular density, contact potential) that could be cross-checked with other surface characterization methods
- To evaluate elements of the class of organic crystals as components of organic FETs
- To develop techniques for thin film deposition and characterization of molecular materials.

Main results in 2008:

The main results obtained in 2008 within the different tasks of the project are given below.

MAIN RESULTS IN 2008

A. Invastigation of the Transport Properties of Self-assembled Hybrid Organic/inorganic Monolayers based on Polyoxometalates

D.Velessiotis, M. Douvas, E.Makarona, E.Kapetanakis, N.Glezos, P.Argitis, P.Normand, T.Gotszalk (WRUT), M.Woszczyna (WRUT)

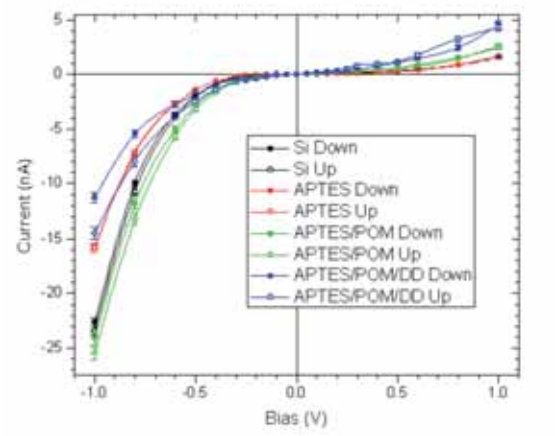
Our aim is to demonstrate the potential of inorganic polyxometalates (POMs) to serve as active layers in molecular electronic devices. So far we have demonstrated the possibility to fabricate organic/inorganic mono- and multi- layers containing polyoxometalates and we are performing electrical measurements with them in various device architectures:

- Vertical capacitor structures with the top electrode evaporated through a mask,
- Planar structures involving nanoelectrodes,
- Vertical capacitor structures fabricated entirely using conventional lithographic patterning techniques, with variable device parameters (capacitor surface, oxide thickness, substrate type),
- Vertical structures using an STM or cAFM tip as the upper electrode.

We have investigated both quantum conductivity effects as well as charging effects. We proceeded along the directions discussed below:

A1. Molecular layer investigations

Silicon n++ samples covered with a) aminosilane (APTES) b) APTES/POM and c) terminated by diamine (DD) APTES/POM/DD were fabricated by NCSR and measured by STM both by NCSR and WRUT. The samples used were fabricated with the layer-by-layer (LBL) method on top of highly doped n+ Si substrates. The obtained IVs were analyzed in two distinctly different ways. Firstly, they were statistically studied so that a "representative" I-V for every sample was constructed. Such an I-V provides us with a general idea of the magnitude of the conductivity for every type of SAM. Secondly, some of the I-Vs were fitted, using the Simmons model for elastic tunnelling in order to estimate the values of the tunneling distance s and the mean energy barrier φ0 for every sample.



Sample	φ_0 (eV)	s (Ä)
Si	0.61	7.5
APTES	0.62	6.7
APTES/POM	0.54	7.7
APTES/POM/DD	0.76	10.59

Fig. 1: 'Representative' I-Vs for the samples studied. A small hysteresis is evident in the case of APTES/POM/DD sample and negative voltages. The parameters obtained by simulation are also presented in a table. The presence of the terminating diamines (DD) obviously changes the tunnelling mechanism.

A2. Fabrication and characterization of capacitor structures.

We fabricated POM mono- and multi- layers on n-type and p-type substrates with a reference oxide. The fabrication process is CMOS compatible. The devices are packaged and the molecular layers are protected from environmental conditions The objective is to obtain systems capable of being controlled (charging / uncharging) only from one side. This depends on the type of doping, the oxide type and thickness and the covering metal. These parameters were evaluated by I-V and C-V measurements. We defined the conditions for this selective charging by varying the geometry of the substrate. Our conclusion is that these materials are capable for molecular memory node applications.

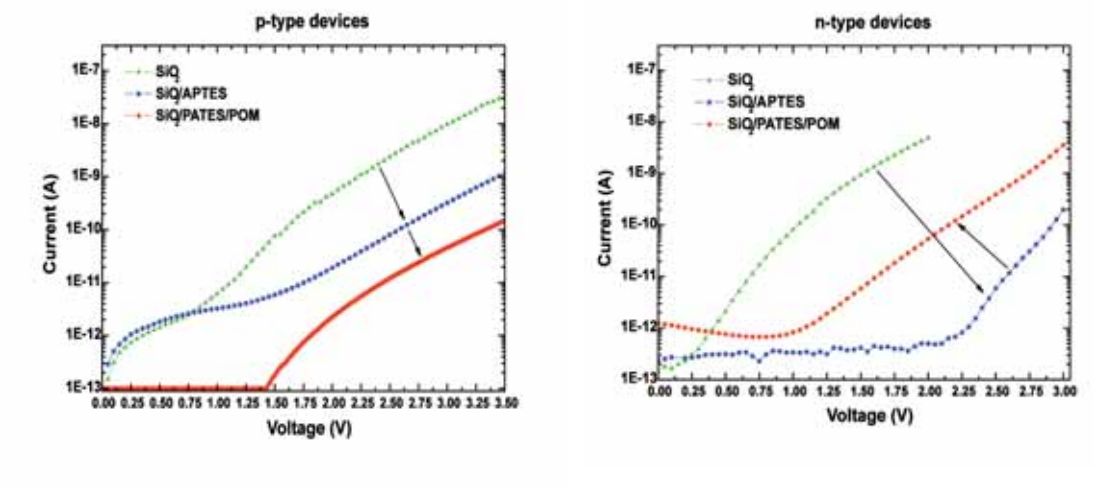


Fig. 2: Depending on the type of the substrate the transport mechanism changes: Electron injection from the top Al electrode (p-type), electron injection from the Si n substrate (n-type)

B. Study of the transport and host - guest properties of cyclodextrin nanowires for molecular devices

D. Maffeo, V. Chinnuswamy, D. Velessiotis, N.Glezos, K.Yannakopoulou and I.M.Mavridis

B1. Investigation of electronic transport properties of nanowires.

Molecular nanowires are essential for the development of molecular electronic devices both because of their quantum properties as well as for the possibility of serving as interconnections with other device components. In this work we studied supramolecular wires in the nanoscale based on the non-covalent interactions between metallocyclodextrins and metalloguests. The resulting surfaces were examined as far as morphology and constitution with STM microscopy and other techniques. Furthermore the study of the tunneling current ins an STM setup provided useful information concerning the wire stability, transport properties and the band alignment of the molecules with the Au binding surface. As an example of the whole procedure we examine the case of a hepta-substituted β-CD with (±)-1,2-dithiolane-3-pentanoic acid [(±)-α-lipoic acid] deposited on gold and then incubated with a suitable metallo-guest containing Iridium, thus making up a model molecular wire whose electrical conductivity was investigated.

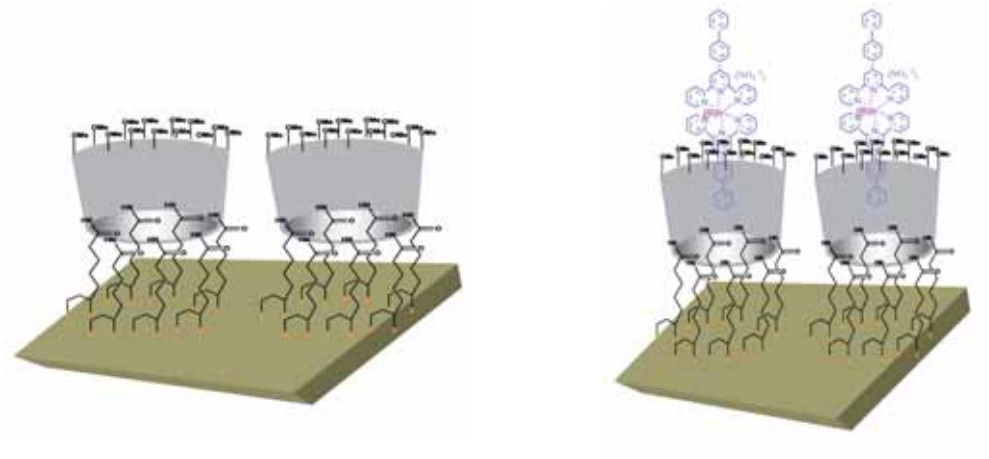


Fig. 3: Schematic representation of the surface organization of CD DMBLIP and with the metalloguest IrGuest .

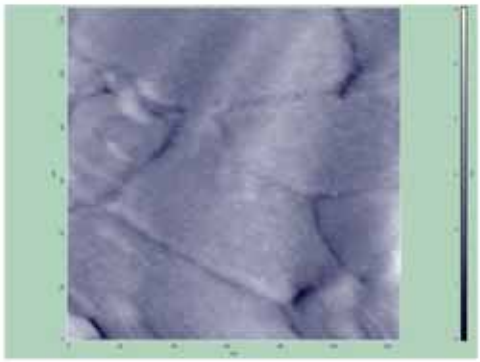


Fig. 4a: DMB Lipoic + Iridium Guest (120nmx120nm)

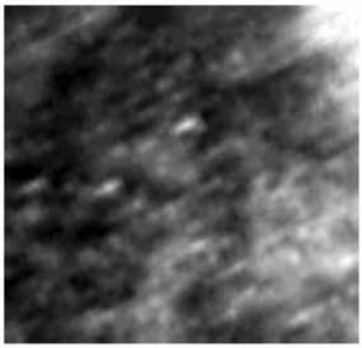


Fig. 4b: DMB Lipoic + Iridium Guest (20nm x 20nm), molecules oriented along the surface.

The method of IV Spectroscopy i.e. scanning the bias voltage of an STM tip at a specific position over the sample provides useful information regarding the potential between the surface and the tip and the conductivity of the molecular system involved. In our case the electronic "device" consists of the Au substrate , the molecular layer and the Ir/Pt tip of the STM system (Solver Pro 45, NT-MDT). All three cases are plotted in figure 5. This current obtained in the case of the reference Au sample (black line) is dominated by barrier tunneling and there is no significant effect of the reversal of the voltage bias . The **DMBLIP** layer (red line) acts as an insulating layer and modifies the potential enhancing non linear tunneling effects which are more prominent when electrons are injected from the surface to the tip than the reverse. In this case traps are created on the surface and the overall barrier is lowered and broadened as will be shown in the next step. The addition of **IrGuest** results in a linear metallic behaviour in the voltage region investigated (green line). In this case the molecular layer facilitates electronic transport.

The tunneling regimes in the first two cases are analyzed using the relation:

$$I = C_1 \exp(-a)V + C_2 V^2 \exp(-b/V) \qquad \textbf{(1)}$$

Where C_1 and C_2 are constants, $a = 2s\sqrt{2m\varphi}/(3e\hbar)$ $b = \frac{2}{3}a\varphi$ φ is the potential barrier and s is the effective barrier length . The first term stand for low voltage tunneling and the second term represents situation where the barrier is modified to a triangular form thus resulting in increased currents (Fowler - Nordheim tunneling). The analysis is better visualized in a Fowler-Nordheim plot (figure 5b). In the case of the Au substrate the fitting according to relation (1) results in φ=0.87eV and s=0.72nm. The presence of the **DMBLIP** layer modifies these values to =0.22eV and s=1.44nm. Thus the presence of the insulating layer results in lower and broader barrier for the electrons. The presence of a metal containing guest (Iridium) results in metallic behaviour of the contact despite the tunneling effect. This is promising if these systems will be used as metallic self-assembled conductors in a molecular scale.

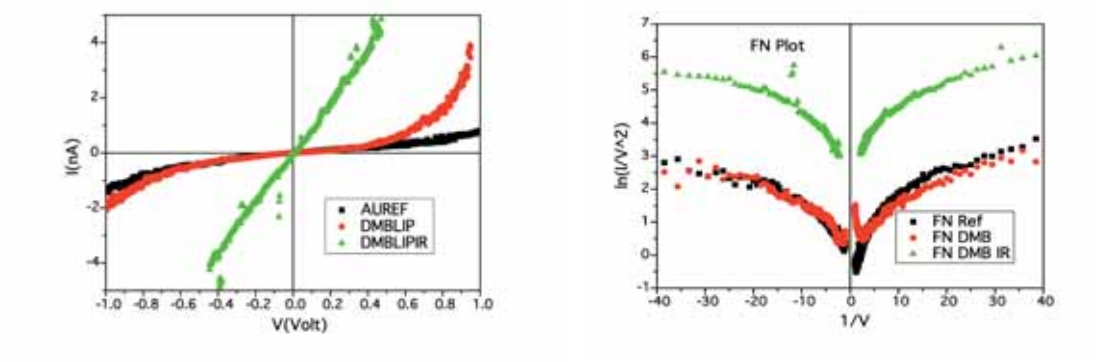


Fig. 5: Electronic transport properties in STM configuration. The I-V characteristics are averaged over different points on the surface. Au reference: black; **DMBLIP** on Au, red line; **IrGuest/DMBLIP** on Au, green line.

B2. Surface Characterization with AFM functionalized probes

The aim of this task is to exploit the potential of cyclodextrins to act as hosts to other molecules. Specifically modified cyclodextrin hosts can bind via weak intermolecular forces with suitable guest molecules, bound also via -SH bonds to AFM tips, in a manner that manifests molecular recognition.

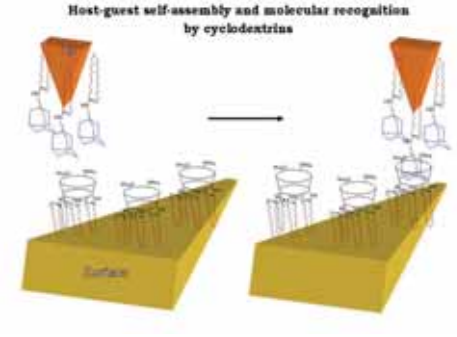


Fig. 6: DMB Lipoic + Iridium Guest (120nmx120nm)

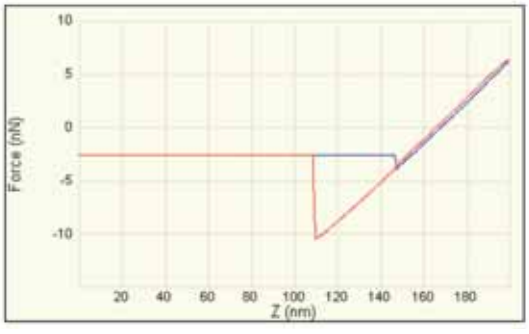


Fig. 7: DMB Lipoic + Iridium Guest (20nm x 20nm),molecules oriented along the surface.

The functionalization of gold surfaces and cantilevers was carried out using the following compounds:

1) The natural cyclodextrins are molecules of increasing cavity size in the order αCD <βCD<γCD. Three different modified cyclodextrin molecules (Hosts) of increasingly larger cavity size (αTHIO <DMβTHIO <γTHIO) specifically prepared, were used to functionalise gold surfaces.

2) An adamantane guest molecule was selected to bind specifically and strongly with a βCD-type cavity and much less with either an α- or a γ-type cavity, ADASH.. This was used to functionalize AFM tips.

Force measurements of the above complementarily functionalized pairs, Guest on-Gold AFM Tip/Host-on-gold surface, were carried out at the University of Wroclaw. The results showed that significant attractive forces were recorded in the pair ADASH/DMβTHIO, as expected, since the adamantyl group-βCD entities constitute an acknowledged pair with strong ands specific binding. On the contrary, the pairs ADASH/αTHIO and ADASH/γTHIO show attractive forces of approximately the same order, showing no specificity in either binding.

The measured results are summarized in the following table:

	αTHIO	DNβTHIO	γTHIO	Difference DMβTHIO/αTHIO	Difference DMβTHIO/γTHIO
Plain tip	6.8	9.3	6.2	2.5	3.1
ADASH charged tip	22	27	19	5	8

Therefore the specific molecular recognition ordinarily observed in aqueous environment is also demonstrated in the surface/AFM tip interactions.

C. SPM nanopatterning of biotin monolayers

P. Petrou, F. Saurenbach, D.Velessiotis, N.Glezos

Scope of the activity was to define a process based on a biomolecular layer for sub 10nm lithography. A biotin covered surface was prepared according with methods developed at NCSR and patterned by AFM tips at SIS in order to create patterns with dimensions below 10 nm. The pattern has been identified before and after reaction with streptavidin by employing AFM imaging. The streptavidin-biotin system is an ideal demonstrator of pattern recognition due to the high affinity of streptavidin for biotin (affinity constant $K=10^{15}$ L/mol) that makes their binding almost irreversible even under very harsh conditions.

The biotin covered surfaces were sent to SIS for patterning with AFM tips. The pattern created was imaged by AFM both at NCSR and SIS. Two types of patterns were created (a) A line pattern where the minimum dimension achieved was about 15 nm and (b) A dot pattern where the minimum dimension achieved was about 8 nm.

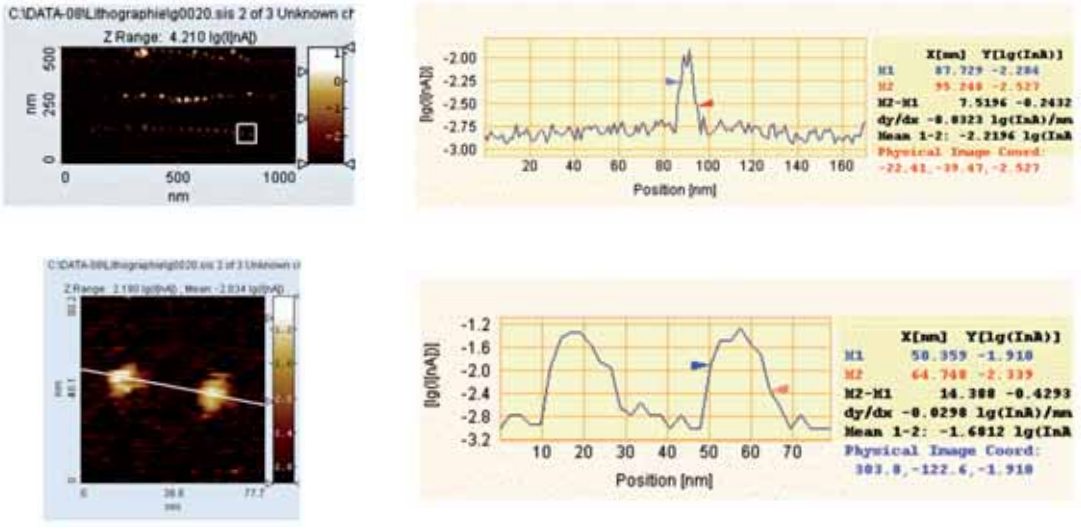


Fig. 8: Example of nanopatterning of biotin / streptavidin monloayers with an STM probe with a tresolution of 8nm.

PROJECT OUTPUT IN 2008

Publications in International Journals

1. "Molecular nanodevices based on functionalized cyclodextrins", Velessiotis, D. , Maffeo, D. , Millios, C., Makarona, E. , Viswanathan, C., Yannakopoulou, K. , Mavridis, I. , Pikramenou, Z. , Glezos, N. (2008) Physica Status Solidi (A) Applications and Materials, 205 (11), pp. 2532-2535, 2008.
2. "Soluble substituted phthalocyanines for OFET applications", Chaidogiannos, G.a, Petraki, F., Glezos, N., Kennou, S., Nešpurek, S. Materials Science and Engineering B: Solid-State Materials for Advanced Technology, 152 (1-3), pp. 105-108 , 2008
3. "Vertical devices of self-assembled hybrid organic/inorganic monolayers based on tungsten polyoxometalates", Makarona, E. , Kapetanakis, E. , Velessiotis, D.M. , Douvas, A. , Argitis, P. , Normand, P. , Gotszalk, T. , Woszczyna, M. , Glezos, N., Microelectronic Engineering, 85 (5-6), pp. 1399-1402, 2008.
4. "Polyoxometalate-based layered structures for charge transport control in molecular devices", Douvas, A.M. , Makarona, E. , Glezos, N. , Argitis, P. , Mielczarski, J.A. , Mielczarski, E. ACS Nano, 2 (4), pp. 733-742, 2008.

Conference Presentations

1. "Characterization of surfaces and interactions of self-assembled cyclodextrin monolayers with STM and functionalized AFM probes", D. Maffeo, M. Woszczyna, D. Velessiotis, V. Chinnuswamy, K. Yannakopoulou, A. Paulidou, I.Mavridis, Th. Gotszalk, J. Milecszarski, E. Milecszarski, N. Glezos, , MNE 2008 Athens
2. "Molecular proton memory", E. Kapetanakis, A. M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand, , MNE 2008, Athens
3. "Quantitative force and mass measurements using piezoresistive cantilever with integrated thermal deflection actuator " M. Woszczyna, P. Zawierucha, M. Świą

MECHANICAL AND CHEMICAL SENSORS

Key Researchers: S. Chatzandroulis, P. Normand, I. Raptis, C. Tsamis

Collaborating Researchers: A. Tserepi, D. Goustouridis

Post-doctoral scientists:E. Makarona, F. Farmakiss

Phd students: R. Triantafyllopoulou, V.Tsouti, I. Ramfos, K. Manoli, P. Oikonomou, Ch. Kokkinos, P. Broutas

External Collaborators: M. Sanopoulou (IPC, NCSR 'Demokritos'), Th. Speliotis (IMS, NCSR 'Demokritos'), A. Economou (Chemistry Dept. Uni. Athens), K. Beltsios (Materials Sci. Dept. Uni. Ioannina), E. Sarantopoulou, Z. Kollia, A.C. Cefalas (NHRF), J. R Morante (Univ. of Barcelona), G. Petersson (Chalmers Univ.), M. Kompitsas (EIE), I. Zergioti (NTUA), D. Tsoukalas (NTUA), D. Kafetzopoulos (IMBB/FORTH)

Objectives:

- Development of micromachining processes for the realization of novel chemical and mechanical sensors.
- Development of low power silicon sensors based on new materials and new processes.
- Design, fabrication and testing of microsystems using silicon sensors.
- Realization of sensors for specific industrial applications with emphasis on medical, food and automotive fields.

Funding:

- EU - IST-FP6-STREP-027333 Micro2DNA, "Integrated polymer-based micro fluidic micro system for DNA extraction, amplification, and silicon-based detection", P. Normand
- GSRT Greece-Italy bilateral cooperation "Fabrication and characterization of an array of transparent conductive thin film polymeric composite as multiparametric sensitive layers for a new e-nose", D. Goustouridis
- GSRT-PENED 03ED630, "Micromachined chemical sensors for controlling food safety and quality", C. Tsamis
- GSRT- ENTER 05EP032, "Development of MOSFET type chemical sensors for wireless sensor networks", C. Tsamis

Main Activities in 2008:

In 2008, our main activities were focused on the following tasks:

A. Low power Metal-Oxide (MOX) Chemical Sensors

B. FET-type chemical sensors for wireless applications

C. Polymer based chemical sensor arrays

D. Capacitive Type Sensors

E. Microfabricated electrochemical sensors

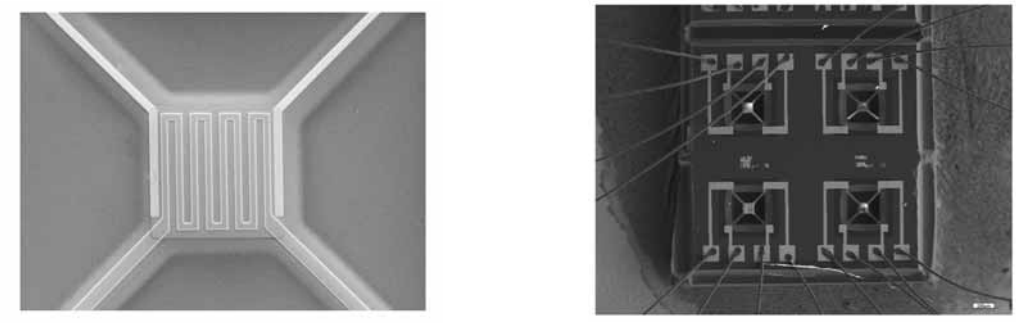
RESEARCH ACTIVITIES AND MAIN RESULTS WITHIN 2008

A. Low power Metal-Oxide (MOX) Chemical Sensors*

R. Triantafyllopoulou, S. Chatzandroulis, A. Tserepi and C. Tsamis

* In collaboration with Department of Electronics, University of Barcelona (J. R Morante)

Solid state chemical sensors are one of the most common devices employed for the detection of hazardous gases, like NH_3, CO and NO. Their principle of operation is based on the changes of the conductivity of a sensitive material, which is deposited between two electrodes, due to the adsorption of reducing or oxidizing agents onto its surface. Many techniques have been developed for the deposition of catalytic materials. The most widely used techniques to deposit a sensitive material are either by sputtering or by microdropping. In the first case thin films were prepared by reactive r.f. magnetron sputtering using a 99.9% pure SnO_2 target (Fig.1a). In the second case sensitive materials are prepared by a sol-gel solution with metal additives, in order to enhance its sensitivity, and then deposit the additive-modified nanostructured metal oxides on micro-hotplates, by microdroping. In this way, the use of Porous Silicon micro-hotplates allows for the fabrication of sensor arrays (Fig. 1b) that incorporate varying sensitive materials, while at the same time they exhibit a significant reduction of the power consumption.

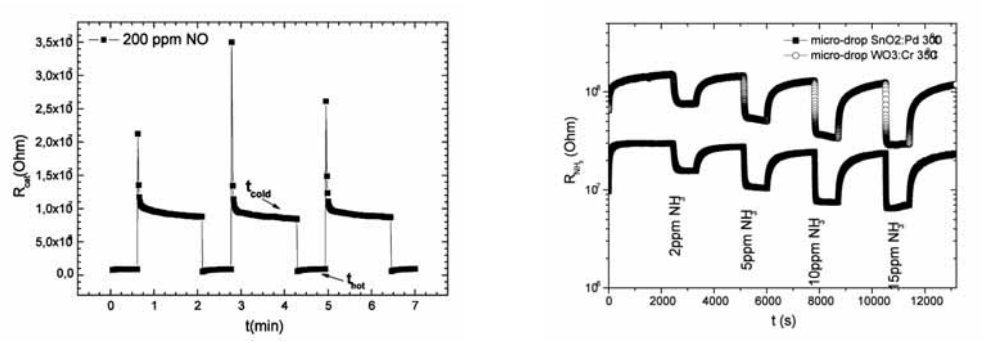


a **b**

Fig. 1: SEM image **(a)** of the sputtered SnO_2 deposited on a micro-hotplate and **(b)** of a sensor array with micro-dropped nanostructured sensitive materials SnO_2:Pd and WO3:Cr, mounted on a package.

During this year, we developed gas sensors for food safety and quality applications as well as for environmental monitoring, fabricated by sputtering and micro-dropping. The sensors are based on suspended Porous Silicon micro-hotplates. Porous Silicon provides improved thermal isolation, thus reducing heat dissipation to the substrate. For further reduction of power consumption, various methodologies have been developed, such as alternative measuring techniques to constant temperature operation, such as pulsed-temperature mode. In Fig. 2a the response of the sputtered SnO_2 gas sensors towards NO is shown, operating in pulsed temperature mode, by applying voltages pulses to the heater. In this case, the sensitivity and selectivity of the sensors was estimated as a function of the total shape of the pulse cycle, the duration of the pulses and the temperatures of the "hot" and the "cold" part of the measuring cycle. Sensors were characterized in CO and NO ambient, for gas concentrations (100-500 ppm). Operation in pulsed temperature

mode, results in higher sensor sensitivity and enhanced selectivity towards NO, with reduced power consumption. In Fig. 2b the response of the two nanostructured sensitive materials SnO_2:Pd and WO_3:Cr towards NH_3 is shown, for gas concentrations (2-15 ppm). The sensors operated in isothermal mode, by keeping constant the micro-hotplate temperature. The gas sensors with micro-dropped sensitive materials and especially SnO_2:Pd exhibit the highest sensitivity towards NH_3, with lower power consumption.



a **b**

Fig. 2: (a) Sensor response towards NO for pulsed temperature operation mode for sputtered SnO_2 sensitive material, **(b)** response of gas sensors with SnO_2:Pd and WO_3:Cr micro-dropped sensitive materials, in isothermal operation, for low concentrations of NH3 (2^{-15} ppm).

For more information please contact Dr. C. Tsamis (e-mail: ctsamis@imel.demokritos.gr)

B. FET-type chemical sensors for wireless applications

F. Farmakis, K. Alexandrou, C. Tsamis, M. Kompitsas[1], I. Fasaki[1], P. Jedrasik[2], G. Petersson[2], B. Nilsson[2]

[1] National Hellenic Research Foundation, Theoretical and Physical Chemistry Institute

[2] Dept. of Microtechnology and Nanoscience, MC2, Chalmers Univ. of Technology

Chemical sensors for wireless applications are of major interest since they turn into reality the possiblity to sense and monitor environmental changes in hard-accessible mediums or even to escort environment-sensitive products (such as food) in order to monitor and build environment-related database. Low-energy consumption (low current operation), room-temperature operation as well as integration in small dimension are some of the most important requirements of such sensors. To this end, we investigate two candidate devices: i) MOS capacitive sensors and ii) FET-type sensors with active catalytic layer.

During this year, we focused our efforts on the fabrication of interdigitated bottom-gate FET devices (gasFET) with various channel lengths (from 0.3 μm to 2 μm) (Figure 3a). On the top of the interdigitated electrodes, a 50-nm-thick zinc oxide layer was grown by pulsed laser deposition, as the active layer. Alternatively, Au-doped ZnO was also grown in order to investigate the influence of Au doping in ZnO. Figure 3b shows an AFM image of as-deposited thin ZnO film grown on oxidized silicon wafer. The average grain size of around 30-40 nm is not affected by the annealing process due to the low (400°C) temperature used. Surface roughness at 22 nm is slightly reduced after annealing. The indicated high surface-to-volume ratio favors the application of such films as gas sensors since the chemical active area is enhanced.

Figure 4a shows a comparison in CO sensing between a ZnO gas sensor without Au and with Au nanoparticles. It has to be noted that both sensors were held at 200°C during the experiments and that the CO was introduced with dry air. It is easily observed that the sensitivity is more than 1.5 times higher for the sensor with the Au nanoparticles. In addition, the response time t90 (t90 is defined as the time needed for the signal to achieve the 90% of its final value) is 3 times shorter for the ZnO/Au nanoparticles gas sensor. Figure 4b shows the comparison of the sensitivity between the two samples for various values of CO concentration. In both cases the gas sensor sensitivity seems to be linearly depended on the

CO concentration in dry air at 200°C. However, for the Zn/Au gas sensor the slope of the sensitivity is 4.8 x10^{-4} ppm^{-1} compared to the as-deposited ZnO sensor that has a slope of 1.9 x10^{-4} ppm-1

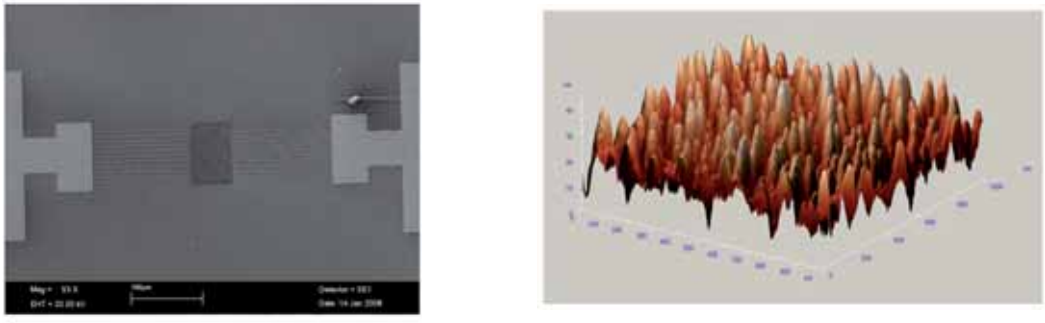


Fig. 3: (a) SEM images showing the interdigitated source and drain electrodes of the bottom gate FET device. **(b)** AFM image picture of as-deposited thin ZnO film grown on oxidized silicon wafer. The average grain size of around 30-40 nm is not affected by the annealing process due to the low (400° C) temperature used.

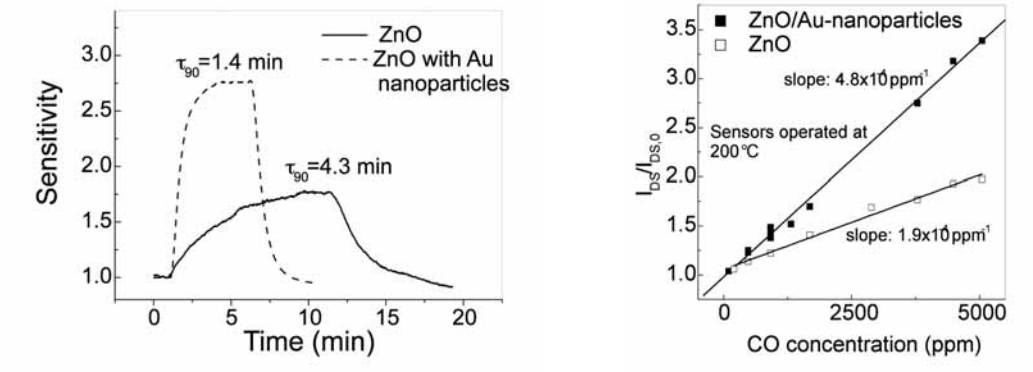


Fig. 4: ppm (VDS=6 V, VGS=0 V) and measurements were performed at 200oC. (b) Drain current increase (sensitivity) against CO concentration for ZnO sensors with and without gold nanoparticles. The sensors were at 200 AC (VDS=6 V, VGS=0 V).

For more information please contact Dr. C. Tsamis (e-mail: ctsamis@imel.demokritos.gr)

C. Polymer Based Gas sensors

K. Manoli, P. Oikonomou, D. Goustouridis, S. Chatzandroulis, I. Raptis, M. Sanopoulou[1], K. Beltsios[2], E. Sarantopoulou[3], A.C. Cefalas[3]

[1] Institute of Physical Chemistry, NCSR 'Demokritos'
[2] Material Science Dept. University of Ioannina
[3] Theoretical and Physical Chemistry Institute, National Hellenic Research Foundation

Capacitive-type chemical sensors rely on changes in the dielectric properties of the sensing polymeric layer due to absorption of VOCs. Such polymer-based chemocapacitive sensors are promising devices in terms of processability, low fabrication cost, reversibility and the wide range of material choice, commercially available or to be tailor-made, to meet the needs of specific VOC applications.

Our research aims at i) the development of capacitive sensor arrays based on InterDigitated Electrodes (IDEs) coated with polymers as sensing layers and ii) on the development of the necessary hardware - software for the measurement of these arrays. In this framework our research was focused on a) development and characterization of arrays with 4 sensors coated with different polymers b) development of methodologies for the sensitivity enhancement and c) development of PCA algorithms for substance identification.

Arrays of 4 IDEs were fabricated with conventional microelectronic processing technology and coated with polymeric films. The response of the sensor array in various analytes is illustrated in fig. 5. The response clearly depends on the polymer-analyte combination.

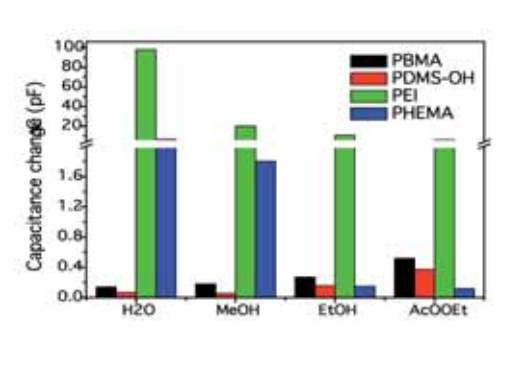


Fig. 5: Equilibrium capacitance response of IDC array to 5000 ppm of each of the four analytes. Initial capacitance of the polymer layers Cp (pF): 11 (PBMA); 9 (PDMS-OH); 80 (PEI); 40 (PHEMA).

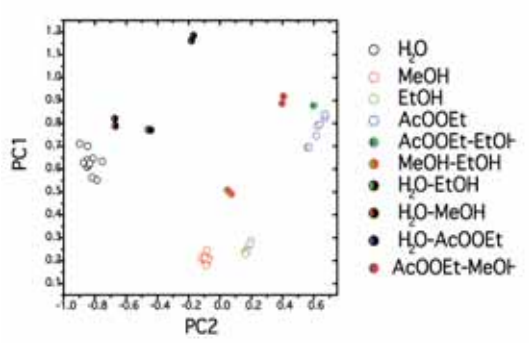


Fig. 6: PCA analysis of the sensor array responses to 5000 ppm of the four analytes and their 1:1 mixture

Due to the inherently partial sorption selectivity of the sensing polymeric materials, it is necessary to apply a data processing technique to the responses of the sensor array, in order to enhance its discriminating ability towards complex vapor environments. A Principle Component Analysis (PCA) algorithm was developed to improve in the discrimination capability of the sensor array. PCA analysis of the capacitance responses upon exposure of the sensor array to single analytes and to mixtures is shown in Fig. 6. The plot, containing 92.7 % of the total variance of the data, depicts distinct separate clusters for the different analytes and their binary mixtures.

Furthermore, innovative InterDigital Chemocapacitive (IDC) sensors, based on polymer layers filled with various amounts of BaTiO3 nanoparticles were investigated in order to evaluate the effect of incorporated BaTiO3 on the sensitivity and selectivity of the pure polymer- based sensors. In fig. 7, optical micrographs of sensors with polymeric layers with and without BaTiO3 are shown. The capacitance changes ΔC of a pure PBMA sensor, as well as of composite PBMA -BaTiO3 sensors, upon exposure to 5000 ppm of various analytes, are shown in Fig. 8. As expected, in the more hydrophobic PBMA polymer, exhibiting a higher sorption capacity for the less polar analytes, the capacitance response of the pure PBMA-sensor decreases with increasing polarity of analyte.

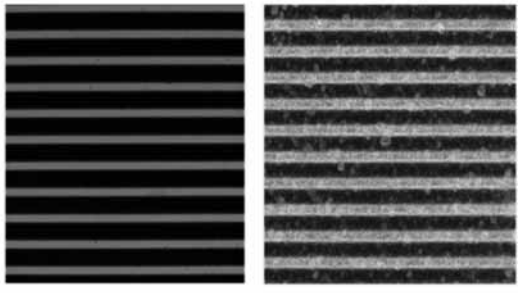


Fig. 7: Optical micrograph of the interdigitated electrodes coated with pure PBMA and PBMA/ BaTiO3 10%v/v composite.

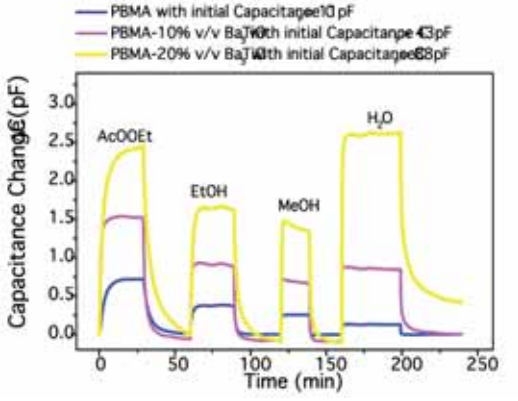


Fig. 8: Effect of BaTiO3 load on capacitance response of PBMA- based sensors to 5000ppm of ethyl acetate, ethanol, methanol and water vapors.

D. Capacitive Type Sensors

S. Chatzandroulis, D. Goustouridis, V.Tsouti, I. Ramfos, P. Broutas, C. Boutopoulos*, I. Zergioti*, D. Tsoukalas*, D. Kafetzopoulos, P. Normand**

*National Technical University of Athens
**IMBB/FORTH

Capacitive DNA Sensors Arrays

Unlabeled DNA detection has been the focus of great interest in recent years as it simplifies sample preparation and testing procedures. To this end and within the framework of the European Project Micro2DNA, we have developed a capacitive type chemical/biological sensor array organized in a 16 x 16 sensor matrix. Each sensor in the array consists of a single crystal silicon membrane which is able to sense surface stress changes which could be exerted by either a chemically sensitive layer or the interaction between immobilized biological species with other target biological species. In the first case the array is operated as a chemical sensor array (figure 9), while in the second case it is operated as a DNA sensor. In figure 10, CD19 bThalassemia normal and mutated probes were immobilized on the thin membrane surface. The sensor was then exposed to PCR containing the CD19 oligos and was hybridized.

Furthermore, in order to facilitate portable measurement the developed dedicated ASIC for the readout of the whole 16x16 array has been incorporated on a PCB together with a microcontroller. The board can then be controlled from a PC/laptop using Labview and a standard USB port.

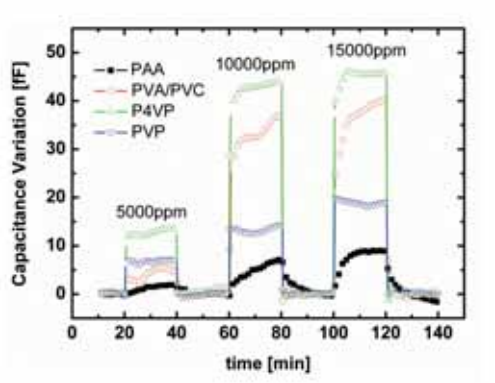


Fig. 9: Polymeric films sensitive to humidity and Volatile Organic Compounds (VOCs) have been deposited using the Laser Induced Forward Transfer (LIFT) technique. As analyte molecules are absorbed in the polymer film the membrane deflects causing a change in capacitance between membrane and substrate.
The response to water vapors of membranes of 250μm diameter partially covered with four different polymers.

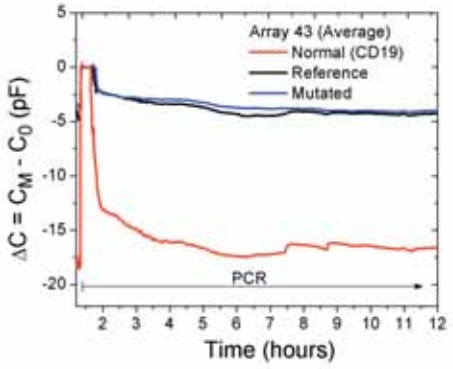


Fig. 10: Hybridization of the CD19 bThalassemia oligonucleotide. CD19 normal and mutated probes (50uM) are first immobilized on the thin membrane surface of different sensors in the array at IMBB/FORTH. Then the PCR product (72nM) is inserted into the hybridization chamber and over the sensor. In the figure the region of the curves after the insertion of the PCR and obtaining the baseline is depicted. The sensor signal remains stable at first and then decreases for both mutated and normal as well as the reference. However the decrease in the normal CD19 is by far larger than the other two

Capacitive Strain Sensors

Online strain measurement is sought for in many industrial, aerospace and civil applications where monitoring of an engineering structure health is crucial in maintaining its integrity and avoiding catastrophic structural failure. Measuring strain on selected places of a structure can give information about overall deformation and lead to early detection of potential damage. This in effect reduces periodic inspection costs while, at the same time, increasing safety.

In this work a robust capacitive type strain sensor is demonstrated which consists of a cavity etched in a thick wet oxide, a fixed electrode and a thin Si membrane that seals the cavity and operates as a flexible electrode. When the flexible electrode is under stress, it deflects and the device capacitance changes. The whole structure is mounted onto a flexible film and is subsequently

embedded into a solid layer of PDMS (polydimethylsiloxane) polymer. The latter covers the sensor in its entirety and is used to transfer stress to the flexible electrode from the surface under measurement. The device exhibits linear behavior with a gauge factor of 1.0 and sensitivity of 4.1 fF/mstrain.

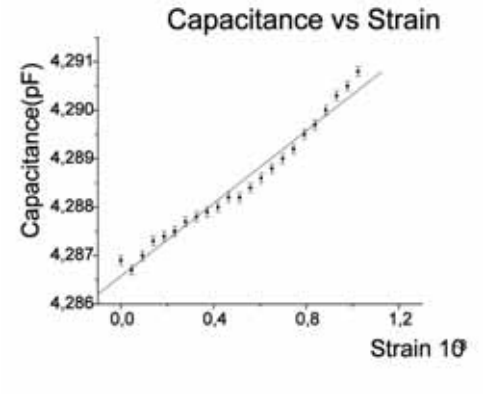


Fig. 11: Capacitance vs. Strain for a downwards deflected cantilever end.

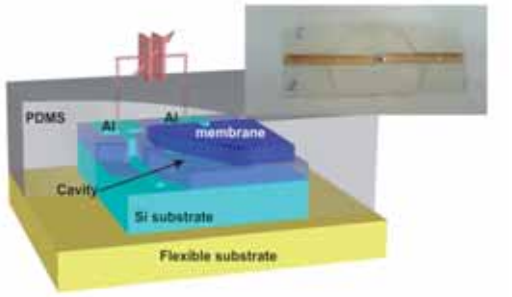


Fig. 12: Strain sensor mounted on the flexible structure: a) schematic, b) photographic view

E. Microfabricated electrodes for stripping voltametry

Ch. Kokkinos[1], I.Raptis, Th. Speliotis[2], A. Economou[2]

[1] Institute of Materials Science, NCSR 'Demokritos'
[2] Chemistry Dept. University of Athens

Stripping voltammetry (SV) has proved a powerful technique for the determination of trace metals in samples of environmental, clinical and industrial origin. Mercury film electrodes (MFEs) and the hanging mercury drop electrode have been traditionally used in SV, based on the ability of mercury to form amalgams with many heavy metals. However, the increased risks associated with the use, manipulation and disposal of metallic mercury or mercury salts have led to the search for alternative more environmentally friendly electrode materials. In this direction Bismuth electrodes appear to be an alternative environmental friendly approach exhibiting comparable performance to MFEs.

Methodologies were developed for the parallel production of sputtered bismuth electrodes with predefined geometry based on photolithography and paying particular attention to the preservation of sensing properties of the deposited thin bismuth films (fig. 13). Furthermore developed patterning approaches were further extended to the integration of the reference and counter electrodes on the same chip (fig. 14). With the developed technology disposable three-electrode cells were developed and successfully evaluated at Chemistry Dept., University of Athens for the trace determination of Ni.

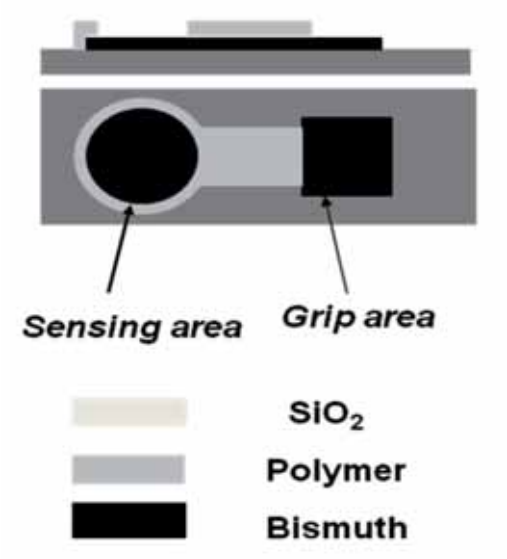


Fig. 13: Cross section and top-view of the bismuth sputtered sensor

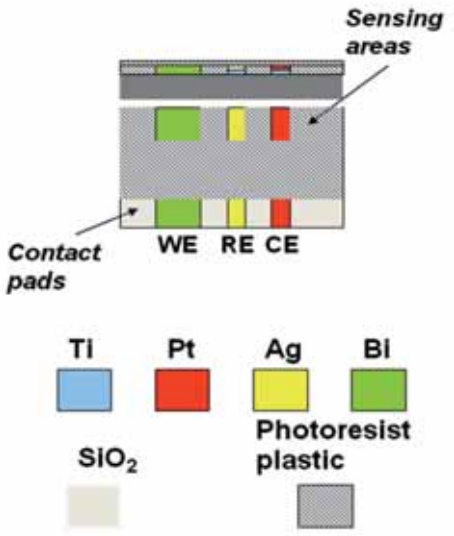


Fig. 14: Schematic of the three electrode cell

PROJECT OUTPUT in 2008

Publications in International Journals

1. "Structural and sensing properties of nanocrystalline SnO2 films deposited by spray pyrolysis from a SnCl2 precursor", Gaiduk, P.I., Kozjevko, A.N., Prokopjev, S.L., Tsamis, C., Nylandsted Larsen, A., Applied Physics A: Materials Science and Processing 91 (4), pp. 667-670 (2008)
2. "Nanostructured Oxides on Porous Silicon Microhotplates for NH3 Sensing", R. Triantafyllopoulou, X. Illa, O. Casals, S. Chatzandroulis C. Tsamis, A. Romano-Rodriguez and J.R. Morante, Microelectronic Engineering 85 (5-6), pp. 1116-1119 (2008)
3. "Field-effect transistors with thin ZnO as active layer for gas sensor applications", F. V. Farmakis, A. Speliotis, K. P. Alexandrou, C. Tsamis, M. Kompitsas, I. Fasaki, P. Jedrasik, G. Petersson, B. Nilsson, Microelectronic Engineering 85 (5-6), pp. 1035-1038 (2008)
4. "Disposable mercury-free cell-on-a-chip devices with integrated microfabricated electrodes for the determination of trace nickel(II) by adsorptive stripping voltammetry" Ch.Kokkinos, A.Economou, I.Raptis, Th.Speliotis Anal. Chem. Acta 622 111(2008)
5. "Lithographically-fabricated disposable bismuth-film electrodes for the trace determination of Pb(II) and Cd(II) by anodic stripping voltammetry" Ch.Kokkinos, A.Economou, I.Raptis, C.E.Efstathiou Electroch. Acta. 53 5294(2008)
6. "Surface modification of polymeric thin films at SiO2 interfaces with vacuum ultraviolet light" E.Sarantopoulou, J.Kova_, Z.Kollia, I.Raptis, S.Kobe, A.C.Cefalas Surf. Interface Anal. 40 400(2008)
7. "Surface nano/micro functionalization of PMMA thin films by 157 nm irradiation for sensing applications" E.Sarantopoulou, Z.Kollia, A.C.Cefalas, K.Manoli, M.Sanopoulou, D.Goustouridis, S.Chatzandroulis, I.Raptis Appl. Surf. Sci. 254 1710(2008)
8. Design and fabrication of a Si micromechanical capacitive array for DNA sensing", V.Tsouti, S.Chatzandroulis, D.Goustouridis, P.Normand, D.Tsoukalas, Microelectronic Engineering, 85 (5-6), pp. 1359-1361 (2008)

9. "Direct laser printing of biotin microarrays on low temperature oxide on Si substrates", C.Boutopoulos, P.Andreakou, D.Kafetzopoulos, S. Chatzandroulis, I.Zergioti, Physica Status Solidi (a), vol. 205, no. 11, pp. 2505 - 2508, (2008)
10. "Liquid phase direct laser printing of polymers for chemical sensing applications", C.Boutopoulos, V.Tsouti, D. Goustouridis, S.Chatzandroulis and I.Zergioti, Appl. Phys. Lett. 93, 191109 ,2008.
11. "Detection of the Biotin-Streptavidin interaction by exploiting surface stress changes on ultrathin Si membranes", V.Tsouti, C.Boutopoulos, P.Andreakou, M.Ioannou, I.Zergioti, D.Goustouridis, D.Kafetzopoulos, D.Tsoukalas, P.Normand, S.Chatzandroulis, Microelectron. Eng., In Press, Available online 7 December 2008

Publications in International Conference Proceedings

1. "Detection of CO and NO Using Low Power Metal Oxide Sensors", R. Triantafyllopoulou, and C. Tsamis, Phys. Stat. Sol. (c) 5, No. 12, 3647-3650 (2008) / DOI 10.1002
2. F.V. Farmakis, K. Alexandrou, C. Tsamis, Th. Speliotis, I. Fasaki, M. Kompitsas, S. Kennou, S. Ladas and P. Jedrasik, "Gas sensing properties of ZnO filed-effect transistor enhanced by Au nanoparticles", EUROSENSORS XXII Proceedings, p. 1011-1013 (2008)
3. "Lithographically-Fabricated Bismuth-Film electrodes as disposable Mercury-Free voltammetric sensors for trace analysis of Pb(II)" Ch.Kokkinos, A.Economou, I.Raptis, Th.Speliotis Sensing in Electroanalysis, Uni. Pardubice (Czech Republic) 3 91(2008)
4. "Interdigital chemicapacitive sensors based on polymer/BaTiO3 composites" K.Manoli, P.Oikonomou, D.Goustouridis, E.Karonis, I.Raptis, M.Sanopoulou EuroSensors 2008 (Dresden, Germany, 09/2008)
5. "Evaluation of a chemocapacitive sensor array for the detection of vapor analytes and their mixtures" K.Manoli, E.Karonis, M.Chatzichristidi, D.Goustouridis, S.Chatzandroulis, I.Raptis, M.Sanopoulou IEEE Sensors 2008 (Lecce, Italy, 10/2008)
6. "A Capacitive Biosensor Based On Ultrathin Si Membranes", V.Tsouti, C.Boutopoulos, P.Andreakou, M.Ioannou, I.Zergioti, D.Goustouridis, S.Chatzandroulis, J.Hue, R.Rousier, D.Kafetzopoulos, D.Tsoukalas and P.Normand, The Seventh IEEE Conference On Sensors, IEEE SENSORS, October, 26-29, 2008 Lecce, Italy
7. "Capacitive Strain Sensors Using Polymer Embedded Thin Si Membranes", P.Broutas, D.Goustouridis, S.Chatzandroulis, P. Normand, D. Tsoukalas, EUROSENSORS XXII, Dresden, Germany 7-10 September 2008
8. "A Chemical Sensor Array Based On Si/Polymer Bimorphs", V.Tsouti, S.Chatzandroulis, D.Goustouridis, P.Broutas, P.Normand, C.Boutopoulos, I. Zergioti, D. Tsoukalas, , EUROSENSORS XXII, Dresden, Germany 7-10 September 2008

Conference Presentations

1. "Gas sensing properties of ZnO filed-effect transistor enhanced by Au nanoparticles", F.V. Farmakis, K. Alexandrou, C. Tsamis, Th. Speliotis, I. Fasaki, M. Kompitsas, S. Kennou, S. Ladas and P. Jedrasik, EUROSENSORS XXII, Dresden, Germany, September 7-10 2008 (poster)
2. "Direct laser printing of polymer materials for chemical sensing applications", C. Boutopoulos, V. Tsouti, S. Chatzandroulis, D. Goustouridis, P. Normand, D. Tsoukalas, and I. Zergioti, , poster presentation in the 34th International Conference on Micro and Nano Engineering (MNE08), Athens, Greece, September 15-18, 2008.
3. "Detection of the Biotin-Streptavidin interaction by exploiting surface stress changes on ultrathin Si membranes", V.Tsouti, C.Boutopoulos, P.Andreakou, M.Ioannou, I.Zergioti, D.Goustouridis, D.Kafetzopoulos, D.Tsoukalas, P. Normand, S.Chatzandroulis, poster presentation in the 34th International Conference on Micro and Nano Engineering (MNE08), Athens, Greece, September 15-18, 2008.

4. "Direct laser printing of polymers for chemical sensing applications", C.Boutopoulos, V.Tsouti, S.Chatzandroulis, D.Goustouridis and I. Zergioti, oral talk in the 16th international conference on Advanced Laser Technologies (ALT08), Siofok, Hungary, September 13-18, 2008.
5. "Laser microprinting on chemical and bio sensors", C. Boutopoulos, I. Zergioti, P. Andreakou, V. Tsouti, S. Chatzandroulis D. Goustouridis, D. Kafetzopoulos, oral talk in the 9th Symposium on Laser Precision Microfabrication (LPM 2008), Quebec, Canada, June 16 - 20, 2008.
6. "Laser induced forward transfer on capacitive sensors", I. Zergioti, C. Boutopoulos, P. Andreakou, D. Tsoukalas, D. Goustouridis, V. Tsouti, S. Chatzandroulis, D. Kafetzopoulos, oral talk in the symposium B, EMRS 2008 Spring Meeting, Strasbourg, France, May 26 - May 30, 2008.
7. "A Biosensor Based on Surface Stress Changes of Ultrathin Silicon Membranes", V. Tsouti, C. Boutopoulos, P. Andreakou, M. Ioannou, I. Zergioti, D. Goustouridis, S. Chatzandroulis, D. Kafetzopoulos, D. Tsoukalas, P. Normand, XXIV Panhellenic Conference on Solid State Physics and Materials Science Heraklion, Crete, September 21-24, 2008

Ms Thesis

C.Boutopoulos, "Laser induced deposition of biomaterials with application to biosensors" (Εναπόθεση Βιοϋλικών με LASER με Εφαρμογές σε Βιοαισθητήρες), NTUA/SEMFE

Conference Organization

MRS-Spring Meeting 2008, Symposium PP: The Business of Nanotechnology, March 24 - 28, San Francisco (USA),

Organizers: L. Merhari (Ceramec), A. Gandhi (Applied Materials), S. Giordani (TTP Lab), L. Tsakalakos (General Electric), C. Tsamis (IMEL/NCSR "Demokritos")

ENERGY HARVESTING MATERIALS AND DEVICES

Project Leader: C. Tsamis
Post-doctoral scientists: E. Makarona
PhD candidates: G. Niarchos
MSc Students: A. Darsinou, V. Smyrnis
Graduate Students: F. Katsikeris
External Collaborators: T. Speliotis (IMS/NCSR "D"), D. Niarchos (IMS/NCSR "D")

Objectives:

- Design and optimization of Energy Scavengers for autonomous Microsystems
- Novel materials for high efficiency energy conversion (mechanical, thermal, etc)
- Development of single and dual-transduction mechanical harvesters for improved power characteristics
- Device fabrication and characterization

Funding:

- MEMSE (National Project, accepted for funding)

RESEARCH ACTIVITIES AND MAIN RESULTS WITHIN 2008

Energy Scavenging from the environment has been actively explored using several methods such as solar power, electromagnetic fields, thermal gradients, fluid flow, energy produced by the human body, and the action of gravitational fields. Most of all, mechanical vibration is a potential power source which is easily accessible through Microelectromechanical Systems (MEMS) technology for conversion to electrical energy. The reported examples use a mass-spring system which resonates when the frame of the device is vibrated. The motion of the mass relative to the frame is damped by one of several energy conversion mechanisms, namely electromagnetic force, electrostatic force, or piezoelectric force.

From these scavenger types, the ones based on electromagnetic and piezoelectric principle appear to be the most promising ones and has been the main target of our activities. Furthermore our research effort focuses on an innovative concept and design approach, targeting to a novel energy scavenger, capable of harvesting mechanical vibration energy with the aid of two transduction mechanisms.

A. ZnO nanorod growth for efficient energy conversion

G. Niarchos, E. Makarona, C. Tsamis, T. Speliotis*

*Inst. of Material Science, NCSR "Demokritos"

ZnO, a II-VI wide direct band-gap semiconductor, has attracted a lot of attention over the last years for optoelectronic applications due to its unique combination of properties, such as its large exciton binding energy at room temperature (60meV) and high optical gain (300cm-1). However, another exciting application has recently emerged based on the piezoelectric and semiconducting properties of ZnO. It has been demonstrated that ZnO nanostructures can serve as a key component for the development of mechanical energy nanogenerators, due to their ability to convent efficiently mechanical energy into electricity in forms of nanorods or nanobelts.

During this year, our research effort focused on the growth of ZnO nanorods on patterned substrates using a low temperature, silicon-compatible, solution-based approach. The method consists of a hydrothermal growth step atop a various seeding layers (Gold or ZnO) prepared by room-temperature radio frequency magnetron sputtering on Si wafers as well as on silicon surface. A mixture of aqueous solutions of zinc nitrate and hexamine in a water bath at 90oC constitutes the hydrothermal part of the method. The morphology and structural properties of the ZnO seeding layer and nanowires are studied using Scanning Electron Microscopy (SEM) and X-ray diffraction (XRD). Various parameters are studied in order to understand and to control the growth of ZnO nanorods such as: (a) the Ar pressure during the sputtering of the seeding layer, (b) the post-growth thermal treatment of the seeding layer, (c) the time duration of the hydrothermal part of the growth. Depending on the nature the seeding layer and the growth condition various nanorod configurations have been developed (Figure 1, 2).

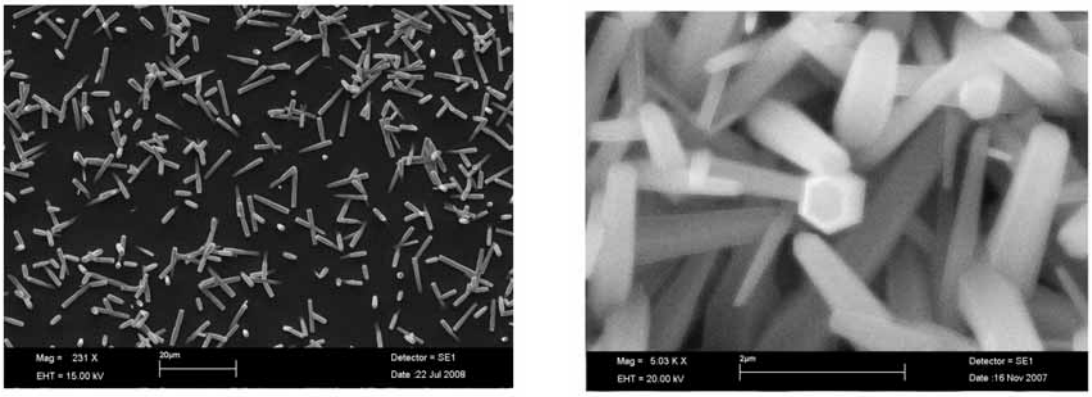


Fig. 1: SEM images of ZnO nanorods grown by the hydrothermal technique on patterned silicon substrates.

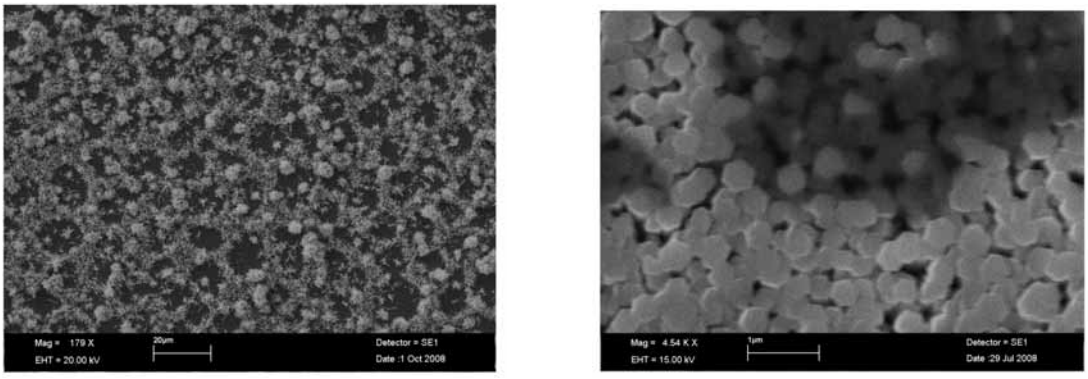


Fig. 2: SEM images of ZnO nanorods grown by the hydrothermal technique on (a) Gold and (b) ZnO substrates. In the case of ZnO substrate highly dense arrays of vertical nanorods has been achieved.

For more information please contact Dr C. Tsamis (e-mail: ctsamis@imel.demokritos.gr) or Dr. E. Makarona (e-mail: elmak@imel.demokritos.gr)

B. Integration of SmCo thin films onto Si-based microstructures for electromagnetic energy harvesters

V. Smyrnis, A. Darsinou, E. Makarona, C.Tsamis, T. Speliotis*, D. Niarchos*

*Inst. of Material Science, NCSR "Demokritos"

This past year, our research effort concentrated on the first -but essential- step towards the realization of electromagnetic energy harvesters, namely the detailed study of the magnetic material- which acts as its functional core-, and its compatibility with conventional semiconductor processing techniques. SmCo was the material of choice for the fabrication of vibrating micromagnets in form of thin films deposited onto suspended silicon microcantilevers. SmCo was deemed a suitable candidate for the fabrication of micromagnets due to its unique combination of attractive properties: high Curie temperature, relatively high spontaneous magnetization at room temperature, large coercive field (Hc), and most importantly its strong magnetocrystalline

anisotropy, which can be modified through the deposition conditions, the subsequent thermal treatment and the material opted as adhesive and capping layers.

The magnetic and mechanical properties of the films and the suspended micromagnets, were scrutinized under a variety of growth and post-growth thermal treatment conditions, while FEM (Finite Element Method) analysis of the experimental results was performed to determine the "effective" stresses that can develop in such structures (Figure 3, 4). This way, a methodology and a process window is determined according to which SmCo hard magnetic thin films can be integrated onto microstructures with controllable magnetic and mechanical properties suitable for electromagnetic energy harvesters

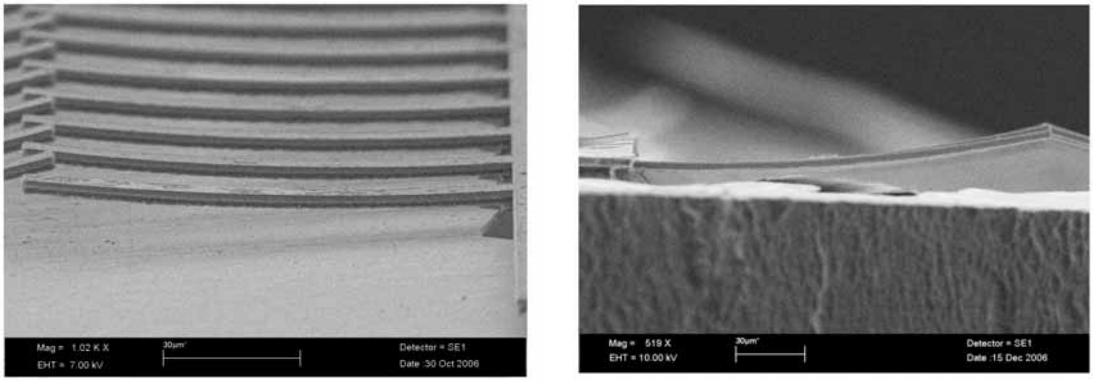


Fig. 3: Influence of thermal treatment on Silicon Cantilevers coated with the multilayer magnetic film of Cr(100nm)/ SmCo (500nm)/ Cr (100nm) after annealing at 600oC for (a) 1min and (b) 5 min. Mechanical stresses are induced in the films resulting in cantilever deflection.

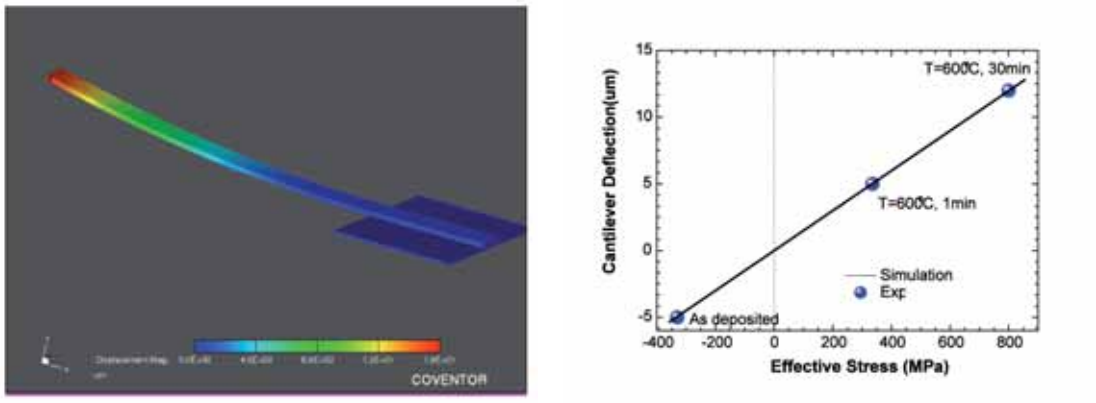


Fig. 4: (a) Representative FEM simulation of the structure using Coventroware, where the estimated deflection and stresses are shown (b) From comparison between experimental data and simulation results the intrinsic stresses that are induced in SmCO films can be estimated as a function of the thermal treatment.

For more information please contact Dr C. Tsamis (e-mail: ctsamis@imel.demokritos.gr) or Dr. E. Makarona (e-mail: elmak@imel.demokritos.gr)

PROJECT OUTPUT in 2008

Publications in International Conference Proceedings

1. "ZnO nanorod growth based on a low-temperature silicon-compatible combinatorial method", E. Makarona, Th. Speliotis, G. Niarchos, D. Niarchos, and C. Tsamis, Phys. Stat. Sol. (c) 5, No. 12, 3809-3812 (2008) / DOI 10.1002.
2. "Effect of deposition pressure and post deposition annealing on SmCo thin film properties", Th. Speliotis, E. Makarona, F. Chouliaras, C. A. Charitidis, C. Tsamis, and D. Niarchos, , Phys. Stat. Sol. (c), 1-4 (2008) / DOI 10.1002
3. "Characterization and Modeling of SmCo micro-magnets for energy harvesting applications", E. Makarona, V. Smyrnis, T. Speliotis, D. Niarchos and C. Tsamis, Proceeding of EUROSENSORS XXII, p. 400-403 (2008)

Conference Presentations

1. "Characterization and Modeling of SmCo micro-magnets for energy harvesting applications", E. Makarona, V. Smyrnis, T. Speliotis, D. Niarchos and C. Tsamis, EUROSENSORS XXII, Dresden, Germany, September 7-10, 2008 (Poster)

Master Thesis

1. "Implementation of magnetic films on micro-cantilevers for energy harvesting applications", A. Darsinou, Informatics Dept., Univ. of Athens (2/2008)
2. "Growth and characterization of nanostructured piezoelectric materials for energy scavenging", G. Niarchos, Informatics Dept., Univ. of Athens (9/2008)
3. "Growth and optimization of Magnetic films for energy harvesting", V. Smyrnis, Informatics Dept., Univ. of Athens (10/2008)

BIO-MICROSYSTEMS

Project leader: K. Misiakos

Key Researchers: A. Tserepi, I. Raptis, E. Gogolides, P. Argitis, H. Contopanagos

Research Associate: D. Goustouridis

Post-doctoral scientists: K. Kotsovos, E. Makarona

PhD students: M. Kitsara

Research Engineer: Athanasios Botsialas

External Collaborators: S.E. Kakabakos (IRRP/NCSRD), P.Petrou (IRRP/NCSRD)

Graduate Students: Alex Salapatas, Ioannis Arxontas

Objectives:

- Development of bioanalytical lab-on-a-chip devices based on monolithic optoelectronic transducers (bioactivated optocouplers).
- Development of monolithically integrated interferometric biochips for label-free biosensing
- Development of white light interferometric setup for label free monitoring of biomolecular reactions.
- Develop highly sensitive and/or label free assays suitable for point of care applications
- Develop microfluidc channels integrated on transducer silicon chips
- Use soft lithography, Deep Plasma Etching, and plasma assisted bonding to fabricate PDMS, PMMA (and other organic polymer) based microfluidic devices
- Fabricate capillary electrophoresis, and chromatography devices
- Develop open microfluidics using electrowetting actuation
- Develop novel plasma based micro array technologies

Funding

- EU, IST, STREP, “NEMOSLAB”, NanoEngineered Monolithic Optoelectronic transducers for highly Sensitive and LAbel-free Biosensing (coordinated by K. Misiakos start 1-1-2006, end 30-6-2009)
- EU, FP7-ICT, STREP, “PYTHIA”, Monolithically integrated interferometric biochips for label-free early detection of human diseases (coordinated by I. Raptis start 01-05-2008, duration 36months)

EXAMPLES OF RESEARCH RESULTS IN 2008

A. Bioanalytical lab-on-a-chip based on monolithic Silicon optocouplers

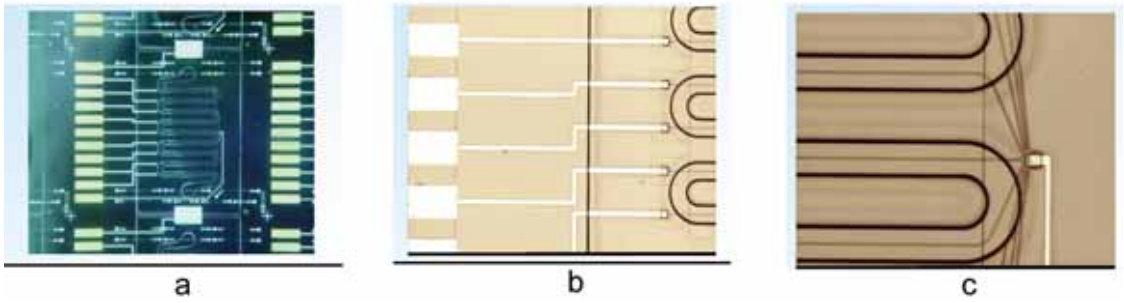


Fig. 1: Photograph of a completed optocoupler chip showing gold pad contacts, Al interconnects, especially the detector long interconnect to the opposite side (single sided geometry) (b). Also shown are SU-8 open microchannels, the LEDs **(b)** and the single detector where all waveguides converge **(c)**

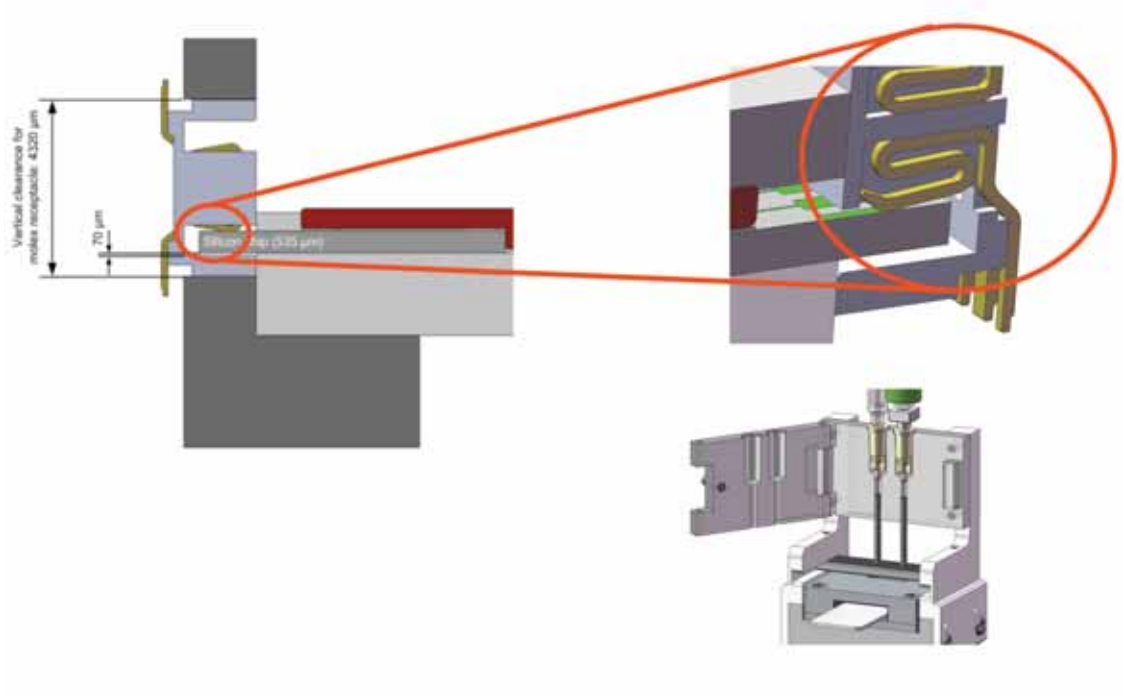


Fig. 2: Packaging and testing of the optocoupler chips. The chips is packaged in a cartidge **(left)** and insertred in a socket where a board-to-board connector is making contact with the pads. The sample and reagents for the bioassay are introduced via syringes coming from above **(lower right)**.

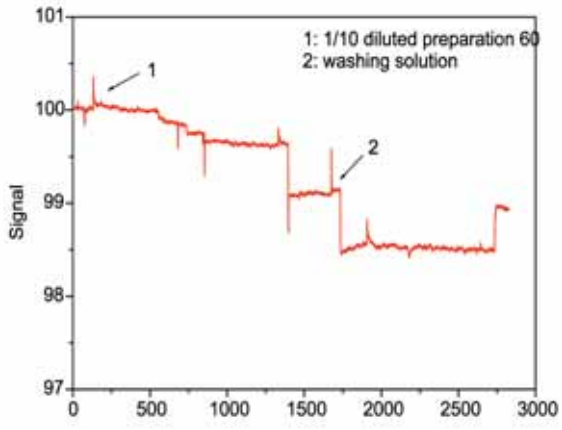


Fig. 3: Real-time response from a 2 micron wide and 150 nm thin silicon nitride waveguide coated with streptavidin during flow of vesicles at a 1/10 dilution in 80 mM NaCl, 10 mM phosphate buffer, pH 7.4. The flow rate was 100 μl/min. The vesicles had a diameter of 100 nm, had biotin molecules on their outer surface and were containing a fluor with absorption at 650 nm. Individual binding and de-binding events are evident.

B: Monolithically integrated interferometric biochips for label-free biosensing

The progress of integrated optical structures, such as waveguides and gratings, has allowed the implementation of various evanescent wave sensors which found strong application in real-time monitoring of biomolecular interactions offering high sensitivity, and fast response time. Among the evanescent field sensors, the Mach-Zehnder Interferometric (MZI) biosensor is one of the most promising devices due to its high sensitivity and accuracy. However, MZI device presents certain drawbacks when monochromatic light is used: *Optical coupling, Ambiguity, and Signal fading*.

We are suggesting a novel approach, **Broad-Band Mach-Zehnder Interferometry (BB-MZI)** (fig. 1), as an alternative operation principle for optical biochemical sensors that can form the basis of versatile and **ultra-sensitive label-free, multi-analyte detection schemes**. The characteristics of the suggested method were compared with the ones from the conventional Single-Wavelength MZI (SW-MZI) structure.

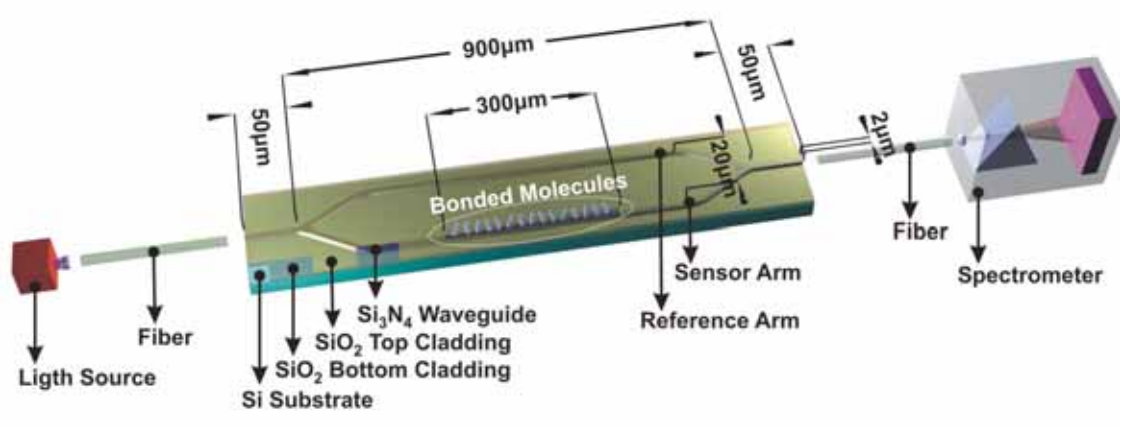


Fig. 1: Broad-Band Mach-Zehnder Interferometry Approach

To evaluate the BB-MZI performance, 2D and 3D optical simulation with BeamProp software was carried out by considering aqueous glucose solutions (model system) in the sensing area and protein adlayers (biosensing) as well. The simulation considerations were: 1mm overall BB-MZI length, incoherent light as input, human γ-immunoglobulin, IgG, on the sensing arm. In fig. 2 the simulation results for the biosensing case are illustrated for the 450-750nm spectrum. The ultra-thin protein adlayer can be detected by the proposed BB-MZI, either by recording the spectrum changes (if a spectrometer is employed) or by the changes of the integrated intensity (if a photodetector is opted as the recording medium).

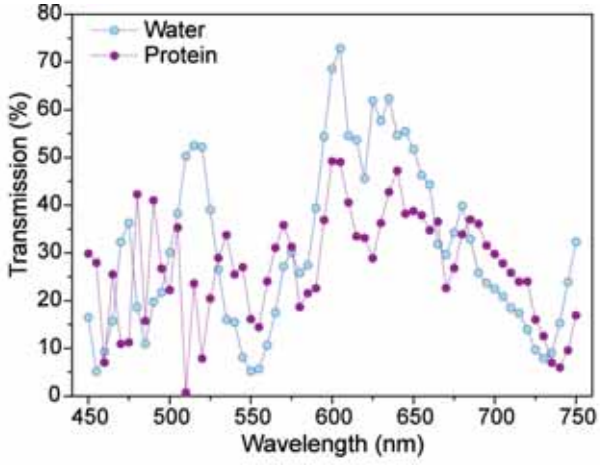


Fig. 2: Transmission Spectra of the 1mm long BB-MZI for pure water and 3nm thick protein adlayer (n=1.38) bound on the sensing arm

To evaluate the BB-MZI approach, 1mm long structures were designed by using the simulation results and fabricated (fig. 3). The bottom (3μm thick) and top cladding (2μm) layers are from SiO2 and the core from Si3N4. The fabrication of MZI structures was carried out with 2.0μm conventional silicon processing technologies. In fig. 4 the optical efficiency of the fabricated BB-MZI structures for various geometries is illustrated along with results from simulation. A very good agreement is shown between the simulation and experimental results. Furthermore, a very good repeatability is monitored between the structures fabricated in different Si dies.

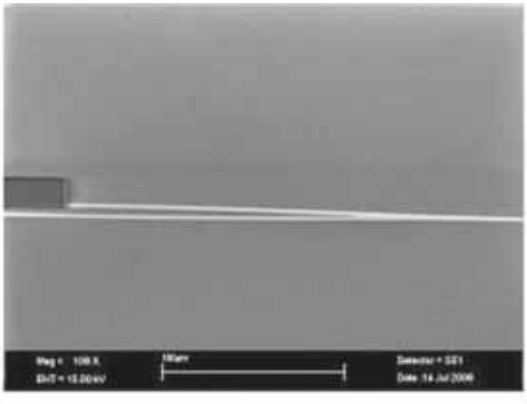


Fig. 3: top-down SEM image of the sensing arm are of the BB-MZI test structures

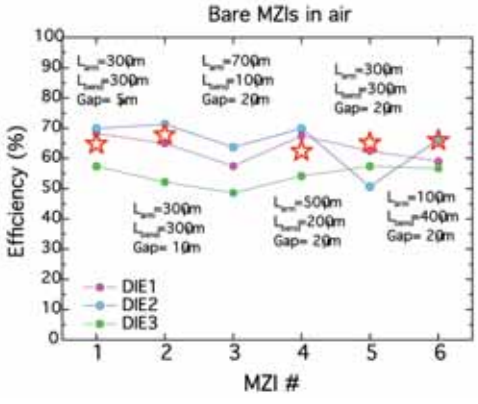


Fig. 4: BB-MZI output efficiency for various geometries

C. Microfluidics and Microarrays

Objectives:

- For microfluidics we use Deep Plasma Etching, and plasma assisted bonding to fabricate PDMS, PMMA, PEEK and Si microfluidic devices, such as chromatography columns. We also demonstrate a novel plasma-based protein patterning process for micro array fabrication.
- We nano-texture polymers in plasmas, and find that protein adsorption is greatly enhanced on such smart surfaces.

1. Fabrication of microfluidic devices on plastic substrates and Silicon using deep plasma etching

1.1 Plasma etching of PMMA, PEEK, PDMS, and Silicon microfluidics

(K. Tsougeni, K. Kontakis, N. Vourdas, M. Vlachopoulou, G. Boulousis, A. Tserepi, E. Gogolides)

We demonstrate a new mass production amenable technology for fabrication and surface modification of plastic disposable microfluidic devices, namely direct lithography on the plastic substrate followed by deep polymer etching. We applied plasma processing to fabricate polymeric microfluidics in Poly(methyl methacrylate) (PMMA) and Poly(ether ether ketone) (PEEK), PDMS, and Silicon. Deep anisotropic O_2 or SF6 or SF6/ C4F8 plasma etching was utilized to etch (pattern) the polymeric substrate after lithography. Etch rates were optimized to minimize the process time and surface roughness was controllably adjusted from very rough (high aspect ratio nanocolumns) to smooth channels, by choosing appropriate plasma conditions. *We demonstrated control on the topography of the etched surfaces, depending on the etching conditions; either smooth surfaces or very rough columnar-like surfaces were obtained*. After engraving the PMMA, PEEK and Si microfluidic a bonding step was done to seal the channels and provide their fourth wall. Fig. 1a demonstrates a PEEK plate, after the plasma treatment and after sealing with a pressure adhesive. Demonstration of a mixer was also done on PMMA (Fig. 1b). For PDMS oxygen plasma bonding was done.

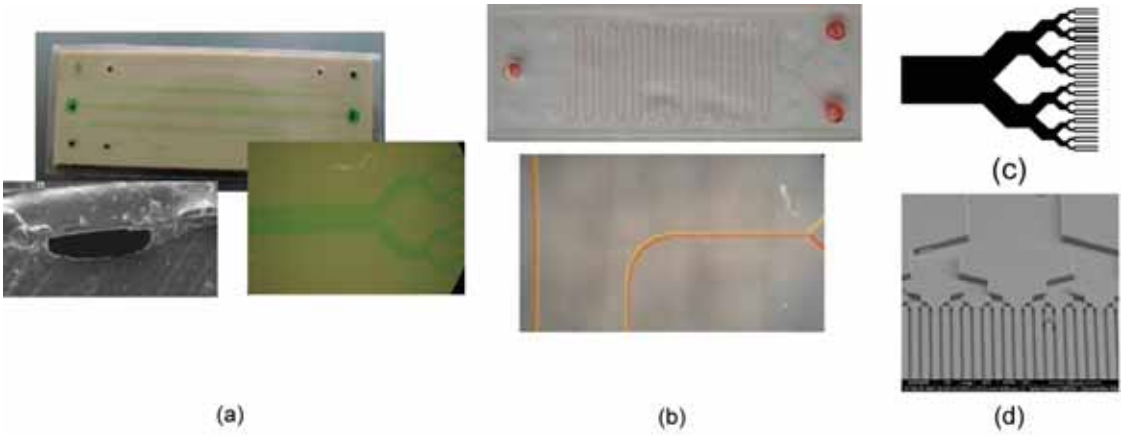


Fig. 1: (a) The microfluidic channel of PEEK and details in SEM of the cross section after the sealing. **(b)** Mixing of two liquids in PMMA plasma etched microfluidic mixer. **(c)**, **(d)** Photos of the mask layout of parallel channels in Silicon microfluidic devices.

2. Protein microarrays on plasma-treated substrates and protein adsorption on plasma nanotextured polymers

2.1 Method for fabrication of protein microarrays through plasma treatment of patterned substrates

(P. Bayiati, A. Malainou, A. Tserepi, P. S. Petrou, S. E. Kakabakos)

Protein patterning through plasma selective FC deposition on patterned SiO_2/Si and glass substrates is pursued. The capability to immobilize two different proteins on such substrates was demonstrated (Fig. 2(a)), while the stability of protein binding on C_4F_8 plasma treated surfaces was also investigated and was found comparable to commercial PS microtitration plates. Therefore, with the proposed method, high density and high quality (signal to noise 25:1, Fig. 2(b)) protein microarrays can be fabricated exhibiting very good intra-spot homogeneity and inter-spot repeatability.

Fig. 2: (a) Fluorescence image of fluorocarbon modified Si substrate bearing SiO_2 spots after immobilization of two different proteins, gamma globulin IgG (green spot) and b-BSA (red spot), **(b)** fluorescence image of a modified glass substrate patterned with AZ photoresist, demonstrating selective (10:1) protein adsorption on 100 μm glass spots after treatment in O_2 plasmas

2.1 Plasma nanotexturing of PMMA and PDMS for increased protein adsorption

(K. Tsougeni, M. Vlachopoulou, P. S. Petrou, S. E. Kakabakos, E. Gogolides)

We demonstrated fabrication of random columnar/filamented-like, low and high-aspect ratio micro or nano-structures based on O2 plasma-induced roughening (nanotexturing) of poly(methyl methacrylate) (PMMA), or SF6 roughening of PDMS. The effect of topography and protein adsorption capacity was investigated. Conditions (plasma treatment, ageing) are sought for maximum and uniform protein adsorption on nanotextured PMMA surfaces. Specifically, adsorption of biotinylated-BSA was found to increase with plasma duration. A 2x-4x times increase in protein adsorption (depending on the protein concentration) was observed following 5-60 min plasma treatment compared to untreated surfaces. Highly homogeneous bright protein microspots on such optimized plasma-nanostructured surfaces are also shown.

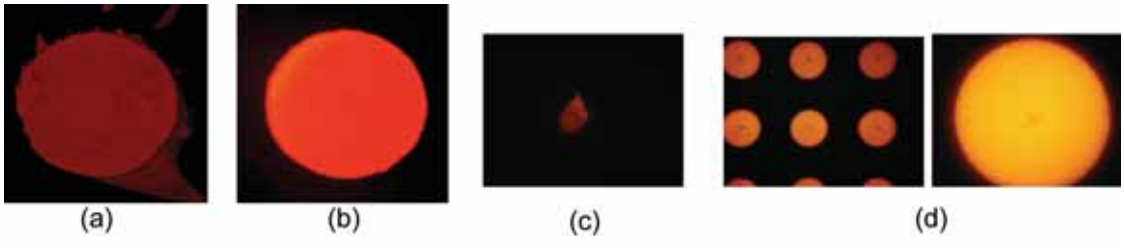


Fig. 3: Fluorescence images of b-BSA spots on a **(a)** flat untreated, **(b)** 5-min 20-min O_2 plasma-treated PMMA surface. Spotting of b-BSA on fresh SF6 treated surfaces with a nanoplotter. Fluorescence images of spots of 200 μg/ml b-BSA **(c)** on an untreated PDMS surface, **(d)** on a 6 min SF_6 treated PDMS surface.

More details of the above can be found in Project I.2 Lithography and Plasma Processes for Electronics, Microfluidics, and Surface Nano-Engineering.

PROJECT OUTPUT in 2008

Publications in International Journals

1. "Monolithic silicon optocoupler engineering based on tapered waveguides" K. Misiakos, E. Makarona, M. Kitsara, I. Raptis, Microelectronic Engineering, 85, 1074-1076, (2008)

Conference Papers

1. "Integrated biochemical broad-band Mach-Zehnder sensors", M.Kitsara, I.Raptis, K.Misiakos, E.Makarona EuroSensors 2008 conference, Dresden, Germany, 09/2008
2. "Broad-band Mach-Zehnder Interferometry as a detection principle for label-free biochemical sensing", M.Kitsara, I.Raptis, K.Misiakos, E.Makarona, IEEE Sensors 2008, Lecce, Italy, 10/2008)

For publications concerning Microfluidics and Microarrays:
see relevant publications of Project I.2 Lithography and Plasma Processes for Electronics, Microfluidics, and Surface Nano-Engineering.

Patent Applications

1. "Monolithically integrated physical chemical and biological sensor arrays based on broad-band Mach-Zehnder Interferometry" (inventors, I. Raptis, E. Makarona, M. Kitsara, K. Misiakos, S. Kakabakos, P. Petrou, OBI Application 20080100174)
2. "Integrated optoelectronic silicon biosensor for the detection of biomolecules labeled with chromophore groups or nanoparticles" (inventors K. Misiakos, S. kakabakos, I. Raptis, E. Makarona, P. Petrou, OBI application 20080100390)

Organization of Workshops

The 3rd International Workshop on Multianalyte Biosensing Devices, was organized in Athens, September 18-19, 2008. The workshop was attended by 30 participants. Detailed information about the scope and the program of the workshop can be found at http://www.imel.demokritos.gr/projects/nemoslab/workshop/workshop.htm

THIN FILM DEVICES for LARGE AREA ELECTRONICS

Project leader: Dr. D.N. Kouvatsos

Collaborating researchers from other projects: Dr. F.V. Farmakis, Dr. D. Davazoglou

Ph.D. candidates: D.C. Moschou, G.P. Kontogiannopoulos, L. Michalas.

External collaborators: Dr. G.J. Papaioannou (University of Athens), Dr. M. Exarchos (Royal Holloway University of London), Dr. N. Stojadinovic (University of Nis), Dr. A.T. Voutsas (Sharp Laboratories of America).

Funding

• PENED contract, project code 03ED550, 19/12/2005 - 30/6/2009.

Objectives:

This research aims at the optimization of the active layer of polysilicon films obtained using advanced excimer laser crystallization methods and of the resulting performance parameters of thin film transistors (TFTs) fabricated in such films. Such advanced TFTs are necessary for next generation large area electronics systems, which are now in the research and development phase. Specifically, the targets of the project are:

- Evaluation of device parameter hot carrier and irradiation stress-induced degradation and identification of ageing mechanisms in TFTs fabricated in advanced excimer laser annealed (ELA) polysilicon films with sequential lateral solidification (SLS).
- • Investigation of the influence of the crystallization technique and the film thickness on TFT performance, defect densities and degradation for technology optimization.
- Investigation of effects of variations in TFT device structure and in the fabrication process on device performance and reliability.
- Investigation of polysilicon active layer defects using transient drain current analysis in ELA TFTs.
- Assessment of material properties of ELA poly-Si TFTs using optical measurements.

MAIN RESULTS IN 2008

Task 1: Characterization of SLS ELA TFTs

An easy way to estimate the polysilicon film quality prior to TFT fabrication would be of great importance to the industry. We determined that the difference $V_{g,max}$ - V_{th} (Fig. 1) is a parameter related differently to the poly-Si quality than field-effect mobility μ and threshold voltage V_{th}. It can be used as a new, experimentally obtained, important device parameter characterizing the polysilicon film quality. In Table I the proposed figure of merit $V_{g,max}$ - V_{th} and more typical parameters are shown. We observed much lower μ for TFTs with channels vertical to the boundaries (B vs A and D vs E), as expected, since the grain boundaries reduce μ. However, Vth does not seem to be as affected just by the channel orientation (B vs A and D vs E). Other parameters, such as oxide trapped charges and interface charges affect Vth. Observing Vg,max - Vth, we see that its value is also not as strongly dependent on channel orientation as μ (A vs B). Nevertheless, this parameter does not seem to follow exactly the same behavior as V_{th} (C vs D and D vs E). The previous observations imply that the difference $V_{g,max}$ - V_{th} reflects technological parameters different, or through different relationships, than μ and Vth. We probed the physical meaning of $V_{g,max}$ - V_{th} using two approaches, both relating it proportionally to electrically active traps in TFTs. Vg,max - Vth was then plotted for a double gate TFT (Fig. 2), allowing us to see how it varies with the bottom gate bias V_{gb} and, therefore, what is the effect of V_{gb} on the electrically effective film defects.

TABLE I: DEVICE PARAMETERS

TFT name	Grains vs channel	Field effect mobility μ_{fe} ($cm^2/V \cdot sec$)	V_{th} (V)	$V_{g,max}$-V_{th} (V)
A		38	0.22	0.48
B	//	145	0.24	0.46
C	//	137	0.53	0.57
D	//	101	0.93	0.57
E		31	0.94	1.26

To probe the effects of channel doping, both n- and p-channel TFTs fabricated with a novel technique were investigated, oriented along the preferential (X) or the non-preferential (Y) direction. Their degradation mechanisms proved very different, while the channel orientation had a larger effect on n-channel devices than on p- ones (Fig. 3, Fig. 4). To investigate whether the mechanisms are similar for more intense stress, we applied larger stress biases to p-channel devices only. Observing the V_{th} degradation of both X and Y oriented p-channel devices (Fig. 5), we see again very similar behavior for both cases. The stress gate bias being larger, V_{th} degradation is also more intense. The initial electron trapping, implied by the V_{th} increase, has been simulated by others and attributed to a high vertical electric field under the gate, near the drain junction, attracting hot electrons. For large stress times, the trapped negative charges increase the potential barrier. Thus, electron injection tends to saturation, allowing hot hole injection along the whole channel to dominate, causing the subsequent logarithmic V_{th} decrease.

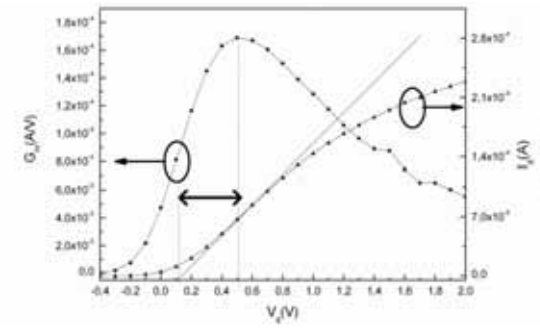


Fig. 1: Graphic representation of the difference of the extrapolated threshold voltage V_{th} and the bias for maximum transconductance $V_{g,max}$.

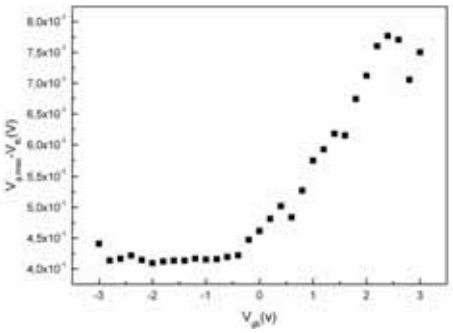


Fig. 2: $V_{g,max}$ - V_{th} variation with bottom gate bias Vgb for double gate devices.

The stress intensity, however, seems to affect significantly the μ degradation, since we see a much larger increase for stressing times (Fig. 6). Despite larger degradation, we still do not see any μ decrease. This μ increase has been attributed to a channel shortening effect, due to hot electron injection near the drain. This effect is observed at much larger times, compared to n-channel TFTs, since in these TFTs the spreading of the degraded region along the channel takes longer, due to a lower lateral electric field.

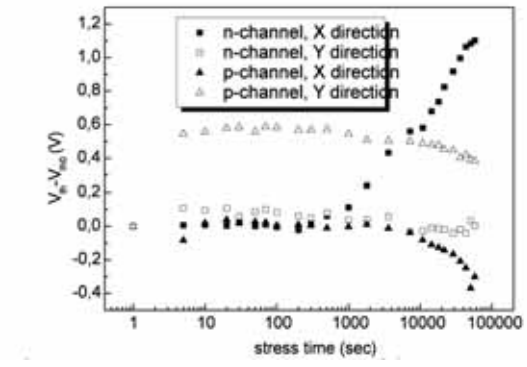


Fig. 3: Evolution of V_{th}-V_{th0} with stress time for both n- and p-channel devices under analogous stress conditions.

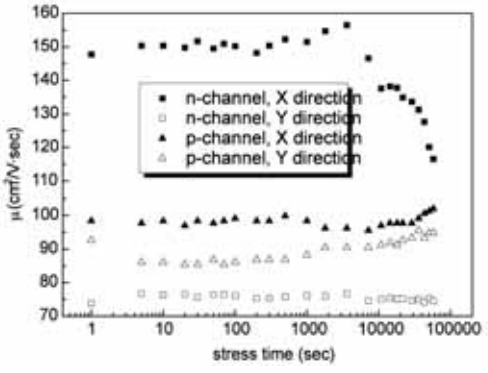


Fig. 4: Evolution of μ with stress time for both n- and p-channel devices under analogous stress conditions.

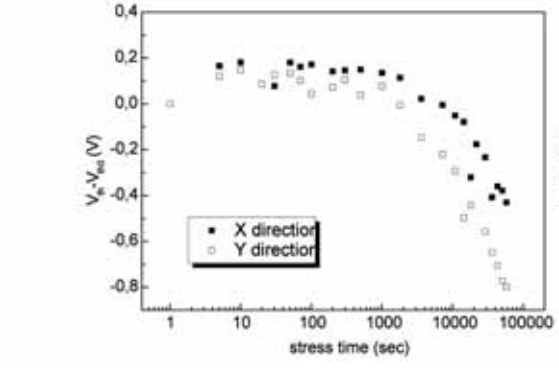


Fig. 5: Evolution of V_{th}-V_{th0} with stress time for p-channel devices under more intense stress.

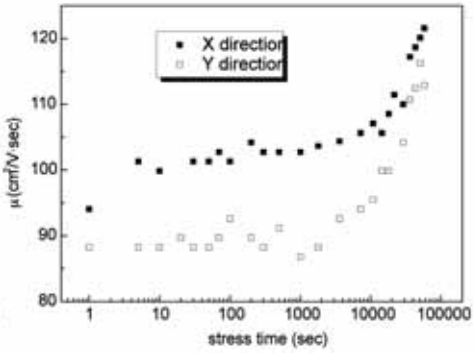


Fig. 4: Evolution of μ with stress time for p-channel devices under more intense stress.

Task 2: Device lifetime investigation under stress

TFTs of different widths W = 2, 8 and 16 μm and of a common length (L = 2 μm) were subjected to different drain biases $V_{DS,stress}$ and gate biases ($V_{GS,stress}$ = around V_{th}, $V_{DS,stress}$ /5, $V_{DS,stress}$ /3 and $V_{DS,stress}$ /2). The on current degradation was examined. The maximum point of degradation of our TFTs was defined to find the magnitude of the degradation as function of $V_{DS,stress}$ and determine their lifetime. Fig. 7 and Fig. 8 show the drain on-current percentage variation for V_{GS} = 5 V and stress time t_{stress} = 660 s.

It was found that the application of a gate bias voltage around the threshold voltage (very low $V_{GS,stress}/V_{DS,stress}$ ratios) becomes the worst hot carrier degradation condition for all the tested devices and for all the applied drain bias voltages $V_{DS,stress}$. Unlike typical bulk MOS transistors, which exhibit their worst degradation behavior when they are submitted to the stress condition $V_{GS,stress} = V_{DS,stress}/2$ (where the substrate current takes its maximum value), the maximum point of on-current degradation in polysilicon TFTs is more frequently observed around the condition $V_{GS,stress} = V_{th}$, especially for high lateral fields. Maximum degradation occurs at $V_{GS,stress} = V_{th}$ because both the electric field near the drain in the channel and the hot electron density are increased. This difference between bulk MOS and poly-Si TFTs mainly derives from the existence of one type of carrier in the channel of poly-Si TFTs, which is intrinsic, whereas both carriers (electron and holes) contribute to bulk MOSFET degradation. However, it was noticed (Fig. 9), for all investigated geometries, that the maximum degradation point progressively shifts towards higher $_{VGS,stress}/V_{DS,stress}$ ratios for lower drain bias voltages.

Fig. 10 shows the variation of on-current measured at V_{GS} = 5 V after each stress cycle for the stress condition yielding the maximum on-current degradation (the worst degradation performance in each case), for the different drain bias voltages that were applied during stress and for the devices with channel width W = 2 μm. It was noticed that $|\Delta I_{on}/I_{on}|$ exhibited a power-time dependent law of the form: $|\Delta I_{on}/I_{on}| = At^n$ with $n \approx 0.30\text{-}0.36$ for all $V_{DS,stress}$ values. This behavior was common for all TFTs with different widths (not shown for W = 8 μm and 16 μm), revealing the same stress degradation mechanism, DAHC (Drain Avalanche Hot Carrier). However, for very intense stress, a saturation law dominated (shown for W = 2 μm and for $V_{DS,stress}$ = 7.5 V and 7.25 V). The pre-power law factor A, that expresses the magnitude of degradation (intensity of hot carrier stress), was found to be also width dependent. So was also the stress parameter b, which is larger for wider devices. Consequently, it was derived that the lifetime to failure for the tested narrower devices in the stress regime $V_{th} \leq V_{GS,stress} \leq V_{DS,stress}$ /2 is shorter and narrower TFTs exhibited worse degradation than wider ones

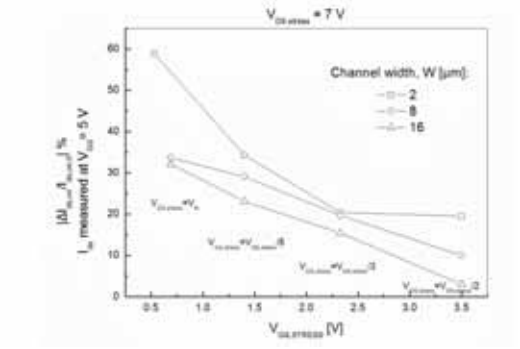


Fig. 7: Relationship between $|\Delta I_{on}/I_{on}|$ % degradation as a function of $V_{GS,stress}$ after 660 s of stress. $V_{DS,stress}$ = 7 V.

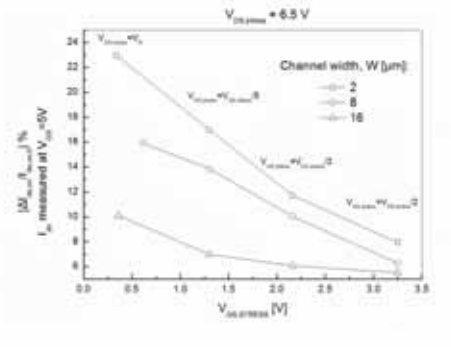


Fig. 8: Relationship between $|\Delta I_{on}/I_{on}|$ % degradation as a function of $V_{GS,stress}$ after 660 s of stress. $V_{DS,stress}$ = 6.5 V.

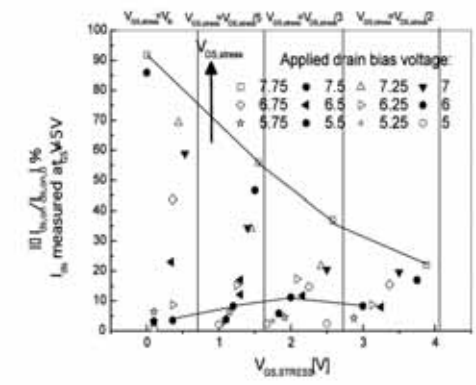


Fig. 9: $|\Delta I_{on}/I_{on}|$ % degradation as a function of $V_{GS,stress}$ and $V_{GS,stress}$ after 660 s of stress. W = 2, L = 2 μm.

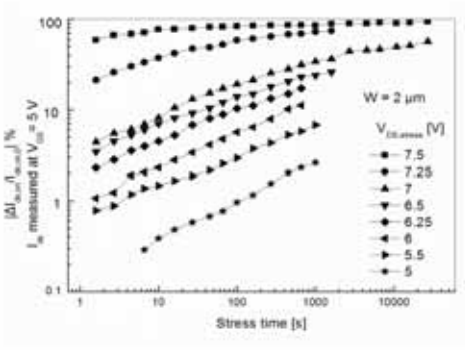


Fig. 10: On drain current % variation measured at V_{GS} = 5 V vs stress duration under various conditions. Parallel shift of the curves is noted. W = 2 μm, L = 2 μm.

Task 3: Investigation of hot carrier stress degradation mechanisms

The relation of the vertical (oxide) field determined by $V_{GS,stress}$ and the lateral field determined by the $V_{DS,stress}$ was investigated to elucidate the degradation mechanisms in the stress regime $V_{th} \leq V_{GS,stress} \leq V_{DS,stress}/2$ and gain insights on improving device hot carrier stress performance. The contribution of the channel width to the degradation was examined for various conditions. To find the origin of the worse degradation performance of narrow width devices the initial normalized stress current was examined; it was noticed that it was more pronounced in narrower devices, i.e. was not proportional to the ratio of their widths, which means that the magnitude of stress is not normalized over width (Fig. 11). An explanation is the different saturation threshold voltages TFTs with different widths have. Specifically, it has been shown that the DIBL parameter was suppressed as the width is scaled down (Fig. 12). Plotting the Vth variation versus the $G_{m,max}$ percentage change (Fig. 13), we noticed that when Vth variation became prominent, the percentage $G_{m,max}$ change was above 15-20%, which implies that: i) the V_{th} variation is apparent and is attributed to the contribution of $G_{m,max}$ to V_{th}, not originating by a significant carrier trapping mechanism, ii) the degraded region in narrow devices is formed faster.

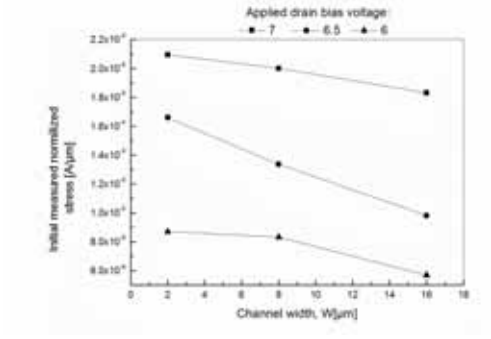


Fig. 11: Normalized (over width) value of initial drain stress current vs. channel width (W = 2, 8 and 16 μm). Conditions: $V_{GS,stress} = V_{th}$, $V_{DS,stress}$ = 6, 6.5, 7 V.

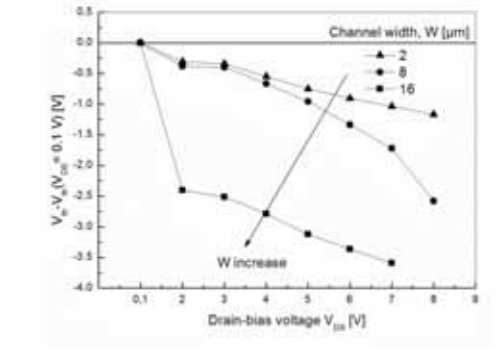


Fig. 12: Difference of V_{th} at saturation as compared to V_{th} in the linear regime for various drain biases for TFTs with different widths (W = 2, 8 and 16 μm).

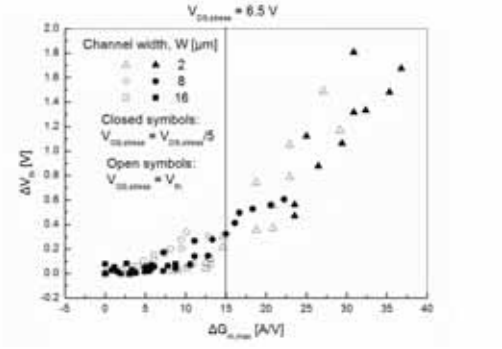


Fig. 13: V_{th} change vs $G_{m,max}$ % variation for 3 widths. $V_{GS,stress} = V_{th}$, $V_{DS,stress}/5$ for $V_{DS,stress}$ = 6.5 V. Points beyond the line are closer to the hottest carrier condition.

Further, the width dependent degradation was examined for $V_{GS,stress} = V_{DS,stress}$. The tested TFTs had various widths (W = 8, 16, 32, 100 μm) and a common length (L = 0.8 μm). For wide channel devices we observed a larger parallel shift of the transfer characteristics during stress, even in the subthreshold region. We also noted that the stressing time at which each TFT exhibited the positive ΔV_{th} onset occurred earlier for wider devices (Fig. 14). Moreover, we observed an initial ΔV_{th} decrease with stress time, and then an increase, a common behavior in all devices. A larger decrease of Vth for TFTs with W = 100 μm was found; TFTs with W = 8 μm did not reach the time point at which ΔVth exhibited the positive onset, for the stress durations used. With further stress, the ΔV_{th} vs. stress duration curve was width independent and all devices exhibited the same behavior of a continuous ΔV_{th} increase with the same slope. This width dependent degradation behavior was also seen in the subthreshold slope.

We proposed a new mechanism to expain the difference in degradation behavior between narrow and wider TFTs. According to it, a width-depended thermal energy source is provided by the self-heating effects (more pronounced for high gate biases, because the current is larger) to the positive mobile ions in the SiO_2 film. Because the heating was higher for wider TFTs (more pronounced self heating effects), the condition of electron injection was satisfied earlier; thus, electron injection changed the direction of V_{th} shift earlier. In addition, the V_{th} negative shift reached a maximum value that depended on temperature, mobile ion density and applied field, approximately the same for all TFTs. Eventually, the typical CHE injection mechanism for $V_{GS,stress} = V_{DS,stress}$ dominated and overwhelmed the initial negative voltage shift.

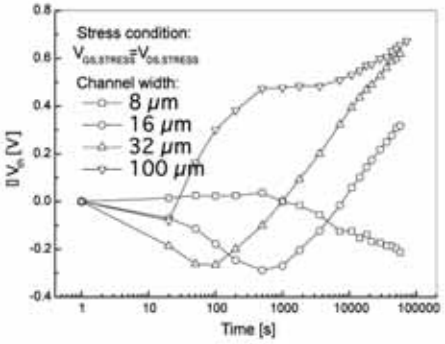


Fig. 14: Vth variation during stress for Y-directed TFTs with various widths. $V_{GS,stress} = V_{DS,stress}$ = 4.8 V.

Task 4: Low temperature and transient current characterization

TFT characterization was performed at 100 K to 450 K for the investigation of thermally activated mechanisms; these measurements and trap state density estimations were carried out at the University of Athens, in a project collaboration. It was found that the activation energies for all parameters become larger as the film thickness is reduced. In thicker films generation takes place mainly through deeper states; in thinner films tail states, introduced by lack of periodicity due to grain boundaries, more frequent in thinner films, are significant. Overshoot and undershoot transient drain currents were investigated and correlated with the thermally generated mechanisms, to extract information on carrier generation and capture processes in SLS ELA polysilicon films.

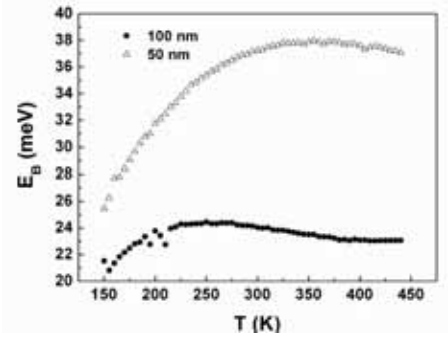


Fig. 15: Temperature dependence of the grain boundary barrier height for TFTs in 50 nm and 100 nm polysilicon films.

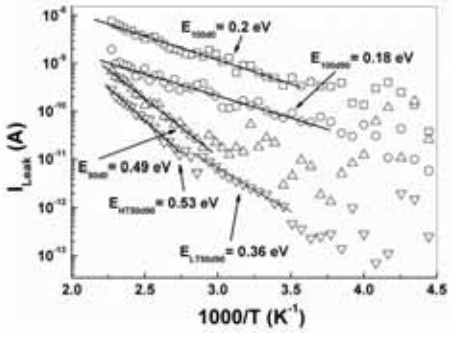


Fig. 16: Leakage current activation energies for X-oriented (0°) and Y-oriented (90°) TFTs in 50 nm and 100 nm polysilicon films.

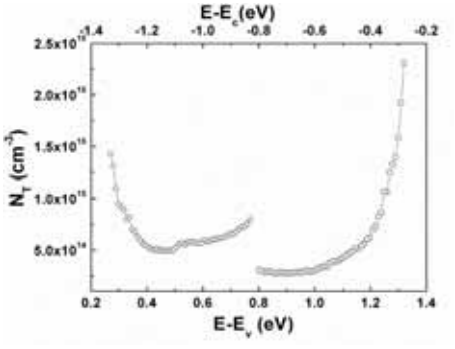


Fig. 17: Estimated trap density (separately calculated in each half of the band gap using DLTS measurements) in the silicon band gap for n-channel TFTs fabricated in 30 nm SLS ELA polysilicon films.

The temperature dependence of the grain boundary barrier height was estimated, comparing measurements for X-oriented vs. Y-oriented TFTs, as shown in Fig. 15. Activation energy E_a values for the leakage current I_{leak} were found to be similar for X-oriented and Y-oriented TFTs, as observed in Fig. 16, indicating that the responsible generation mechanism refers not just to grain boundaries but to intragrain material properties. Moreover, the thermally activated generation mechanisms were related with the gap states; a methodology was developed for the determination of the temperature dependence of the grain boundary potential barriers and of the trap density in the silicon energy gap. The estimated trap density in the silicon band gap is shown in Fig. 17.

Task 5: Material / optical characterization

During 2008, we continued our research on the optical properties of our advanced SLS ELA poly-Si films, a field where little documentation exists, at the moment. Proceeding to the film analysis through spectroscopic ellipsometry measurements, we examined the Ψ parameter in respect to wavelength and attempted fitting of these experimental data using the 4-oscillator Forouhi-Bloomer model to describe the film refractive index. The fitting of the experimental curves with the aforementioned model proved very good. A typical example of the experimental data acquired and the resulting fitting can be seen in Fig. 18. We followed the same fitting procedure for all of the SLS ELA samples, but also for amorphous Si (a:Si) and crystalline Si (c-Si) as references. All SLS-ELA films showed similar behavior with respect to their optical properties, however, that was very different from the cases of a:Si and c-Si.

Having observed this differentiation of SLS ELA optical properties from a:Si and c-Si, we proceeded with XRD measurements of our films, to further probe the nature of the polysilicon we examined. In Fig. 19, we can see the obtained XRD spectra for all three SLS ELA films. As we see, all of the films again show similar behavior, with the prevailing peak angle being at around 21.5°. This angle corresponds to a Si modification named allo-Si, according to literature. The above data indicate that SLS-ELA Si films may possibly have a crystallographic structure similar to that of the so-called allo-Si.

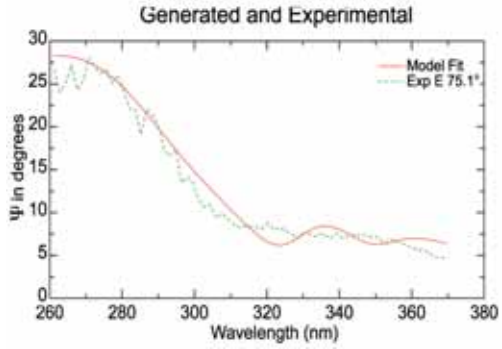


Fig. 18: Fitting of the spectroscopic ellipsometry obtained Ψ parameter, utilizing the Forouhi-Bloomer model, for an advanced SLS ELA thin film.

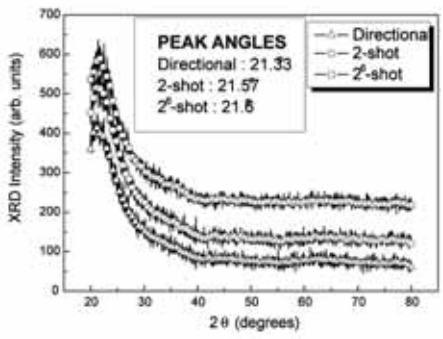


Fig. 19: XRD spectra for the three differently crystallized SLS ELA polysilicon films.

PROJECT OUTPUT in 2008

Publications in International Journals and Reviews

1. Moschou, D.C., M.A. Exarchos, D.N. Kouvatsos, G.J. Papaioannou, A. Arapoyanni and A.T. Voutsas, "Reliability and defectivity comparison of n- and p-channel SLS ELA polysilicon TFTs fabricated with a novel crystallization technique", Microelectronics Reliability 48 (8-9), 1544, August-September 2008.
2. Moschou, D.C., M.A. Exarchos, D.N. Kouvatsos, G.J. Papaioannou and A.T. Voutsas, "A novel SLS ELA crystallization process and its effects on polysilicon film defectivity and TFT performance", Microelectronic Engineering 85 (5-6), 1447, May-June 2008.
3. Michalas, L., G.J. Papaioannou, D.N. Kouvatsos, F.V. Farmakis and A.T. Voutsas, "Characterization of thin film transistors fabricated on different sequential lateral solidified poly-silicon substrates", Microelectronic Engineering 85 (5-6), 976, May-June 2008.

4. Michalas, L., G.J. Papaioannou, D.N. Kouvatsos and A.T. Voutsas, "Investigation of the undershoot effect in polycrystalline silicon thin film transistors", Solid State Electronics 52 (3), 394, March 2008.
5. Kontogiannopoulos, G.P., F.V. Farmakis, D.N. Kouvatsos, G.J. Papaioannou and A.T. Voutsas, "Hot carrier stress induced degradation of SLS ELA polysilicon TFTs - Effects of gate width variation and device orientation", Solid State Electronics 52 (3), 388, March 2008.
6. Michalas, L., G.J. Papaioannou, D.N. Kouvatsos and A.T. Voutsas, "Role of band gap states on the electrical behaviour of sequential lateral solidified polycrystalline silicon TFTs", Journal of the Electrochemical Society 155 (1), H1, January 2008.

Publications in Conference Proceedings

7. Verrelli, E., D. Tsoukalas and D. Kouvatsos, "Deposition and electrical characterization of hafnium oxide films on silicon", Physica Status Solidi (c) 5 (12), 3720, December 2008.
8. Exarchos, M.A., D.C. Moschou, G.J. Papaioannou, D.N. Kouvatsos and A.T. Voutsas, "Performance of thin-film transistors fabricated by sequential lateral solidification crystallization techniques", Physica Status Solidi (c) 5 (12), 3634, December 2008.
9. Moschou, D.C., G.P. Kontogiannopoulos, D.N. Kouvatsos and A.T. Voutsas, "The effect of crystallization technology and gate insulator deposition method on the performance and reliability of polysilicon TFTs", Physica Status Solidi (c) 5 (12), 3630, December 2008.
10. Moschou, D.C., E. Verrelli, D.N. Kouvatsos, P. Normand, D. Tsoukalas, A. Speliotis, P. Bayiati and D. Niarchos, "Investigation of top gate electrode options for high-k gate dielectric MOS capacitors", Physica Status Solidi (c) 5 (12), 3626, December 2008.
11. Michalas, L., G.J. Papaioannou, D.N. Kouvatsos and A.T. Voutsas, "An experimental study of band gap states electrical properties in poly-Si TFTs by the analysis of the transient durrents", Physica Status Solidi (c) 5 (12), 3613, December 2008.
12. Kontogiannopoulos, G.P., F.V. Farmakis, D.N. Kouvatsos, G.J. Papaioannou and A.T. Voutsas, "Width dependent degradation of polycrystalline silicon TFTs", Proceedings of the 26th International IEEE Conference on Microelectronics (MIEL 2008), p. 549, Nis, Yugoslavia, May 2008.

International Conference Presentations

13. Moschou, D.C., M.A. Exarchos, D.N. Kouvatsos, G.J. Papaioannou, A. Arapoyanni and A.T. Voutsas, "Reliability and defectivity comparison of n- and p-channel SLS ELA polysilicon TFTs fabricated with a novel crystallization technique", 19th European Symposium - Reliability of Electron Devices, Failure Physics and Analysis (ESREF 2008), Maastricht, The Netherlands, October 2008.
14. Exarchos, M.A., G.J. Papaioannou, D.C. Moschou, D.N. Kouvatsos, A. Arapoyanni and A.T. Voutsas, "On the study of p-channel Thin-Film Transistors fabricated by SLS ELA crystallization techniques", European Materials Research Society Spring 2008 Meeting, Symposium I: Thin Film Materials for Large Area Electronics, Strasbourg, France, May 2008.
15. Michalas, L., G.J. Papaioannou, D.N. Kouvatsos and A.T. Voutsas, "Back gate influence on front channel operation of p-channel double gate polysilicon TFTs", European Materials Research Society Spring 2008 Meeting, Symposium I: Thin Film Materials for Large Area Electronics, Strasbourg, Fran

CIRCUITS & DEVICES FOR SENSOR NETWORKS & SYSTEMS

Project Leaders: S. G. Katsafouros, S.Chatzandroulis

PhD Candidates: P. Broutas, S. Kokorikos

External Collaborators: E.D. Kyriakis-Bitzaros

Objectives:

The main objective of the activity is the development of the technologies for future sensor networks and systems. In the context of this objective the research targets of sensor readout, wireless telemetry, RF remote powering in the near as well as the far field are pursued. Special consideration is given in operation within a spacecraft environment as well as in integration and packaging.

Funding

ESA Contract No. 21339/08/NL/GLC "Remote RF Powering and Passive Telemetry Link for a Wireless Strain Sensor System"

MAIN RESULTS IN 2008

Task 1: Wireless telemetry and RF remote powering of sensor tags

Health monitoring of structures is a major concern in the space and aviation community, where the need for more sophisticated structural health monitoring (SHM) systems is more and more recognized. The core of SHM technology is the development of self-sufficient systems that use built-in, distributed sensor/actuator networks not only to detect structural discrepancies and determine the extent of damage but also to monitor the effects of structural usage. SHM can provide early warnings of physical damage, which can be used to define remedial strategies before the damage compromises the spacecraft. Furthermore, it may be possible to quickly, routinely and remotely monitor the integrity of an air/spacecraft structure while in service.

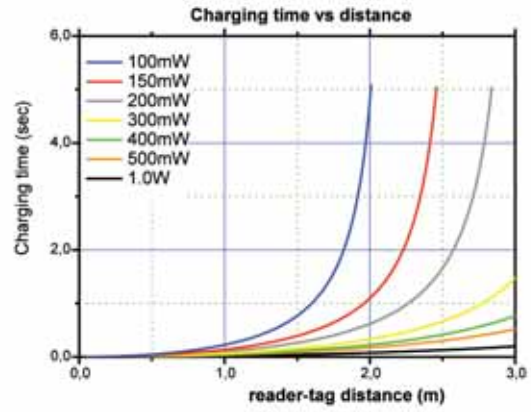


Fig. 1: Charging time versus distance for different reader antenna power (ERP) for matched dipole antennas between reader and tag. Operating frequency is 900MHz. The maximum power consumption of the tag is approximately Pon = 80uW, while the estimated consumption in standby mode is about Pstandby = 12uW.

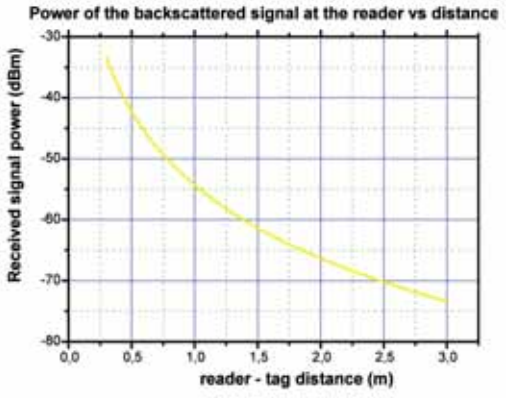


Fig. 2: Power of the backscattered signal received by the reader as a function of reader - tag distance. Operating frequency 900MHz. Dipole antennas have been considered for the reader and the tag (Reader transmitted power: 0dBm).

In this task, a heterogeneous wireless network of strain sensors is developed which may be deployed to air or space vehicles. The network consists of battery powered nodes and batteryless nodes that are able to harvest energy from an incident RF field. Battery powered nodes are based on the Zigbee standard. Both battery and batteryless nodes will be able to include sensors but some battery powered nodes simply serve as relaying points to transfer data to the central computer.

In 2008, the theoretical and practical limits of this network were investigated and the first sensor tag prototypes were designed. It has been found that it is possible to provide enough power to operate the sensor tag circuitry at a distance of up to 2m with 100mW transmitter power, while reading the sensor tag data does not pose any additional limitation when using backscattering to transmit the sensor signal.

Task 2: FPGA based capacitive sensor array system

Capacitive sensor interfacing receives a lot of attention in recent years, as more and more sensors of this type are being developed in view of the advantages they offer in terms of sensitivity, reliability, low temperature dependence and low power consumption. To this end a great number of techniques have been developed to translate the minute changes of capacitance of these sensors into an electrical signal. These make use of full custom switch capacitor or continuous time circuits or even use discrete components. These solutions, though offering high accuracy, precision or high sampling rate, lack the luxury of processing power thus not facilitating their use in systems where quick on the spot processing of the input signal is necessary.

In this task we have designed an embedded system, implemented into a programmable IC (FPGA) which comprises a subsystem able to convert capacitance changes into frequency changes and allows for the embedding of a NIOS processor. The circuit has been implemented on a commercial programmable logic array with a mean sensitivity of 15 Hz/fF. The system is intended to be used in portable, processing-power hungry sensor applications such as identification of complex odors with an electronic nose and point of care diagnostics devices which require the fast processing of the input signal of biosensor arrays. In addition, the system is highly versatile as the FPGA may be easily reprogrammed to add new functions and adapt to a sensor array with different characteristics and sensor population.

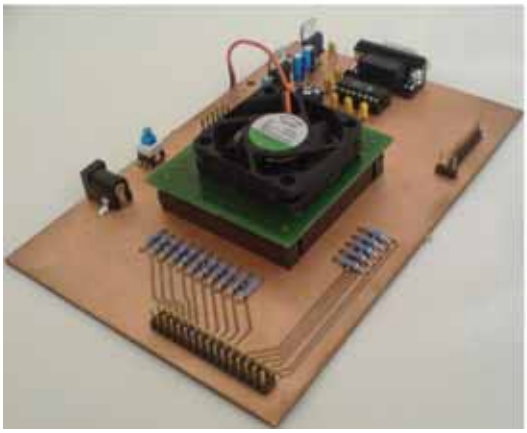


Fig. 1: Testing Board with MAX II FPGA.

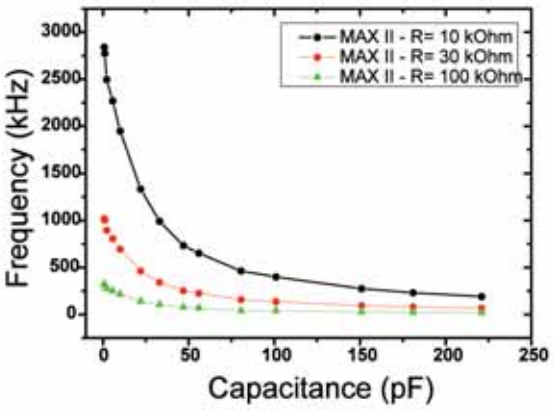


Fig. 2: Response of the capacitive sensing circuit for three different resistor values.

PROJECT OUTPUT in 2008

PUBLICATIONS in REFERREED JOURNALS

1. P. Robogiannakis, E.D. Kyriakis-Bitzaros, K. Minoglou, S. Katsafouros,A.Kostopoulos, G. Konstantinidis, G. Halkias, “Metallic bonding methodology for heterogeneous integration of optoelectronic dies to CMOS circuits”, Microelectronic Engineering Vol. 85, April 2008, pp. 727-732.

2. E. Grivas, E.D. Kyriakis-Bitzaros, G. Halkias, S.G. Katsafouros, G. Morthier, P. Dumon, R. Baets, T. Farell, N. Ryan, I. McKenzie, E. Armadillo, “Wavelength division multiplexing based optical backplane with arrayed waveguide grating passive router”, Optical Engineering Vol. 47, No. 2, Feb. 2008, pp. 025401-1-7.

CONFERENCE PRESENTATIONS

1. S.Pavlos, E.Kyriakis-Bitzaros and S.Chatzandroulis, "A Embedded Readout System for Capacitive Sensor Arrays" , VLSI-SoC 2008, 16th IFIP/IEEE International Conference on Very Large Scale Integration Systems, October 13-15, 2008, Rhodes Greece.

Bachelor Thesis

S.Pavlos, "A Embedded Readout System for Capacitive Sensor Arrays" in co-operation with TEI of Pireas, Department of Electronics.

ANNEXES

ANNEX I : PERSONNEL

Researchers

1. Nassiopoulou A.G., Director
2. Argitis P.
3. Chatzandroulis S.
4. Contopanagos H.
5. Davazoglou D.
6. Gardelis S.
7. Glezos N.
8. Gogolides E.
9. Ioannou-Sougleridis V.
10. Kouvatsos D.
11. Misiakos K.
12. Normand P.
13. Papanikolaou N.
14. Raptis I.
15. Tsamis C.
16. Tserepi A.

Research Engineers

1. Tsoi E.
2. Katsafouros S.

Other Scientific Staff

1. Dimitrakis P.	(IDAX)
2. Douvas A.	(IDAX)
3. Konstandoudis K.	(IDAX)
4. Vassilopoulou M.	(IDAX)
5. Huffman M.	(Contract)

Post Doctoral Scientists

1. Goustouridis D.	
2. Vambakas V.	
3. Makarona E.	
4. Kapetanakis E.	
5. Theodoropoulou M.	(Contract)
6. Farmakis P.	(Contract)
7. Palilis L.	(Contract)
8. Velessiotis D.	(Contract)
9. Patsis G.	(Contract)
10. Kokoris G.	(Contract)
11. Kotsovos K.	(Contract)

PhD Students

1. Mproutas P.	
2. Kelaidis N.	
3. Goupidenis P.	
4. Papadimitropoulos G.	
5. Malenou A.	
6. Vlachopoulou M.	
7. Kitsara M.	
8. Niarchos G.	
9. Oikonomou P.	
10. Papageorgiou D.	
11. Almpanis E.	
12. Georgiadou D.	
13. Kokorikos S.	
14. Asimakopoulos V.	
15. Manouras T.	
16. Bayiati P.	(Contract)
17. Ioannou N.	(Contract)
18. Petropoulos A.	(Contract)
19. Tsouti V.	(Contract)
20. Kontziampasis D.	(Contract)
21. Drygiannakis I.	(Contract)
22. Tsougenni A.	(Contract)
23. Gianetta V.	(Contract)
24. Ramfos I.	(Contract)
25. Tsikrikas N.	(Contract)
26. Moschou D.	(Contract)
27. Boulousis G.	(Contract)
28. Zacharatos F.	(Contract)
29. Zampelis L.	(Contract)
30. Theodoni P.	(Contract)
31. Vissio C.	(Contract)
32. Pavli P.	(Contract)
33. Kontogiannopoulos I.	(Contract)
34. Triantafillopoulou R.	(Contract)

Technical and Administrative Personnel

1. Georgiou C.	
2. Lagouvardou M.	
3. Makridi Z.	
4. Makridis Z.	
5. Mavropoulis I.	
6. Sergis E.	
7. Aspiotis I.	(Contract)
8. Bolomiti E.	(Contract)
9. Boukouras K.	(Contract)
10. Kalpouzou M.	(Contract)
11. Karmpadaki M.	(Contract)
12. Kontakis K.	(Contract)
13. Linarakis E.	(Contract)
14. Mpotsialas A.	(Contract)

ANNEX II: INFRASTRUCTURE AT IMEL

PROCESSING

Equipment	Techniques/competences
Silicon processing laboratory in a clean room area of 500 m2, equipped with the following: • **4 laminar flow chemical benches** • **7 horizontal hot-wall furnace tubes** • **2 horizontal LPCVD tubes for nitride, oxide (TEOS), polysilicon** • **1 horizontal LPCVD tube for LTO** • **Ion Implanter (EATON medium current, 200 KeV)** • **Optical lithography systems (resolution down to 0,6 μm)** • **Reactive Ion Etcher** • **Metallization equipment (thermal, e-gun evaporation, sputtering)** • **Process inspection equipment** Processing equipment not in clean room: • **High Density Plasma Etcher** • **Different thin film deposition systems (Sputtering, MOCVD)**	• Nanopatterning technologies • Plasma etching • Growth of metals and dielectrics • Growth of polycrystalline and nanocrystalline Si • Growth of Si nanostructures embedded in a dielectric matrix, ordering of nanostructures • Fabrication of MOS capacitors and MOSFETs • Nanocrystal non-volatile memories • Micromachining, sensor fabrication, microfluidics • Molecular materials and devices • Thin film devices  

CHARACTERIZATION & MODELLING

Equipment	Techniques/competences
Electrical • Several probe stations • HP measuring systems (4142B, 4084B, 8110A, 700i series, 4140B, 4284, 4192A, 34401, 16500A) • Keithley measuring equipment (230, 220, 617, 195A, 6517A) • Oxford optistat cryostat for temperatures in the range 4.2-320K • Wafer level cryogenic measurements (Janis probe station) • Cascade Microtech Summit 9101 Analytical Probe Station for 150mm wafers • Anritsu 37269D Vector Network Analyzer 40MHz-40GHz **Optical** • Jobin Yvon spectrometer,wavelengths 300-1600nm	**Characterization of Dielectrics** • Admittance measurements (1Hz up to 1MHz, 25-150°C) • I-V measurements (2 up to 4-terminal devices, 25-150°C) • Charge-to-breakdown measurements • Bias-Temperature-Stress measurements **Characterization of MIS Devices** • Admittance measurements (1Hz up to 1MHz, 25-150°C) • I-V measurements (2 up to 4-terminal devices, 25-150°C) • Hot-carrier stress measurements • Bias-Temperature-Stress measurements **EEPROM device characterization and reliability measurements** **Characterization of RF components**

- Ar+ laser
- HeCd 325 nm laser
- UV lamp with monochromator
- Oxford optistat cryostat, 4.2-320K
- FTIR: Bruker, Tensor 27

Morphology, structural characterization

- JEOL JSM-7401F FEG SEM, Point-to-point resolution below ~1nm
- Leo 440 SEM with Elphy/Raith e-beam lithography attachment
- AFM/STM (Veeco CP-II, NT-MDT)
- Stylus profilometer model XP-2 of Ambios Technology

Testing equipment

- Systems for testing of gas flow, gas pressure, acceleration, humidity sensors, biosensors and systems, microfluidics testing etc.

Modeling and simulation software

- SILVACO tools for process and device modeling (Athina and Atlas)
- Suprem and Pisces
- Floops and Floods
- Synopsis - Coventorware
- MATLAB-FEMlab
- Mentor graphics

Optical characterization

- Absorption measurements, wavelength range UV-VIS-IR
- Photoluminescence (PL)
- Laser excitation: 325 nm, 457.8nm, 488nm, 514.5nm
- Spectrometer: 350nm-1600nm
- Electroluminescence (EL): 350nm-1600nm
- Photocurrent-photovoltage (UV-VIS)
- FTIR

Characterterization of sensors

- Gas sensors
- Microflow sensors
- Accelerometers
- Optical devices
- Biosensors
- Microfluidics

Modeling and simulation

- Process and device modeling
- RF modeling








ANNEX III: RESEARCH AND EDUCATION OUTPUT

PUBLICATIONS IN REFEREED JOURNALS

1. "RF characterization and isolation properties of mesoporous Si by on-chip coplanar waveguide measurements", Contopanagos, H., Zacharatos, F., Nassiopoulou, A.G., Solid-State Electr., 52 (11), pp. 1730-1734 (2008)
2. "Optical properties of periodic structures of metallic nanodisks", G. Gatzounis, N. Stefanou, and N. Papanikolaou, Phys. Rev. B 77, 035101 (2008)
3. "Self-assembled hexagonal ordering of Si nanocrystals embedded in SiO2 nanodots", A. G. Nassiopoulou, V. Gianneta, M. Huffman, M. A. Reading, J. A. Van Den Berg, I. Tsiaoussis, N. Frangis, Nanotechnology 19, 495605 (2008)
4. "Highly ordered hexagonally arranged nanostructures on silicon through a self-assembled silicon-integrated porous anodic alumina masking layer", F. Zacharatos, V. Gianneta and A. G. Nassiopoulou, Nanotechnology 19, 495306 (2008)
5. "Understanding artificial optical magnetism of periodic metal-dielectric-metal layered structures", C. Tserkezis, N. Papanikolaou, G. Gantzounis, N. Stefanou, Phys. Rev. B 78, 165114 (2008)
6. "A combined experimental and simulation study on thickness dependence of the emission characteristics in multicolor single layer organic light-emitting diodes", N. A. Stathopoulos, M. Vasilopoulou, L. C. Palilis, D. G. Georgiadou, and P. Argitis, Appl. Phys. Lett. 93, 083310 (2008)
7. "Liquid phase direct laser printing of polymers for chemical sensing applications", C.Boutopoulos, V.Tsouti, D. Goustouridis, S.Chatzandroulis and I.Zergioti, Appl. Phys. Lett. 93, 191109 ,2008
8. "Surface nano/micro functionalization of PMMA thin films by 157 nm irradiation for sensing applications", E.Sarantopoulou, Z.Kollia, A.C.Cefalas, K.Manoli, M.Sanopoulou, D.Goustouridis, S.Chatzandroulis, I.Raptis, Appl. Surf. Sci. 254 1710(2008)
9. "Formation and metrology of dual scale nano-morphology on SF6 plasma etched silicon surfaces", G. Boulousis, V. Constantoudis, G. Kokkoris, E. Gogolides, Nanotechnology, 19 (25), pp.255301 (2008)
10. "Electron beam lithography simulation for the patterning of EUV masks", N.Tsikrikas, G.P.Patsis, I.Raptis, A.Gerardino, E.Quesnel, Jpn. J. Appl. Phys. 47 4909 (2008)
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26. "Flexible WO3 based electrochromic displays using proton conducting solid electrolytes", M. Vasilopoulou, P. Argitis, G. Aspiotis, G. Papadimitropoulos, and D. Davazoglou, Phys. Status Solidi (C) Current Topics in Sol. State Phys. 5 (12), 2008, pp. 3868-3871
27. "Deposition and electrical characterization of hafnium oxide films on silicon", Verrelli, E., D. Tsoukalas and D. Kouvatsos, Phys. Stat. S. (c) 5 (12), 3720, December 2008
28. "Performance of thin-film transistors fabricated by sequential lateral solidification crystallization techniques", Exarchos, M.A., D.C. Moschou, G.J. Papaioannou, D.N. Kouvatsos and A.T. Voutsas, Phys. Stat. Sol. (c) 5 (12), 3634, December 2008
29. "The effect of crystallization technology and gate insulator deposition method on the performance and reliability of polysilicon TFTs", Moschou, D.C., G.P. Kontogiannopoulos, D.N. Kouvatsos, A.T. Voutsas, Phys. Stat. S. (c) 5(12), 3630, 2008
30. "An experimental study of band gap states electrical properties in poly-Si TFTs by the analysis of the transient durrents", Michalas, L., G.J. Papaioannou, D.N. Kouvatsos and A.T. Voutsas, Phys. Stat. S. (c) 5 (12), 3613, December 2008
31. "Investigation of top gate electrode options for high-k gate dielectric MOS capacitors", D.C. Moschou, E. Verrelli, D.N. Kouvatsos, P. Normand, D. Tsoukalas, A. Speliotis, P. Bayiati, D. Niarchos, Phys. Stat. Sol. (c) 5, 3626-3629 (2008)
32. "Simulation of the electrical characteristics of MOS capacitors on strained-silicon substrates", N. Kelaidis, D. Skarlatos, and C. Tsamis, Phys. Stat. Sol. (c) 5, No. 12, 3647-3650 (2008)
33. "ZnO nanorod growth based on a low-temperature silicon-compatible combinatorial method", E. Makarona, Th. Speliotis, G. Niarchos, D. Niarchos, and C. Tsamis, phys. stat. sol. (c) 5, No. 12, 3809-3812 (2008)
34. "Effect of deposition pressure and post deposition annealing on SmCo thin film properties", Th. Speliotis, E. Makarona, F. Chouliaras, C. A. Charitidis, C. Tsamis, and D. Niarchos, phys. stat. sol. (c), 1-4 (2008)

Presentations in Conferences

1. "Nanoelectronics, Micro and Nanosystems", A. G. Nassiopoulou, Information and Brokerage Event, Moscow, 21-23 October 2008
2. "Electronics and micromachining using porous silicon", A. G. Nassiopoulou, Porous Semiconductors - Science & Technology, PSST - 2008, March 10-14 2008, Mallorca

3. “Beyond Moore flexible platform at EU level for Nanoelectronics and MEMS/NEMS”, A. G. Nassiopoulou, 14th Micromachine Summit, Daejeon, Korea, April 30 - May 3, 2008
4. “Micro&Nanoelectronics: Present status and perspectives”, A. G. Nassiopoulou, 14.4.2008, NCSR Demokritos, Athens, Greece
5. "Surface-related states in oxidized silicon nanocrystals enhance carrier relaxation and inhibit Auger recombination", A. Othonos, E. Lioudakis, A. G. Nassiopoulou, 2008 Virtual Conference on Nanoscale Science and Technology VC-NST, July 24-29, 2008 Fayetteville, Arkansas 72701, USA.
6. “CMOS-integrated low-loss porous Si technology for on-chip RF inductors”, F. Zacharatos, H. Contopanagos, and A. G. Nassiopoulou, 38th European Solid-State Device Research Conf. (ESSDERC2008), 15-19 Sept. 2008, Edinburgh, Scotland, U.K.
7. “Hybrid polymer-inorganic solar cells and light-emitting diodes with solution-processed polyoxometalates as exciton blocking/optical spacer and electron transport layers”, L.C.Palilis, M.Vasilopoulou, K.Kotsovos, A.Botsialas, E.Ntantoumis, P.Argitis, European Materials Research Society (E-MRS) Conference 2008, Strasburg, France, 2008.
8. “Self-organization of Cu nanoparticles on polythiophene layers for bistable memory devices”, P.Dimitrakis, L.C.Palilis, M.Vasilopoulou, G.Papadimitropoulos, D.Davazoglou, P.Argitis, P.Normand, European Materials Research Society (E-MRS) Conference 2008, Strasburg, France, 2008.
9. “Hybrid polymer-inorganic solar cells and light-emitting diodes with polyoxometalates as dual-function optical spacer and electron injection layers”, L.C.Palilis, M.Vasilopoulou, K.Kotsovos, D.G.Georgiadou, A.Botsialas, E.Ntantoumis, P.Argitis, 1st International Symposium on Flexible Organic Electronics (IS-FOE), Halkidiki, Greece, 2008.
10. “Air-stable solution-processed polymer optocouplers”, L.C.Palilis, M.Vasilopoulou, N.A.Stathopoulos, A.Botsialas, D.G.Georgiadou, G.Pistolis, D.Davazoglou, P.Falaras, P.Argitis, 1st International Symposium on Flexible Organic Electronics (IS-FOE), Halkidiki, Greece, 2008
11. “Photochemical study of organic dyes for color tuning in dye-doped OLEDs”, M.Vasilopoulou, D.G.Georgiadou, L.C.Palilis, G.Pistolis, P.Argitis, 1st International Symposium on Flexible Organic Electronics (IS-FOE), Halkidiki, Greece, 2008.
12. “Thickness effects on the emitting properties of single layer polymer light-emitting diodes (PLEDs) - A combined experimental and theoretical study”, N.A.Stathopoulos, M.Vasilopoulou, L.C.Palilis, D.G.Georgiadou, P.Argitis, 1st International Symposium on Flexible Organic Electronics (IS-FOE), Halkidiki, Greece, 2008.
13. “Improved charge injection in OLEDs via onium-salt addition inside polymer matrices”, D.G.Georgiadou, M.Vasilopoulou, L.C.Palilis, G.Pistolis, P.Argitis, 1st International Symposium on Flexible Organic Electronics (IS-FOE), Halkidiki, Greece, 2008. Young Researcher's Award for the Best Poster Presentation.
14. “Photochemically Induced Emission tuning of fluorescent and phosphorescent emitters in full colour, single layer organic light emitting didodes”, D.G.Georgiadou, M. Vasilopoulou, L. Palilis, G.Pistolis, P.Argitis, IV International Krutyn summer School, Masurian Lake District, Poland, 2008.
15. "Photoresist-based lithographic process for biomolecules patterning through chemical binding on the substrate", P. Pavli, P.S. Petrou, M. Chatzichristidi, A.M. Douvas, D. Niakoula, S.E. Kakabakos, D. Dimotikali, P. Argitis, 3rd International Workshop on Multianalyte Biosensing Devices 18-19/09/2008.
16. “Photopatterned Polymer Light-Emitting Diode (PLED) arrays for biosensing applications”, M. Vasilopoulou, P. S. Petrou, S. E. Kakabakos, L. C. Palilis , D. Georgiadou, A. Botsialas , P. Argitis, International conference on Micro- and Nano- Engineering, September 18-21 2008, Athens Greece.
17. “Partially Fluorinated Methacrylate Polymers as Active and Cladding Components in Optical Waveguides”, M. Vasilopoulou, A. M. Douvas , L. C. Palilis, P. Bayiati, D. Alexandropoulos, N. A. Stathopoulos and P. Argitis, International conference on Micro- and Nano- Engineering, September 18-21 2008, Athens Greece.
18. “A new imaging approach based on a thermally developable, etch resistant molecular material”, T.Manouras, A.M Douvas, M.Chatzichristidi, N.Vourdas, E.Gogolides, P.Argitis, MNE 2008
19. “Molecular proton memory”, E. Kapetanakis, A. M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N.

Glezos, P. Normand, 34th International Conference on Micro- and Nano-Engineering (MNE), Athens, Greece, September 15-19, 2008

20. “Photoresist-based lithographic process for biomolecules patterning through chemical patterning on the substrate”, P. Pavli, P. S. Petrou, M. Chatzichristidi, A. M. Douvas, D. Niakoula, S. E. Kakabakos, D. Dimotikali, P. Argitis, 3rd International Workshop on Multianalyte Biosensing Devices, Athens, Greece, September 18-19, 2008
21. "Direct laser printing of polymer materials for chemical sensing applications", C. Boutopoulos, V. Tsouti, S. Chatzandroulis, D. Goustouridis, P. Normand, D. Tsoukalas, and I. Zergioti, poster presentation in the 34th International Conference on Micro and Nano Engineering (MNE08), Athens, Greece, September 15-18, 2008
22. “Detection of the Biotin-Streptavidin interaction by exploiting surface stress changes on ultrathin Si membranes”, V.Tsouti, C.Boutopoulos, P.Andreakou, M.Ioannou, I.Zergioti, D.Goustouridis, D.Kafetzopoulos, D.Tsoukalas, P. Normand, S.Chatzandroulis, poster presentation in the 34th International Conference on Micro and Nano Engineering (MNE08), Athens, Greece, September 15-18, 2008
23. “A Biosensor Based on Surface Stress Changes of Ultrathin Silicon Membranes”, V. Tsouti, C. Boutopoulos, P. Andreakou, M. Ioannou, I. Zergioti, D. Goustouridis, S. Chatzandroulis, D. Kafetzopoulos, D. Tsoukalas, P. Normand, XXIV Panhellenic Conference on Solid State Physics and Materials Science Heraklion, Crete, September 21-24, 2008
24. “Plasma etching as a method for fabrication of polymeric microfluidics and micro arrays, and control of their properties (poster)”, N. Vourdas, M.E. Vlachopoulou, K. Tsougeni, D. Papageorgiou, P. Petrou, S. Kakabakos, A. Tserepi, E. Gogolides, Lab-on-a-Chip World Congress, 7-8 May 2008, Barcelona, Spain
25. “High density protein patterning through selective plasma-induced fluorocarbon deposition on Si substrates” (poster), P. Bayiati, E. Matrozos, A. Tserepi, P. S. Petrou, S. E. Kakabakos, A. Malainou, E. Gogolides, 10th World Congress on Biosensors, 14-16 May 2008, Shanghai, China
26. “High-Aspect-Ratio Plasma Induced Nanotexturing of Polymers (PDMS, PMMA, PEEK,…) for protein adsorption applications” (poster), M.E.Vlachopoulou, K.Tsougeni, P.Petrou, S.Kakabakos, A.Tserepi, E.Gogolides, EIPBN (The Fifty Second International Conference on electron, ion and photon beam technology and nanofabrication): 27-29 May 2008, Portland
27. “High-Aspect-Ratio Plasma Induced Nanotexturing of Polymers (PDMS, PMMA, PEEK,…) for protein adsorption applications” (poster), M.E.Vlachopoulou, K.Tsougeni, P.Petrou, S.Kakabakos, A.Tserepi, E.Gogolides, Nanobio : 9-13 June 2008, Barcelona, Spain
28. “Plasma-Induced Nanotexturing of Polymers and application in protein adsorption” (oral), M.E.Vlachopoulou, K.Tsougeni, P.S.Petrou, S.E.Kakabakos, A.Tserepi, E.Gogolides, ISPPBA (1st International Symposium on Plasma Processing and Biomedical Applications), 27-29 August 2008, Milos Island, Greece
29. “Selective plasma modification of patterned Si and glass substrates for the fabrication of high-density biomolecular micro-arrays” (oral), P. Bayiati, A. Malainou, E. Matrozos, A. Tserepi, P. S. Petrou, S. E. Kakabakos, E. Gogolides, ISPPBA (1st International Symposium on Plasma Processing and Biomedical Applications), 27-29 August 2008, Milos Island, Greece
30. “A novel microfluidic integration technology for PCB-based devices: Application to microflow sensing” (poster), K. Kontakis, A. Petropoulos, G. Kaltsas, T. Speliotis, E. Gogolides, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
31. “Effect of surface nanostructuring of PDMS on wetting properties, hydrophobic recovery and protein adsorption” (poster), M.-E.Vlachopoulou, P.S.Petrou, S.E.Kakabakos, A.Tserepi, K.Beltsios, E.Gogolides, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
32. “Nanotexturing of polymeric surfaces using plasma processes and applications in wetting control and in protein adsorption” (oral), K. Tsougeni, P. S. Petrou, A. Tserepi, S. E. Kakabakos, E. Gogolides, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
33. “SAW device integrated with microfluidics for array-type biosensing” (poster), K. Mitsakakis, A. Tserepi, E. Gizeli, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008

Athens, Greece

34. "Fabrication of Polymeric Microfluidic Devices and Control of their Surface Properties by Plasma Processing" (oral), K. Tsougeni, N. Vourdas, K. Kontakis, A. Tserepi and E. Gogolides, 6th International Symposium on Nanomanufacturing, 12-14 November 2008, Vouliagmeni, Athens
35. "Plasma-based fabrication of PDMS microfluidic devices of controlled surface roughness" (oral), M.E. Vlachopoulou, A. Tserepi, G. Boulousis, E. Gogolides, Microflu'08 (1st European Conference on Microfluidics) : December 10-12, 2008, Bologna, Italy
36. "Fabrication, Surface Modification and Characterization of Polymeric Microfluidic Devices UsingPlasma Etching and Plasma Processing Technology" (oral), K.Tsougeni, D. Papageorgiou, K. Kontakis, N. Vourdas, A. Tserepi, E. Gogolides, Microflu'08 (1st European Conference on Microfluidics) : December 10-12, 2008, Bologna, Italy
37. "Modeling of roughness evolution during the etching of inhomogeneous films : Material-induced anomalous scaling" (oral), V.Constantoudis, H. Christogianni, H. Zakka and E. Gogolides, International Conference in Statistical Physics SigmaPhi 2008, 14-18 July 2008, Kolympari - Chania, Greece
38. "Integrated plasma processing simulation framework, linking tool scale plasma models with 2D feature scale etch simulator", M. Hauguth, B.E. Volland, V. Ishchuk, D. Dreíler, T. Danz, I.W. Rangelow, G. Kokkoris, P. Geka, A. Panagiotopoulos, E. Gogolides, 34th Intern. Conf. on Micro and Nano Engineering 2008, 15-18 Sept. 2008 Athens, Greece
39. "Modeling of line edge roughness transfer during plasma etching", V. Constantoudis, G. Kokkoris, P. Xydi, G. P. Patsis, E. Gogolides, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
40. "Periodic nano-structuring of polymers using plasma processes: Towards plasma-directed polymer self-assembly?" (poster), N. Vourdas, D. Kontziampasis, G. Boulousis, V. Constantoudis, A. Tserepi, E. Gogolides, 34th International Conference on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
41. "Coupling Reaction Kinetics of Gas Phase, Reactor Wall, and Wafer Surface in C4F8 and SF6 Plasmas with Global Models" (oral), G. Kokkoris, E. Gogolides, A. Goodyear, M. Cooke, 2008 AVS 55th INTERNATIONAL SYMPOSIUM AND EXHIBITION, Boston, MA, 19-24 October, 2008
42. "Nano-Column Formation on Polymers Using Plasma Processes and Application in Wetting and Optical Properties Control" (oral), K. Tsougeni, M. E. Vlachopoulou, N. Vourdas, A. Tserepi, E. Gogolides, 6th International Symposium on Nanomanufacturing, 12-14 November 2008, Vouliagmeni, Athens
43. "Coupling Gas Phase and Surface Reaction Kinetics In C4F8 and SF6 Plasmas Used for Si and SiO2 Etching" (oral), G. Kokkoris, E. Gogolides, A. Goodyear, and M. Cooke, The AIChE Annual Meeting, 16-21 November 2008, Philadelphia, PA
44. "Plasma-deposited fluorocarbon films as hydrophobic layers for electrowetting on dielectric based droplet transport" (oral), P. Bayiati, A. Tserepi, D. Goustouridis, K. Misiakos, E. Gogolides, Microflu'08 (1st European Conference on Microfluidics) : December 10-12, 2008, Bologna, Italy
45. "Fractal dimension of Line Width Roughness and its effects on transistor performance" (oral), V.Constantoudis and E. Gogolides, SPIE conference: Advanced Lithography 2008, 24-29 February 2008, San Jose, California, USA
46. "Advanced lithography models for strict process control in the 32nm technology node" (oral), G. P. Patsis, D. Drygiannakis, I. Raptis, E. Gogolides, A. Erdmann, 34th Intern. Conf. on Micro and Nano Engineering 2008, 15-18 September 2008 Athens, Greece
47. "Monte Carlo modeling of micro and nano-roughness evolution during the etching of inhomogeneous films : Material origins of anomalous scaling behavior" (oral), V.Constantoudis, H. Christogianni, H. Zakka and E. Gogolides, XXIV Panhellenic Conference: Solid State Physics and Materials Science, 21-24 September 2008, Herakleion, Greece
48. "Wetting, Optical Property and Protein adsorption Control of Polymer Surfaces by Plasma Nanotexturing" (poster), K.Tsougeni, M.-E.Vlachopoulou, K.Kontakis, D.Papageorgiou, P.S.Petrou, S.E.Kakabakos, A.Tserepi, E.Gogolides, 7th Hellenic Polymer Conference : September 28 - October 1 2008, Ioannina,

Greece
49. “Periodic nanodot formation on polymers with plasmas: Towards plasma-directed polymer self-assembly?” (poster), D. Kontziampasis, N. Vourdas, G. Boulousis, V. Constantoudis, A. Tserepi, E. Gogolides, 7th Hellenic Polymer Conference : September 28 - October 1 2008, Ioannina, Greece
50. “Fluorocarbon plasma-treated SiO2 patterns on Si substrates for high density protein arrays”, P. Bayiati, A. Malainou, A. Tserepi, P. S. Petrou, S. E. Kakabakos, 3rd International Workshop on Multianalyte Biosensing Devices, September 18-19, 2008, Athens, Greece
51. “Line Width Roughness measurements and its effects on transistor performance” (oral), V.Constantoudis, G.P.Patsis, E.Gogolides, 6th Fraunhofer IISB Lithography Simulation Workshop, September 18 - 20, Athens, Greece (2008)
52. “Stochastic lithography simulation. Updated material models” (oral), G. P. Patsis, D. Drygiannakis,I. Raptis, 6th Fraunhofer IISB Lithography Simulation Workshop, September 18 - 20, Athens, Greece (2008)
53. “Reliability and defectivity comparison of n- and p-channel SLS ELA polysilicon TFTs fabricated with a novel crystallization technique”, Moschou, D.C., M.A. Exarchos, D.N. Kouvatsos, G.J. Papaioannou, A. Arapoyanni and A.T. Voutsas, 19th European Symposium - Reliability of Electron Devices, Failure Physics and Analysis (ESREF 2008), Maastricht, The Netherlands, October 2008.
54. “On the study of p-channel Thin-Film Transistors fabricated by SLS ELA crystallization techniques”, Exarchos, M.A., G.J. Papaioannou, D.C. Moschou, D.N. Kouvatsos, A. Arapoyanni and A.T. Voutsas, European Materials Research Society Spring 2008 Meeting, Symposium I: Thin Film Materials for Large Area Electronics, Strasbourg, France, May 2008.
55. “Back gate influence on front channel operation of p-channel double gate polysilicon TFTs”, Michalas, L., G.J. Papaioannou, D.N. Kouvatsos and A.T. Voutsas, European Materials Research Society Spring 2008 Meeting, Symposium I: Thin Film Materials for Large Area Electronics, Strasbourg, France, May 2008.
56. “Hybrid organic-inorganic materials for molecular proton memory”, E. Kapetanakis, A. M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand, 34th International Conference on Micro- and Nano-Engineering, MNE 2008, Athens, Greece, September 15-19, 2008.
57. “High Resolution Patterning and Simulation on Mo/Si Multilayer for EUV Masks”, N.Tsikrikas, G.P.Patsis, I.Raptis, A.Gerardino Eur. Mask Lithography Conf. (EMLC 2008), Dresden, Germany, 01/2008
58. “Lithographically-Fabricated Bismuth-Film electrodes as disposable Mercury-Free voltammetric sensors for trace analysis of Pb(II)”, Ch.Kokkinos, A.Economou, I.Raptis, Th.Speliotis Sensing in Electroanalysis, Uni. Pardubice, Czech Republic 3 91(2008)
59. “Electron-Beam-Patterning Simulation and Metrology of Complex Layouts on Si/Mo Multilayer substrates”, G.P.Patsis, D.Drygiannakis, N.Tsikrikas, I.Raptis, Proc. SPIE (2008)
60. “Dissolution optimization of highly etch-resistant, anthracene-based molecular resists”, D.Niakoula, D.Drygiannakis, G.P.Patsis, E.Gogolides, I.Raptis, P.Argitis, V.P.Vidali, D.R.Gautam, E.A.Couladouros EIPBN Conf., Portland, USA, 06/2008
61. “Integrated biochemical broad-band Mach-Zehnder sensors”, M.Kitsara, I.Raptis, K.Misiakos, E.Makarona EuroSensors 2008, Dresden, Germany, 09/2008
62. “Interdigital chemicapacitive sensors based on polymer/BaTiO3 composites”, K.Manoli, P.Oikonomou, D.Goustouridis, E.Karonis, I.Raptis, M.Sanopoulou EuroSensors 2008, Dresden, Germany, 09/2008
63. “Direct laser lithography on silicon substrate using phase mask”, I.Mathioudakis, C.Boutopoulos, I.Raptis, I.Zergioti MNE08 Conf., Athens, Greece, 09/2008
64. “Optical and electrical evaluation of polymer composites for chemical sensing applications”, G.Dendrinos, L.Quercia, I.Raptis, S.Chatzandroulis, D.Goustouridis, K.Beltsios MNE08 Conf., Athens, Greece, 09/2008
65. “Polymer/BaTiO3 nanocomposites based chemocapacitive sensors”, P.Oikonomou, K.Manoli, D.Goustouridis, I.Raptis, M.Sanopoulou MNE08 Conf., Athens, Greece, 09/2008
66. “Evaluation of a chemocapacitive sensor array for the detection of vapor analytes and their mixtures”, K.Manoli, E.Karonis, M.Chatzichristidi, D.Goustouridis, S.Chatzandroulis, I.Raptis, M.Sanopoulou IEEE

Sensors 2008, Lecce, Italy, 10/2008

67. "Broad-band Mach-Zehnder Interferometry as a detection principle for label-free biochemical sensing", M.Kitsara, I.Raptis, K.Misiakos, E.Makarona IEEE Sensors 2008, Lecce, Italy, 10/2008
68. "Simulation of E-Beam Edge Acuity Effect on the Resolution and LER of Chemically Amplified Resists", N.Tsikrikas, D.Drygiannakis, E.Valamontes, I.Raptis, G.P.Patsis MNC08 conf., Fukuoka, Japan, 10/2008
69. "Development and Characterization of an Integrated Thick Resist Film Processing Tool", D.Goustouridis, I.Raptis, E.Valamontes, I.Karanikas, M.Chatzichrisitidi MNC08 conf., Fukuoka, Japan, 10/2008
70. "Thermally induced evaporation of germanium substrate and its influence on dopant diffusion", N. Ioannou, D. Skarlatos, A. Chroneos, C. Tsamis, C. Krontiras, S.N. Georga, M. Pisanias, A. Christofi, D.S. McPhail, E-MRS 2008, 26-20 May, Strasbourg, France
71. "Initial stages of thermal and hot-wire assisted CVD Copper growth on SiLK® and LTO activated with Mercaptopropyl triethoxysilane self-assembled monolayers", G. Papadimitropoulos, T. Speliotis, A. Arapoyianni and D. Davazoglou, MAM 2008 -- Materials for Advanced Metallization Conference, Dresden (Germany), 2-5 March 2008
72. "Selective CVD of Copper on TiN Substrates versus electron beam patterned PMMA by DLI of CupraSelect", G. Papadimitropoulos, S. Cibella, T. Speliotis, R. Leoni, D. Davazoglou, Micro- and Nano-Engineering (MNE) Conference, Athens (Greece), Sept. 15-18, 2008
73. "Antibody array on poly(dimethylsiloxane)-modified glass capillary fluoroimmunosensor for simultaneous determination of cardiac markers", Niotis A.E., Mastichiadis C., Petrou P.S., Christofidis I., Siafaka-Kapadai A., Misiakos K., Kakabakos S.E., Lab-on-a-chip World Congress: Advances in Microarray Technology, Barcelona, Spain, May 7-8, 2008. Event Proceedings P34.
74. "Real-time detection of BRCA1 gene mutations using a monolithic silicon optoelectronic transducer", Petrou P.S., Mavrogiannopoulou E., Kakabakos S.E., Misiakos K., Biosensors 2008, Shanghai, China, May 14-16, 2008. Abstract book P1.170.
75. "Optical fluoroimmunosensor based on glass capillary internally coated with ultra-thin poly(dimethylsiloxane) film", Niotis A.E., Mastichiadis C., Petrou P.S., Siafaka-Kapadai A., Christofidis I., Misiakos K., Kakabakos S.E., 34st International Conference on Micro- and Nano-Engineering 2008 (MNE 2008), Athens, Greece, September 15-19, 2008. Abstract book BIO1-P20.
76. "Detection of BRCA1 gene mutations using a monolithic silicon optoelectronic transducer array", Petrou P.S., Mavrogiannnopoulou E., Kakabakos S.E., Misiakos K., 3nd International Workshop on Multi-analyte Biosensing Devices, Athens, Greece, September 18-19, 2008. Book of Abstracts O10.
77. "Development of a capillary optical fluoroimmunosensor for the simultaneous determination of cardiac markers in human serum", Niotis A.E., Mastichiadis C., Petrou P.S., Siafaka-Kapadai A., Christofidis I., Misiakos K., Kakabakos S.E., 3nd International Workshop on Multi-analyte Biosensing Devices, Athens, Greece, September 18-19, 2008. Book of Abstracts O11.
78. "Simultaneous determination of cardiac troponin I and creatine kinase isoenzyme MB in human serum samples using an optical capillary immunosensor", Niotis A., Mastichiadis C., Petrou P., Siafaka-Kapadai A., Christofidis I., Misiakos K., Kakabakos S. XVI Meeting of Balkan Clinical Laboratory Federation & 7th Penhellenian Congress on Clinical Chemistry and Clinical Bio-Chemistry, Athens, Greece, October 16-18, 2008. Abstracts book p. 78.
79. "Structural, chemical and light emission properties of very thin anodic silicon films fabricated by short single pulses", S. Gardelis, A.G. Nassiopoulou, F. Petraki, S. Kennou, I. Tsiaoussis, N. Frangis, XXIV Panhellenic Conference on Solid State Physics and Materials Science, Heraklion, Crete, 2008, Invited
80. "Enhancement and red shift of photoluminescence (PL) of fresh porous Si under prolonged laser irradiation or ageing: Role of surface vibration modes", S. Gardelis, A.G. Nassiopoulou, M. Mahdouani, R. Bourguiga, S. Jaziri, EMRS Spring Meeting, Strasbourg, France, 2008

Invited talks

1. De la Micro- à la Nanoélectronique et les Microsystèmes", A. G. Nassiopoulou, International Workshop on Research, Innovation, Enterprises in Communication Technologies, 4 November 2008, Pôle Elgazala,

Tunisie

2. "Electronics and micromachining using porous silicon", A. G. Nassiopoulou, International Conference PSST 2008, March 10-14 2008, Mallorca, Spain
3. "Porous anodic alumina thin films on Si as masking layers for silicon surface nanostructuring and as templates for nanostructure growth", A. G. Nassiopoulou, V. Gianneta, F. Zacharatos, M. Kokonou, M. Hauffman, 1st International Conference from Nanoparticles and Nanomaterials to Nanodevices and Nanosystems, Halkidiki, Greece, 16-18 June 2008
4. "The Greek micro-nanotechnology and MEMs landscape", A. G. Nassiopoulou, 14th Micromachine Summit, Daejeon, Korea, April 30 - May 3, 2008
5. "Electronics and micromachining using porous silicon", A. G. Nassiopoulou, 2nd International Summer School on "Nanosciences & Nanotechnologies" (SS-NN08), Thessaloniki, Greece, 12-18 July 2008
6. "Nanoelectronics at the Center of high technologies", A. G. Nassiopoulou, 8th Scientific Symposium on High Technologies in Physical Sciences, 3-5 October, Aegion, Greece
7. "Silicon nanocrystals in SiO2 thin layers: Growth, ordering and light emitting properties", A. G. Nassiopoulou, S. Gardelis, V. Gianneta, E. Lioudakis and A. Othonos, 2008 Virtual International Conference on Nanoscale Science and Technology VC-NST, July 24-29, 2008 Fayetteville, Arkansas 72701, USA
8. "Des alternatives pour les mémoires non-volatiles à grille flottante", P. Normand, IMEP, MINATEC, Grenoble, 24-06-2008.
9. "Structural, chemical and light emission properties of very thin anodic silicon films fabricated by short single pulses", S. Gardelis, A.G. Nassiopoulou, F. Petraki, S. Kennou, I. Tsiaoussis, N. Frangis, XXIV Panhellenic Conference on Solid State Physics and Materials Science, Heraklion, Crete, September 2008
10. "Polymer Nano-Texturing and Stochastic Nano-Patterning Using Plasma Processing" (oral invited), E. Gogolides, A. Tserepi, N. Vourdas, M.-E. Vlachopoulou, K. Tsougeni, and D. Kontziampasis, The AIChE Annual Meeting, 16-21 November 2008, Philadelphia, PA
11. "Micro- and Nano- Structuring of Polymers Using Plasma Processes and Potential Manufacturing Applications" (oral invited), E. Gogolides, A. Tserepi, N. Vourdas, M. Vlachopoulou, K. Tsougeni, V. Constantoudis, G. Boulousis, D. Kontziambasis, 6th Int. Symposium on Nanomanufacturing, 12-14 November 2008, Vouliagmeni, Athens
12. "Nano texturing / Patterning of Polymers with Plasmas: A Versatile Tool for Nanomanufacturing" (oral invited), E.Gogolides, A. Tserepi, N. Vourdas, K. Tsougeni, M.E. Vlachopoulou, G. Boulousis, 1st International Conference from Nanoparticles & Nanomaterials to Nanodevices & Nanosystems, 16-18 June 2008, Halkidiki, Greece
13. "Microfluidics and microarrays on smart, plasma processed, polymeric substrates" (oral invited), E.Gogolides, A. Tserepi, N. Vourdas, K. Tsougeni, M.E. Vlachopoulou, S. Kakabakos, P. Petrou, Nano2Life Annual Meeting, 25-27 June 2008, Heraklion, Crete, Greece

Patents

1. "Memory devices using proton-conducting polymeric materials", E. Kapetanakis, A.M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand, Greek Patent Application No 20080100269, 18-04-2008.
2. "Monolithically integrated physical chemical and biological sensor arrays based on broad-band mach-zhender interferometry", I.Raptis, K. Misiakos, P. Petrou, S. E. Kakabakos, E. Makarona, M. Kitsara, Application: OBI 2008/01/00174 day 17/03/2008
3. "Integrated optoelectronic silicon biosensor for the detection of biomolecules labeled with chromophore groups or nanoparticles" K. Misiakos, S. E. Kakabakos, PCT/GR02/00061, extension filed in 22/05/08 application number 20090100390. k
4. "Method for making a microarray", A.Tserepi, E. Gogolides, P. Petrou, S. Kakabakos, P. Bayiati, E. Matrozos, PCT Request Filing No: PCT/GR08/00048
5. "Method for the fabrication of periodic structures on polymers using plasma processes", E. Gogolides,

A.Tserepi, V. Constantoudis, N. Vourdas, G. Boulousis, M.-E. Vlachopoulou, K. Tsougeni, D. Kontziampasis, Application No: 20080100404

Organizition of Conferences, Symposia, Workshops

1. 6th International Biennial Conference on Porous Semiconductors Science and Technology (PSST 2008). The Conference was held in Mallorca, Spain in the period 10-14 March 2008. Chairpersons of the Conference and Scientific Editors of the Proceedings were: Prof. Leigh T. Canham (pSiMedica Ltd., UK), Dr. Androula Nassiopoulou (IMEL/NCSR "Demokritos", Greece), Prof. Michael Sailor (University of California at San Diego, USA), Prof. Patrik Schmuki (University of Erlangen-Nuremberg, Germany). The Conference was attended by 280 people from 43 countries and 220 papers were presented in oral or poster sessions. The Conference Proceedings were published in a special issue of Physica Status Solidi. Available on line at www.interscience.com
2. 3rd Nano2life Summer School “Methods in Micro-Nano Technology and Nanobiotechnology”, June 30 - July 10 2008, http://imel.demokritos.gr/SummerSchool2008/index.htm
3. 34th Micro and Nano Engineering Conference MNE08, September 15 - 18 2008, http://www.mne08.org

PhD theses

1. Treatment and modification of polymeric materials for the fabrication and electrowetting actuation of microfluidic devices”, Pinelopi Bayiati, Chemist, MSc, National and Kapodistrian University of Athens, Chemistry Dept., Thesis Research Advisor: Angeliki Tserepi, Other co-advisors: Prof. Nikos Hadjichristidis, Ass.Prof. Hermis Iatrou
2. “Defect processes in Germanium", A. Chroneos, Materials Dept., Imperial College, London, UK (1/2008)
3. “Porous anodic alumina thin films on Si: Fabrication, properties, applications”, M. Kokonou, PhD thesis, Thesis Advisor-Supervisor: Androula G. Nassiopoulou. Thesis defended at the National Technical Univeristy of Athens (2008)

Master theses

1. “Optical properties of metal-dielectric microstructures”, P. Theodoni, Master Thesis, University of Athens (2008)
2. “Design and FPGA/CPLD implementation of electronic readout for capacitive sensor arrays”, S. Pavlos, Supervisors: E.D. Kyriakis-Bitzaros, S. Chatzandroulis
3. “Plasma etching of polymers for microfluidics fabrication and sealing”, Konstantinos Kontakis, Electronics Engineer, MSc, Thesis Advisor-Supervisor: Evangelos Gogolides, Masters Programme in Microelectronics, National and Kapodistrian University of Athens
4. "Growth and characterization of magnetic materials on cantilevers for microgenerators", A. Darsinou, MSc course in Microelectronics, Informatics Dept., Univ. of Athens (2/2008)
5. "Growth and characterization of piezoelectric materials for microgenerators", G. Niarchos, MSc course in Microelectronics, Informatics Dept., Univ. of Athens (9/2008)

Courses and Seminars

1. “Conventional patterning schemes for hard substrates for bioanalytic microdevices”, E. Gogolides, 3rd Nano2Life Summer School on Methods in Micro - Nanotechnology and Nanobiotechnology, 30 June - 10 July 2008, Athens, Greece (2008)
2. “Microfabrication technologies for plastic analytical microfluidics”, A. Tserepi, 3rd Nano2Life Summer School on Methods in Micro - Nanotechnology and Nanobiotechnology, 30 June - 10 July 2008, Athens, Greece (2008)
3. “Fabrication of microfluidic devices on plastic substrates by Soft lithography”, A. Tserepi, 3rd Nano2Life Summer School on Methods in Micro - Nanotechnology and Nanobiotechnology, 30 June - 10 July 2008,

Athens, Greece (2008)
4. "Fabrication of plastic microfluidic devices by Lithography and deep polymer plasma etching techniques", E. Gogolides, 3rd Nano2Life Summer School on Methods in Micro - Nanotechnology and Nanobiotechnology, 30 June - 10 July 2008, Athens, Greece (2008)
5. "A Primer to Top-down Micro and Nano Patterning of Materials for Lab on a Chip applications", E.Gogolides, A. Tserepi, Nano2Life Annual Meeting, 25-27 June 2008, Heraklion, Crete, Greece
6. "Line Edge Roughness (LER, LWR): from the origins to effects on transistor performance", V. Constantoudis and G. P. Patsis, 34th International Conference on Micro and Nano Engineering 2008, 15 September 2008
7. "Microtechnology for the fabrication and liquid transport in microfluidic devices", Angeliki Tserepi, University of Crete, Department of Materials Science and Technology, Colloquia 2007-2008, March 14, 2008
8. "From Micro- to Nanoelectronics: Chellenges and Perspectives", A. G. Nassiopoulou, Summer School, NCSR Demokritos, July 2008
9. "Current trends in Nanoelectronics and MEMS", A. G. Nassiopoulou, 8.7.2008, NCSR Demokritos, Athens, Greece
10. "Microelectronic Materials and Device Technology", S. Gardelis, 3rd Nano2Life Summer School on Methods in Micro - Nanotechnology and Nanobiotechnology, 30 June - 10 July 2008, Athens, Greece (2008)
11. "Optolectronics and Applications", S. Gardelis, Summer School, NCSR Demokritos, July 2008
12. "Structural, chemical and light emission properties of very thin anodic silicon films fabricated by short single pulses", S.Gardelis, University of Cyprus, Department of Mechanical Engineering, Colloquia 2007-2008, November 26, 2008

ANNEX IV: FUNDED PROJECTS

A. EU Projects

- **SINANO (NoE-IST-FP6)** - Contract No 506844
  "Silicon based Nanodevices"
  Duration: 1/1/2004-31/12/2008
  Project leader: A. G. Nassiopoulou

- **MORE-MOORE (IP-IST-FP6)** - Contract No 507754
  "Exploring new limits to Moore's law"
  Duration: 1/1/2004-31/3/2008
  Project leader: E. Goggolides

- **NANO2LIFE (NoE-NMP-FP6)** - Contract No 500057
  "Unidirectional nanoscale supramuleculawires assembled by photo - and electro-active metallocyclodextrine cups"
  Duration: 1/2/2004-31/1/2008
  Project leader: K. Misiakos

- **TASNANO (STREP-NMP-FP6)** - Contract Nr 516865
  "Tools and Technology for the Analysis and Synthesis of Nanostructures"
  Duration: 1/1/2005-30/06/2008
  Project leader: N. Glezos

- **NEMOSLAB (IST-NoE- FP6)** - Contract No 027804
  "NanoEngineered Monolithic Optoelectronic transducers for highly sensitive and Label-free Bionsensing"
  Duration: 1/1/2006-31/12/2008
  Project leader: K. Misiakos

- **Micro2DNA (MMP-STREP)** - Contract No 027333
  "Integrated polymer-based micro fluidic micro system for DNA extraction, amplification, and silicon-based detection"
  Duration: 1/2/2006-31/1/2008
  Project leader: P. Normand

- **NANOPLASMA (STREP-NMP-FP6)** - Contract No 016424
  "Plasma Etching for desired nanofeature shape and nanotexture: An advanced reactor and simulation software for feedback loop plasma control"
  Duration: 1/4/2006-31/3/2009
  Project leader: E. Goggolides

- **ANNA (IST-I3)** - Contract No 026134
  "European Integrated Activity of Excellence and Networking for Nano and Micro-Electronic Analysis"
  Duration: 1/12/2006-1/12/2010
  Project leader: A. G. Nassiopoulou

- **MD3 (FP7) -** Contract No 214948
  "Material Development for Double exposure and Double patterining"
  Duration: 1/12/2007-30/11/2009
  Project leader: E. Goggolides

- **NANOSIL (FP7)** - Contract No 216171
  "Silicon based Nanostructures and nanodevices for long term nanoelectronics applications"
  Duration: 1/1/2008-30/12/2010
  Project leader: A. G. Nassiopoulou

- **ESA** - Contract ESTEC No 21339/08/NL/GLC
  "Remote RF Powering and Passive Telemetry Link for a wireless Strain Sensor System"
  Duration: 1/3/2008-31/5/2009
  Project leader: S. Katsafouros

- **PYTHIA (FP7)** - Contract No 224030
  "Monolithically Integrated Interferometric Biochips for label-free Early detection of Human Diseases"
  Duration: 1/5/2008-30/4/2011
  Project leader: I. Raptis

- **SPAM (FP7)** - Contract No 215723 (Marie Curie)
  "Surface Physics for Advanced Manufacturing"
  Duration: 1/10/2008-30/9/2012
  Project leader: E. Goggolides

- **ESA** - Contract ESTEC No 21068/07/NL/PA
  "Investigation of the use of III-Nitride quantum dot-resonant tunneling diodes structure as tuneable wavelength UV-VIS Detectors"
  Duration: 28/11/2007-31/10/2008
  Project leader: P. Normand

B. Other International projects

- **Photothermal project (Research agency-Cyprus)**
  "Towards a safe hydrogen production: Photothermal analysis at the limits of parts per trillion"
  Duration: 1/7/2004 - 30/6/2008
  Project leader: A. G. Nassiopoulou

C. Contracts with Industry

- Contract with the company **ST Microelectronics** SA, France
  "Microporous silicon and porous alumina grown electrochemically on silicon substrates applied to the fabrication of passive components and nanoelectronic devices"
  Duration: 30/7/ 05 - 30/7/08
  Project leader: A. G. Nassiopoulou

- Contract with the company **ZENON SA,**
  "Novel photovoltaic panels with vertical positioning of concentration Si cells"
  Duration: 1/7/ 06 - 31/12/08
  Project leader: D. Davazoglou

D. Projects funded by GSRT

- **AKMON**
  "Laboratory of Nanotechnology and Microsystems"
  Duration: 1/3/06 - 30/9/2008
  Project leader: A. G. Nassiopoulou

- **Excellence fund** for:
  "Funding of Excellence at IMEL"
  Duration: 1/12/2005 - 30/6/08
  Project leader: A. G. Nassiopoulou

- **GSRT- PENED-03ED579**
  "Macroporous silicon and anodic porous alumina on silicon for integrated RF components and nanoelectronics"
  Duration: 15/7/2005-30/6/2009
  Project leader: A. G. Nassiopoulou

- **GSRT-PENED-03ED630**
  "Micromachined chemical sensors for controlling food safety and quality"
  Duration: 1/11/2005 - 30/6/2009
  Project leader: C. Tsamis

- **GSRT- PENED-03ED496**
  "Dopant diffusion and activation in Group-IV semiconductors (Strained Silicon and Germanium) for novel nanoelectronic devices"
  Duration: 28/12/2005 - 30/6/2009
  Project leader: C. Tsamis

- **GSRT-PENED-03ED276**
  "Critical sub-100 Industrial scale Patterns for CMOS - NANO Architectures" (CMOS-NANO)
  Duration: 1/12/2005 - 30/6/2009
  Project leader: I. Raptis

- **GSRT- PENED-03ED202**
  "Fabrication, Properties, and Actuation Technologies for Microfluidic Devices"
  Duration: 1/12/05-30/6/2009
  Project leader: A. Tserepi

- **PENED - 03ED550**
  "Development of polysilicon TFT technology with advanced techniques of film annealing and device characterization"
  Duration: 15/12/2005 - 30/6/2009
  Project leader: D. Kouvatsos

E. Bilateral projects

- **Bilateral project (Greece-Romania)**
  "Drug delivery system based on microreservoirs array with porous silicon resorbable membrane caps"
  Duration: 1/2/2006-31/3/2008
  Project leader : A. G. Nassiopoulou

- **Bilateral project (Greece-France)**
  "Silicon nanocrystal synthesis by plasma immersion ion implantation for electronic memory applications"
  Duration: 1/4/2006 - 31/3/2008
  Project leader: P. Normand

- **Bilateral project (Greece-Italy)**
  "Fabrication and characterization of an array of transparent conductive thin film polymeric composite as multiparametric sensitive layers for a new e-nose"
  Duration: 29/1/2007- 31/3/2008
  Project leader: D. Goustouridis

- **Bilateral project NON-EU-204 (Greece-USA)**
  "Process-induced strain modification in strained silicon layers and influence on device performance"
  Duration: 1/3/2006-28/2/2008
  Project leader: C. Tsamis

- **Bilateral project NON-EU-99 (Greece-Japan)**
  "Cooper nano-electrodes and novel transistors based on tungsten oxides nano-rods (CONECTOR)"
  Duration: 1/ 4/2006-31/3/2008
  Project leader: D. Davazoglou

- **Bilateral project NON-EU-99 (Greece-Tunisia)**
  "Optical non-volatile memory using Si nanocrystals"
  Duration: 19/7/2006- 19/7/2008
  Project leader: A. Nassiopoulou

- **Bilateral project NON-EU-99 (Greece-Singapore)**
  "Proton Beam NANOlithography for high aspect ratio structures of optical Components (PB.NANOCOMP)"
  Duration: 1/2/2007- 31/3/2008
  Project leader: I. Raptis

- **Bilateral project 05NON-EU-408 (Greece-USA)**
  "Fabrication of uniform size nanoparticles for thin film growth and their application in electrical charge storage"
  Duration: 11/3/2007- 31/3/2008
  Project leader: P. Normand

DHMOEREYNA

- "Influence of surface plasmon-polariton excitation in nanostructured metallic surfaces on the fluorescence of biological materials"
  Duration: 1/1/2007-31/5/2008
  Project leader: N. Papanikolaou

- "Patterning and surface modification of substrates in the micro- and nano- scale for the fabrication of protein micro-arrays"
  Duration: 1/1/2007-31/5/2008
  Project leader: A. Tserepi