National Center for Scientific Research: “NCSR “Demokritos”

Institute of Microelectronics

Annual Report 2009

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www.imel.demokritos.gr

TABLE OF CONTENTS

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, modelling 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.

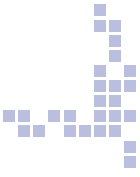
On the national level the expertise and infrastructure of IMEL are unique in Greece, which makes its role also unique in developing novel technologies, in transferring technology and know-how to the industry and in developing human potential through education and training activities. Furthermore, IMEL 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.
IMEL it is also a founding member of SINANO, the European Institute of Nanoelectronics and member of the Hellenic Semiconductor Industry Association.

The year 2009 it was certainly an important year for the Institute. IMEL was recognized as a Center of Excellence in Micro-Nano Systems and awarded a 2M€ fund from the EU programme Regional Potential (REGPOT). IMEL will have thus the opportunity during the next three years to extend its activities well into the nanoscale regime through the purchase of a state-of the art e-beam nanolithography tool. It is expected that nanolithography will impact most of IMEL’s research projects during the coming years.

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.

Prof. D. Tsoukalas
Director of IMEL



IMEL at a glance

OBJECTIVES AND ACTIVITIES

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. In this direction, IMEL has been accredited to international quality and metrology standards (ISO 9001 and ISO/IEC 17025).

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 the increase of 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:

I. MICRO and NANOFABRICATION
   - *Materials for Lithography and Organic/Hybrid Electronics*
   - *Lithography and Plasma Processes for Electronics, Microfluidics and Surface Nano-ngineering*
   - *Front-end Processes for Micro and Nanodevices*
   - *Thin Films by chemical vapor deposition (CVD)*

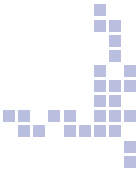
II. NANOSTRUCTURES and NANOELECTRONIC DEVICES
   - *Nanostructures for Nanoelectronics, Photonics and Sensors*
   - *Materials and Devices for Memory Applications*
   - *Molecular Materials as Components of Electronic Devices*

III. SENSORS and MEMs
   - *Mechanical and Chemical Sensors*
   - *Energy Harvesting Materials and Devices*
   - *Bio-microsystems*
   - *Thin Film Devices for Large Area Electronics*
   - *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)

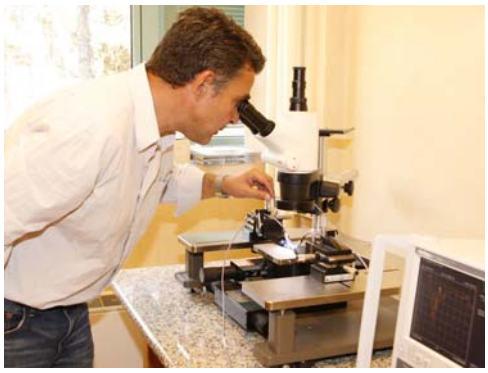
Laboratories and Central Fabrication Facilities at IMEL

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 clean 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.

Lithography equipment

FEG SEM JEOL JSM-7401F

High density plasma etcher



RF probe station

Electrical characterization equipment

Lithography and etching area

Management

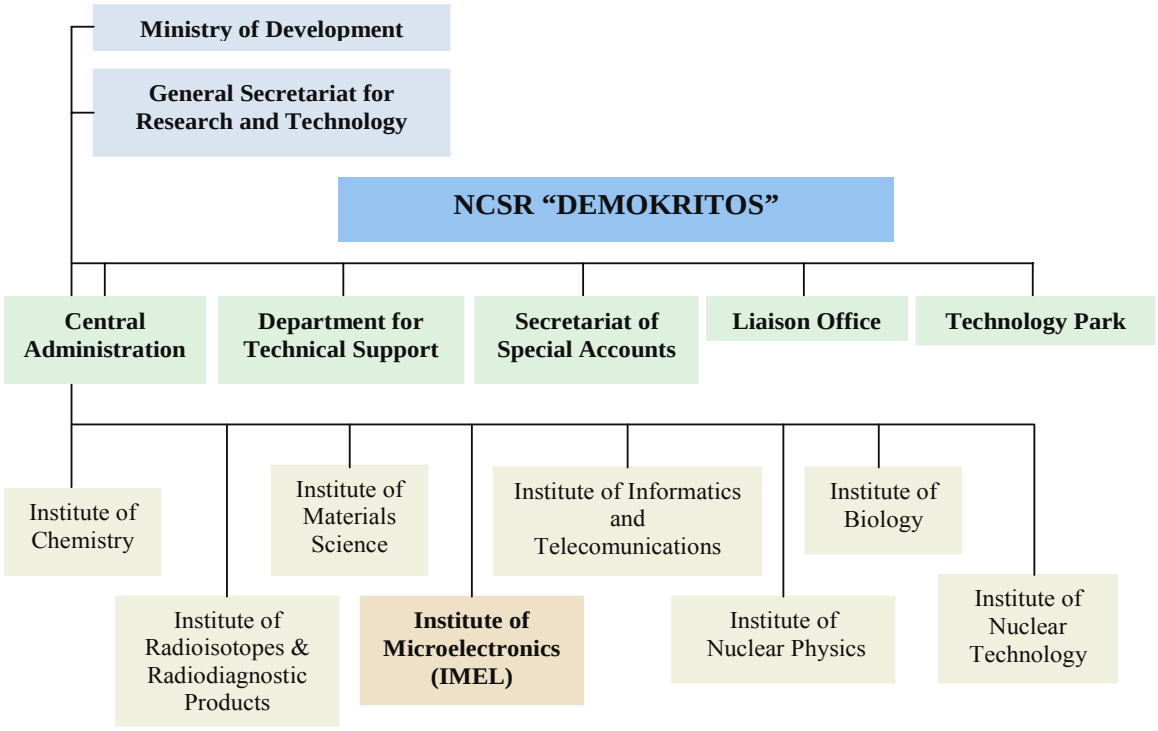
The management of the Institute is carried out by its Director, who is elected for a 5 year term by an International Scientific Committee and is assisted by a Deputy Director and an Institute Scientific Advisory Board, elected every 2 years by the Researchers. The Director represents the Institute in 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. The processing and electrical characterization laboratories are certified by ISO 9001 ensuring the high quality services that offers. Furthermore, the electrical characterization laboratory is now accredited to ISO/IEC 17025:2005, the most important metrology standard for test and measurement, by the Hellenic Accreditation System. This latest accreditation expands the list of IMEL certifications by industry recognized standards for quality such as ISO 9001. The accreditation recognizes that IMEL's electrical characterization services meet the requirements of this international standard demonstrating its competence to carry out test and measurement on MIS devices. The scope and the application field of the accreditation are described at http://www.esyd.gr/portal/p/esyd/en/catalogues.jsp .

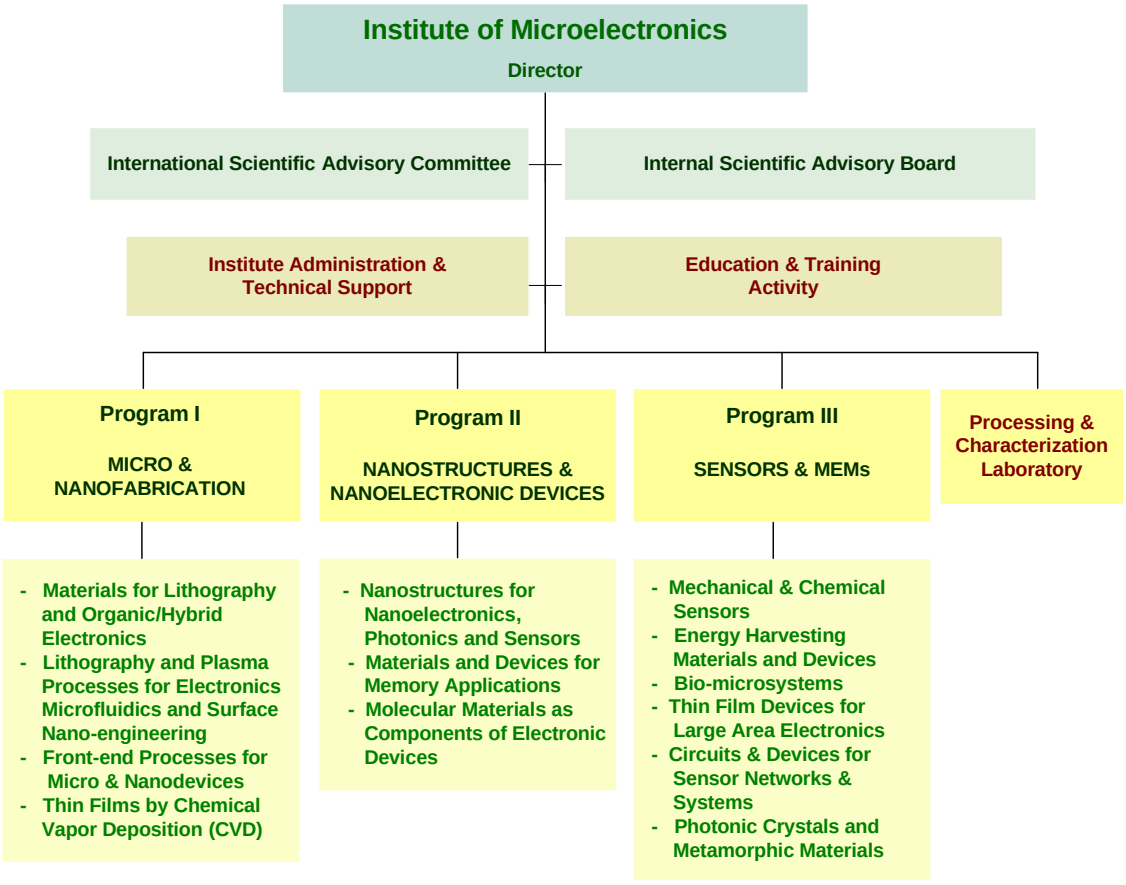
Personnel

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).

Organizational structure of NCSR Demokritos



Organizational structure of IMEL



MAIN RESEARCH RESULTS

PROGRAM I

MICRO and NANOFABRICATION

PROJECT I.1 MATERIALS FOR LITHOGRAPHY AND ORGANIC/HYBRID ELECTRONICS

Project Leader : P. Argitis

Key Researchers : P. Argitis, I. Raptis

Permanent research staff : M. Vasilopoulou, A.M. Douvas,

Post-doctoral Research Associate : L. Palilis

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

Master students : S. Karakitsiou

Collaborating researchers from other IMEL groups : D. Davazoglou, P. Normand, N. Glezos, P. Dimitrakis, E. Gogolides, A. Tserepi

External Collaborators: M. Chatzichristidi (Univ of Athens), G. Pistolis (IPC-NCSRD), S. Kakabakos, P.S. Petrou, (IRRP-NCSR-D), N. Stathopoulos, S. Savaidis (TEI Piraeus), D. Dimotikali (Nat. Tech. Univ. Athens), S. Kennou (Univ. of Patras), J.A.G.Williams (Univ. of Durham)

Objectives

A. Development of new lithographic materials and micro- nanopatterning processes

Research topics
- Investigation of new resist chemistries
- Optimization of patterning processes for ultra high resolution patterning
- Lithographic schemes for patterning in the areas of MEMs, bio-MEMs and related fields

The current research priorities include new resists based on imaging through polymer back-bone breaking and new patterning processes for biosystems fabrication

B. Materials research for organic/hybrid electronic devices of improved performance

Reasearch topics
- Electron transporting interfacial layers of organic optoelectronic devices
- Emission colour tuning in Organic Light Emitting Diodes (OLEDs)
- Material options for improving charge separation and transport in organic/hybrid photovoltaics (OPVs)

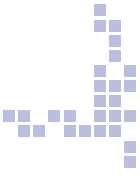
The current research priorities include investigation of W or Mo polyoxometallates (POMs) and corresponding oxides as electron transporting layers in OLEDs and OPVs, photochemically induced emission tuning of OLEDs, nanostructuring of p-n junctions in OPVs and development of processing technology for POMs-containing materials

MAIN RESULTS 2009

A. Lithographic materials and micro-nano patterning processes

A.1 New photoresists based on polymer back-bone breaking

A new class of photoresist materials is under development by our group, where imaging is based on backbone cleavage under the influence of photogenerated acid. These materials exhibit etch resistance comparable to the one of novolac-based resists and are expected to lead to high resolution and small side roughness structures. On the other hand they can find applications in the microsystems fabrication area. Ketals/ Aketals are chosen for functional groups in the main polymer chain since these groups are cleaved in the presence of acid while they remain untouched in alkaline conditions. An appropriate design of the polymers allows the incorporation of suitable functional groups for the achievement of desirable lithographic chracteristics (thermal stability, glass transition temperature, etch resistance, dissolution behaviour etc).



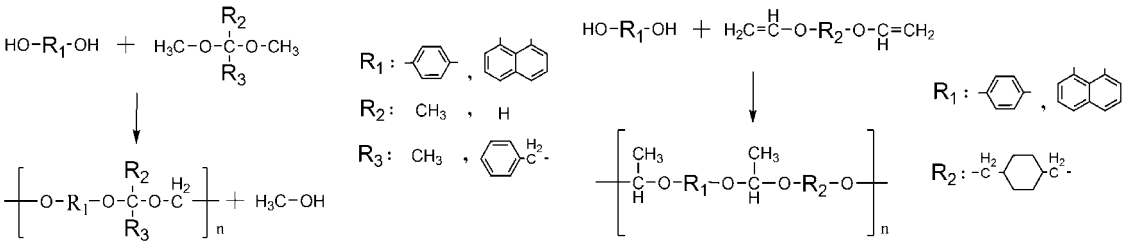


***Fig.1**. Design possibilities for the synthesis of resist polymers with optimized performance*

Lines with 1 μm width

Holes with diameter of 500 nm

***Fig.2** Promising imaging results with new resist materials (contact exposure at 248 nm)*

A2 Nonfouling PVA structures

Precise patterning of biomolecules on solid substrates is very important in bio-microsystems, drug delivery, tissue engineering and bioanalytical applications. In this content patterning of bovine serum albumin (BSA) layers was demonstrated by using an approach applied for the first time in bio-patterning, which is based on the different performance, in terms of protein physisorption, of polystyrene and crosslinked polyvinyl alcohol films. Primarily a polystyrene film was spin coated on a silicon wafer. Above that film polyvinyl alcohol stripes were created by developing a photolithographic process based on the crosslinking of PVA in the exposed areas. The immobilized protein was BSA tagged with biotin. The immobilized BSA was detected under fluorescence microscope after reaction of the tagged biotin with AlexaFluor 546 labeled streptavidin. The BSA was immobilized only on the polystyrene stripes as expected.

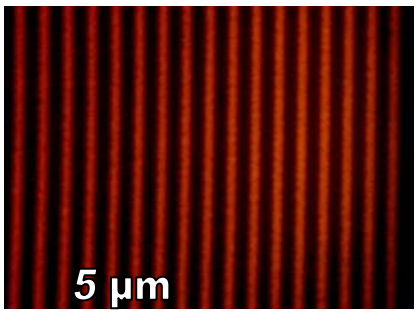


***Fig. 3**. Bovine serum albumin (BSA) 5μm line patterns on polystyrene, obtained by using photo-crosslinked PVA as non fouling surface.*

B. Materials for organic/hybrid electronics

B1 Nanocrystalline tungsten oxides (n-WO_3) as Electron Injection Layers in Hybrid Inorganic−Polymer Light-Emitting Diodes (Hy-PLEDs)

Improved performance polymer light-emitting diodes (PLEDs) based on a polyfluorene derivative, in particular the green emitting copolymer poly[(9,9-dioctylfluorenyl-2,7-diyl)-co-(1,4-benzo-{2,1',3}-thiadiazole)] (YE), were demonstrated. A thin layer of nanocrystalline tungsten oxide (n-WO_3) was deposited between YE polymer and the cathode (see Fig.1 for device structure and the corresponding energy diagram). The deposition was carried out by heating a W filament in a vacuum chamber, while hydrogen was flowing through the chamber. The surface of tungsten oxide films is nanostructured with the characteristic appearance of

rather well-defined surface grain features (Figure 2). The improved interfacial contact of those films with Al may be beneficial for charge injection. Indeed, improved current density and luminance were achieved as a result of the improved electron injection and transport at the cathode/n-WO_3 interface in PLEDs (Figure 3). Photovoltaic open circuit voltage measurements demonstrate a considerable lowering of the electron injection barrier height at the n-WO modified YE/Al interface that is responsible for the improved charge injection and recombination, and thus the increase of the device luminance and the decrease of the operating voltage.

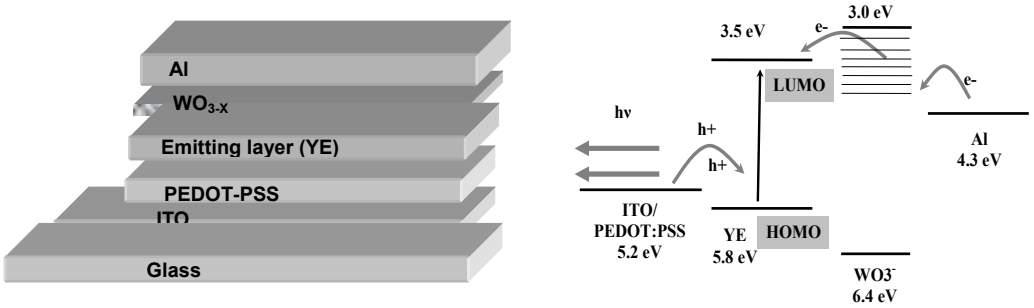
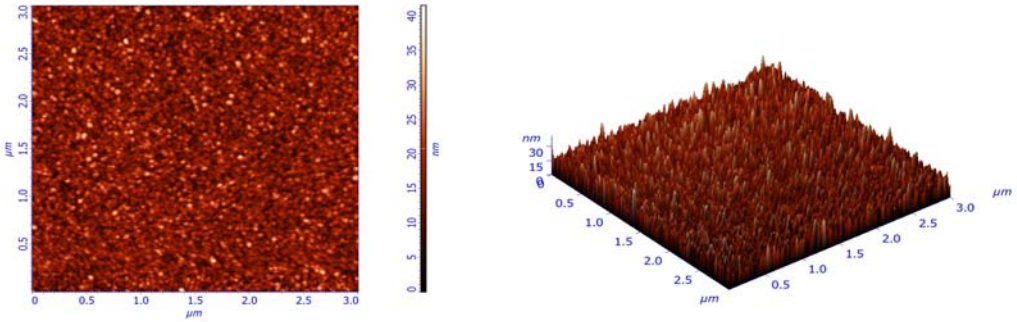


Fig. 4: *Device structure (left) and the corresponding energy level diagram of a YE based Hy-PLED having a thin nanocrystalline tungsten oxide layer inserted between the cathode and the active layer.*



Mean Diameter ~ 35 nm RMS = 3.4 nm

Fig. 5: *AFM (2D and 3D) topographic images of nanocrystalline tungsten oxide thin films.*

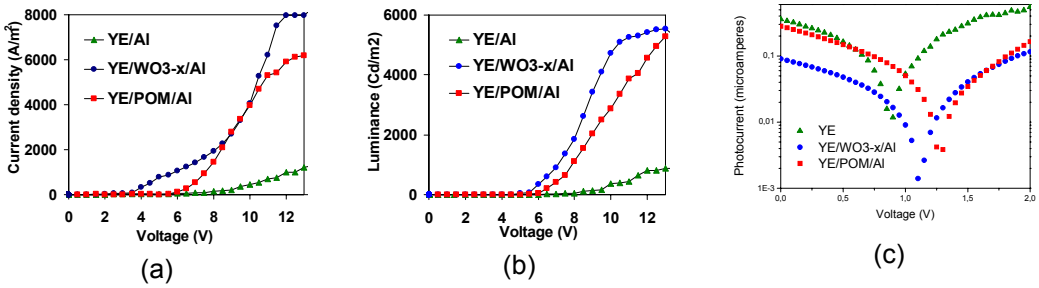


Fig. 6: *a) J-V, b) L-V characteristics of the Hy-PLEDs. A notable increase in the current density and luminance is demonstrated upon using a very thin reduced WO_{3-x} layer as a EIL which is further enhanced upon device annealing (after Al deposition). c) Photovoltaic open circuit voltage (V_{oc}) measurements reveal an increased built in potential and, therefore, a reduced electron injection barrier height when WO_{3-x} is inserted at the YE/Al interface. Note that a similar improvement on the J-V-L characteristics was observed when a tungsten polyoxometalate inorganic oxide molecule ($H_3PW_{12}O_{40}$) was inserted as a cathode interfacial layer at the YE/Al interface, and was attributed to a considerable reduction of the electron injection barrier as demonstrated by photovoltaic open circuit voltage measurements (See 2008 Annual Report).*

B2 Triphenyl sulfonium salts as potential molecular components of Polymer Light Emitting Diodes (PLEDs)

Triphenyl sulfonium triflate and nonaflate salts are investigated as potential molecular components of polymer light emitting diodes. Triphenyl sulfonium (TPS) salts are well known compounds in photolithography, where they are widely used in photoacid generation (PAG). Improved performance of single-layer polymer light-emitting diodes (PLEDs) based on a polyfluorene derivative was demonstrated. TPS salts were either blended with the green emitting copolymer poly[(9,9-dioctylfluorenyl-2,7-diyl)-co-(1,4-benzo-{2,1',3}-thiadiazole)] (YE) at different concentrations or, alternatively, a thin solution-processed layer of the salt was introduced between the emitting copolymer and the cathode. In the case when the TPS salt is added inside the polymer matrix, by application of a forward bias, the ions move to electrodes, where a space charge is formed resulting in the lowering of the potential barrier. This leads to improved charge injection and transport to the bulk and consequently increased current, luminance and current efficiency (see solid lines in Fig. 4). The film morphology depends on the TPS concentration as can be seen in Figure 5. As the TPS concentration increases, a phase separation between the polymer and the salt phases is observed, which results in efficient transport but inefficient recombination and decreased luminescence. When the TPS salt is inserted as a separate layer between the cathode and the emitting polymer, the interfacial energetics play a major role in the increased charge injection and improved performance (see dashed lines in Fig. 4). Possible mechanisms for improved device performance in the context of energetic level alignment at the cathode/TPS interface are investigated.

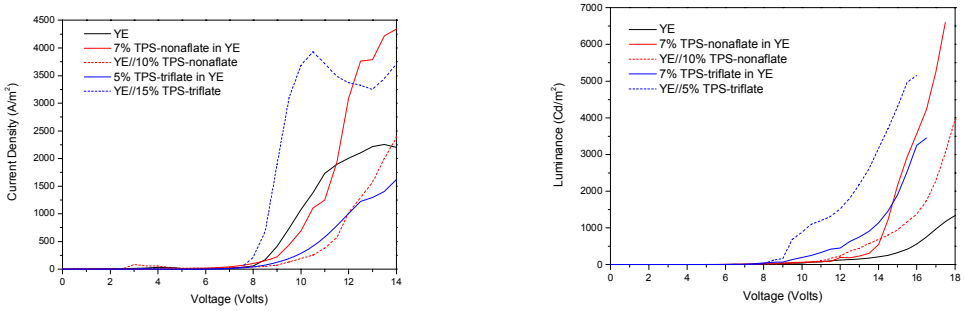


Fig. 7: *Current density-voltage (left) and luminance-voltage (right) characteristics of PLEDs depicting the influence of a) the addition of TPS-salt photoacid generators in the emissive layer of PLEDs (solid lines) and b) the insertion of a TPS-salt layer as a cathode interfacial layer (CIL) (dashed lines), using YE as the emitting polymer.*

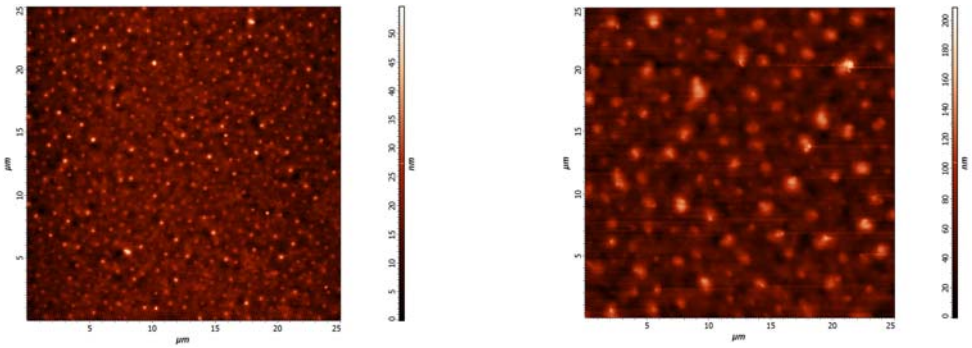


Fig. 8: *AFM 2D topography images of a 70 nm thin film of YE copolymer containing 30% wt (left) and 50% wt (right) triphenyl sulfonium triflate.*

B3 Hybrid polymer-metal oxide solar cells with a stoichiometric WO_3 cathode interfacial layer as an electron extraction/transport layer

Improved performance hybrid polymer-metal oxide bulk-heterojunction photovoltaic cells (Hy-PVs) based on donor/acceptor polymer (regioregular poly(hexyl-thiophene)(P3HT)/fullerene ([6,6]-phenylC_{70}-butyric acid methyl ester)(PCBM70) heterostructures were demonstrated upon inserting a thin layer of a stoichiometric n-type metal oxide WO_3 layer (see Fig. 7, left icon) at the Al cathode/active layer interface. To probe the impact of WO_3 thickness on the photovoltaic cell performance, we calculated a Figure of

Merit, namely the normalized Q (= $\overline{Q_j}$) across the visible spectrum, which is given by equation:

$$\overline{Q_j} = \frac{\int_{\lambda_L}^{\lambda_H} \int_{0}^{d_j} Q_j(z,\lambda) dz d\lambda}{\int_{\lambda_L}^{\lambda_H} \int_{0}^{\infty} Q_j(z,\lambda) dz d\lambda}$$

and is a measure of how many charge pairs are generated within the active layer (External Quantum Efficiency, EQE). The EQE is also directly proportional to the modulus square of the current in the photoactive layer, and therefore, the number of the generated excitons at the same position. Using this equation for the visible spectrum from λ_L=400nm to λ_H=700nm, $\overline{Q_j}$ has been calculated and plotted in Fig. 7 (right graph), versus active layer thickness, for four distinct WO_3 thicknesses (5 nm, 10 nm, 20 nm, and 40 nm) and is compared with that of a reference cell (without WO_3). The addition of a WO_3 layer reduces the EQE of an OPV cell with an already optimum active layer thickness, in terms of maximum normalized Q. However, for an active layer thickness of approximately 50 and 180 nm, $\overline{Q_j}$ is rather insensitive to the presence of a WO_3 layer with a thickness of up to 20 nm. Due to this fact, any change in the produced photocurrent, should reflect the influence of the WO_3 layer on the internal quantum efficiency (IQE) of the device.

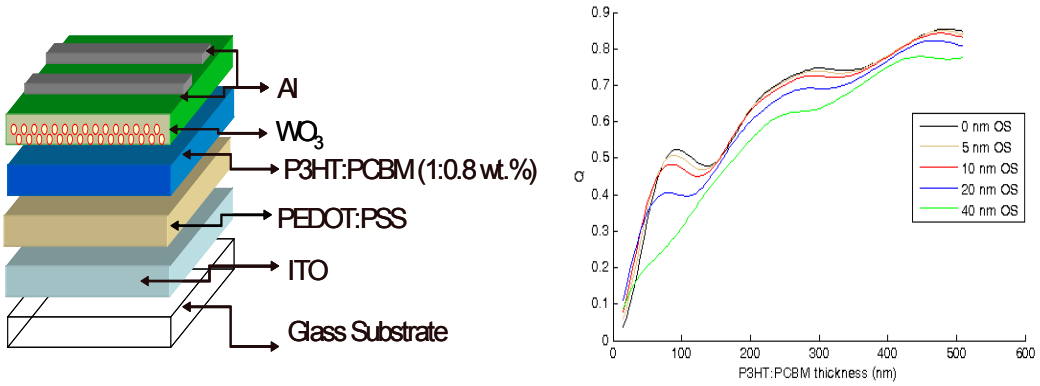


Fig. 9: *Hy-PV device structure (left) and the normalized absorbed light energy Q over the visible spectrum, versus active layer thickness, for WO_3 thickness of 5nm, 10nm, 20nm, and 40nm (compared with that of a reference cell (without WO_3)) (right).*

Figure 8 shows the dark current-voltage characteristics of reference and Hy-PV cells (left graph) as well as the photocurrent-voltage characteristics of the same cells (right graph) with a 180 nm thick P3HT:PCBM70 active layer and a 20 nm thick WO_3 cathode interfacial layer.

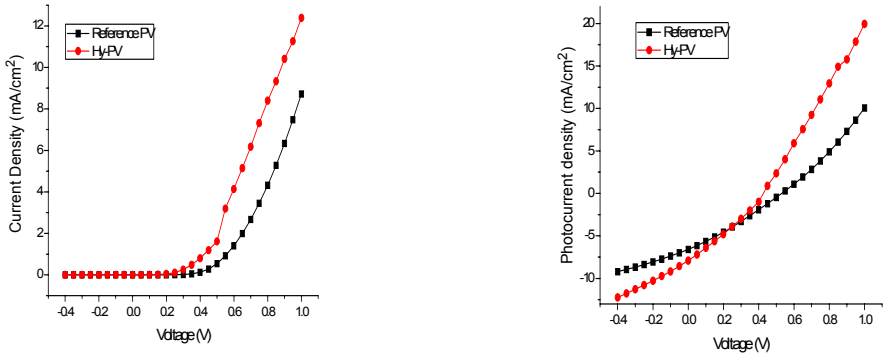


Fig. 10: *Dark current-voltage characteristics of reference and Hy-PV cells (left) and the photocurrent-voltage characteristics of these cells (right).*

The insertion of a 20 nm thick WO_3 layer results in a significant increase of the forward-bias dark current of the Hy-PV, suggesting that WO_3 increases electron injection from the Al cathode and/or improves the transport of electrons at this interface, possibly due to its large n-type conductivity. Also a decrease of the diode turn-on voltage is observed, indicating a smaller built-in potential present in the Hy-PV. The Hy-PV exhibits a short circuit photocurrent density (J_{sc}) of 7.9 mA/cm^2, compared to 6.6 mA/cm^2 for the reference cell. The "saturation" photocurrent density reaches ~12.5 mA/cm^2 and ~9.5 mA/cm^2 at -0.5 V for the Hy-PV and the reference cell, respectively, suggestive of a field dependent charge separation and collection process that is more pronounced in the Hy-PV. We note that these values are an overestimation of the real values (under standard AM 1.5G solar illumination conditions) due to the spectral mismatch between our lamp source and the standard AM 1.5G spectrum and the limited accuracy in the calibration of the lamp intensity. If we apply a "typical" spectral mismatch correction factor of 1.35, as has been reported for a P3HT:PCBM OPV cell, the corrected photocurrent density is ~9 mA/cm^2 and ~7 mA/cm^2 for the Hy-PV and the reference cell, respectively, which are in good agreement with the simulation values. The corrected power conversion efficiency is ~1.1% for both structures due to the slight (~0.1 V) decrease of the open circuit voltage of the Hy-PV, probably due to the formation of shunt paths upon deposition of WO_3. Taking into account that the selected photoactive layer thickness provides an almost equal EQE for both cells, the photocurrent improvement of the Hy-PV cell can be attributed to the influence of the WO_3 layer on the cell's IQE. In this particular case, its use as a cathode interfacial layer may facilitate electron transport/extraction leading to a 20-30% photocurrent improvement.

B4 Tuning the emitting colour of OLEDs: Towards device performance optimization

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 device performance by replacing fluorescent emitters with phosphorescent ones, since the latter are able to harvest both singlet and triplet excitons, resulting in a theoretical internal phosphorescence quantum efficiency of 100% (compared to just 25% for fluorescent emitters). The photochemical tuning of emission colour from orange to green of a phosphorescent dimethylamino-Pt(II) complex inside a PVK matrix, triggered by acid photogeneration, is investigated. Both photo- and electroluminescence spectra of PtL^{9}Cl before and after protonation clearly indicate this blue shift (Fig. 6). Other hosts are under investigation as well as different types of photoacid generators and device architectures, in order to optimize device performance.

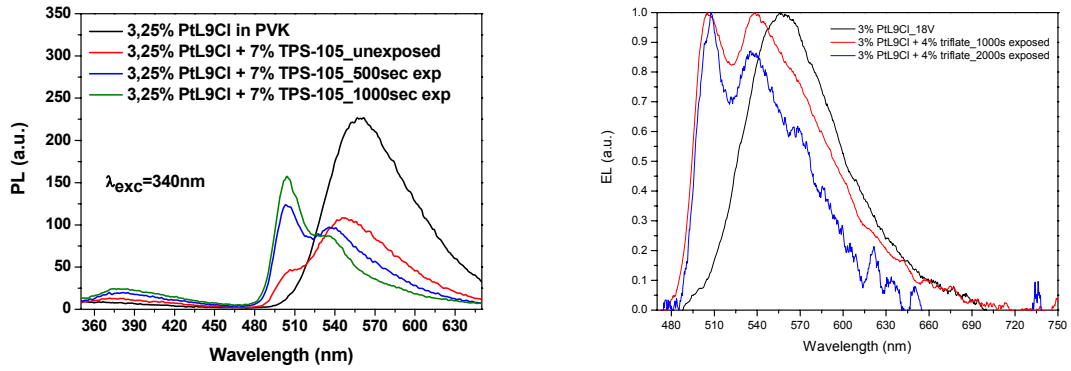


Fig. 11: *PL (left) and normalized EL (right) spectra depicting the photochemical tuning from orange to green of films made of PtL^{9}Cl and TPS-triflate inside a PVK matrix before and after exposure at 249 nm.*

PROJECT OUTPUT IN 2009

Publications in international Journals

1. "Materials for lithography in the nanoscale", P. Argitis, D. Niakoula, A.M. Douvas, E. Gogolides, I. Raptis, V.P. Vidali, E.A. Couladouros, Int. J. Nanotechnol., 6, 71-87, 2009.
2. "Photochemically-induced acid generation from 18-molybdodiphosphate and 18-tungstodiphosphate within poly(2-hydroxyethyl methacrylate) films", A.M. Douvas, A. Kapella, D. Dimotikali, P. Argitis, Inorg. Chem. Vol. 48, 4896-4907, 2009
3. "Chemical binding of biomolecules to micropatterned epoxy modified surfaces for biosensing applications", P. Pavli, P.S. Petrou, D. Niakoula, A.M. Douvas, M. Chatzichristidi, S.E. Kakabakos, D. Dimotikali, P. Argitis, Microelectronic Engineering, Vol. 86, 1473-1476, 2009
4. "Ordering domains of spin-cast blends of conjugated and dielectric polymers on surfaces patterned by soft- and photo-lithography" J.Jaczewska, A.Budkowski, A.Bernasik, I.Raptis, E.Moons, D.Goustouridis, J.Haberko, J.Rysz, Soft Matter 5, 234, 2009
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8. "Surface modification of polyhedral oligomeric silsesquioxane copolymer films by 157 nm laser light", E. Sarantopoulou, Z. Kollia, A.C. Cefalas, A.E. Siokou, P. Argitis, V. Bellas, S. Kobe, Journal of Applied Physics, Vol. 105, Article number 114305, 2009
9. "Hybrid organic-inorganic materials for molecular proton memory devices", E., Kapetanakis, A.M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand, Organic Electronics, vol. 10, 711-718, 2009
10. "A low temperature surface modification assisted method for bonding plastic substrates", M.-E. Vlachopoulou, A. Tserepi, P. Pavli, P. Argitis, M. Sanopoulou, K. Misiakos, J. Micromech. and Microeng. Vol. 19, art. no. 015007, 2009

Publications in International Conference Proceedings

1. "Memory structures based on the self-organization of Cu nanoparticles deposited by hot-wire CVD on polythiophene layers", P.Dimitrakis, G. Papadimitropoulos, L.Palilis, M.Vasilopoulou, P.Normand, P.Argitis, D.Davazoglou, *ECS Transactions,* Vol. 25, p. 1073-1079, *2009*

Conference Presentations

1. "Organic and Polymer Semiconductors – A New Class of Electronic Materials and Their Applications in Optoelectronic and Photonic Devices", L.C.Palilis, M.Vasilopoulou, D.G.Georgiadou, D.Davazoglou, P.Argitis, XXV Panhellenic Conference on Solid State Physics & Materials Science, Thessaloniki, Greece, 2009 (Invited)
2. "Polyoxometalate molecules in hybrid polymer-inorganic electronic and photonic devices", P.Argitis, L.C.Palilis, M.Vasilopoulou, A.M.Douvas, E.Kapetanakis, E.Makarona, D.Velessiotis, G.Papadimitropoulos, P.Normand, N.Glezos, International Polyoxometalate Symposium, Bremen, Germany, 2009, (Invited)
3. "Improved performance hybrid-polymer optoelectronic devices using polyoxotungstates and tungsten oxides as cathode interfacial layers", P.Argitis, M.Vasilopoulou, L.C.Palilis, G.Papadimitropoulos, D.G.Georgiadou, A.M.Douvas,N.A.Stathopoulos, K.Kotsovos, E.Ntantoumis, I.Kostis, A.Iliadis, N.Konofaos, D.Davazoglou, , 1st International Commission for Optics Topical Meeting on Emerging Trends and Novel Materials in Photonics, Delphi, Greece, 2009 (Invited)
4. "Memory structures based on the self-organization of Cu nanoparticles deposited by hot-wire CVD on polythiophene layers", P.Dimitrakis, M.Vasilopoulou, L.C.Palilis, G.Papadimitropoulos, P.Normand, P.Argitis, D.Davazoglou, 216th Electrochemical Society (ECS) Meeting, EuroCVD-17 and CVD XVII, Vienna, Austria, 2009.
5. "Simulations of the electric field in hybrid organic photovoltaics using a transmission line model – Comparison with experimental results", N.A.Stathopoulos, S.P.Savaidis, S.Yesayan, L.C.Palilis, M.Vasilopoulou, P.Argitis, 1st International Commission for Optics Topical Meeting on Emerging Trends and Novel Materials in Photonics, Delphi, Greece, 2009.

6. “Characterization of MoOx nanostructured thin films for application in organic photonic devices”, I.Kostis, M.Vasilopoulou, L.C.Palilis, D.G.Georgiadou, P.Argitis, N.A.Stathopoulos, A.Iliadis, N.Konofaos, D.Davazoglou, 1st International Commission for Optics Topical Meeting on Emerging Trends and Novel Materials in Photonics, Delphi, Greece, 2009.
7. “Inorganic metal oxides as cathode interfacial layers for polymer electronic devices”, M. Vasilopoulou, L. C. Palilis, D. G. Georgiadou, P. Argitis, I. Kostis, G. Papadimitropoulos, N. A. Stathopoulos, A. Iliadis, N. Konofaos and D. Davazoglou, 2nd International Symposium on Flexible Organic Electronics, 8-10 July 2009, Halkidiki, Greece.
8. “Photochemical Tuning of the Photo- and Electroluminescence Spectrum of a phosphorescent Pt complex inside PVK matrix” D. G. Georgiadou, L. Murphy, M. Vasilopoulou, L. C. Palilis, G. Pistolis, D. Dimotikali, J.A.G. Williams and P. Argitis, 2nd International Symposium on Flexible Organic Electronics, 8-10 July 2009, Halkidiki, Greece.
9. “Electromagnetic Simulation of Organic Photovoltaic Devices Using a Transmission Line Model” N.A.Stathopoulos, S.P.Savaidis, S.Yesayan, L.C.Palilis, M.Vasilopoulou and P.Argitis. 2nd International Symposium on Flexible Organic Electronics, 8-10 July 2009, Halkidiki, Greece,
10. “Integrated tool for the spreading, thermal treatment and in-situ process monitoring of thick photoresist films” D.Goustouridis, I.Raptis, E.Valamontes, M.Chatzichrisitidi Micro & Nano Engineering Conference (Gent, Belgium, 09/2009)
11. Proton Transport in Polyoxometalate-Embedded Polymeric Films: Towards the Development of Novel Proton Memory Devices, A. M. Douvas, E. Kapetanakis, P. Goupidenis, K. Beltsios, P. Normand, P. Argitis, *International Polyoxometalate Symposium, 28 July-1 August, 2009,* Bremen, Germany

Ph.D Thesis

1. “Simulation of electron beam lithography for structures with critical dimension <45nm”, Nikolaos Tsikrikas, School of Applied Mathematics & Physical Sciences, National Technical University of Athens

Patents

1. “Photoresists Prcessable Under Biocompatible Conditions” , P. Argitis, K. Misiakos, S. Kakabakos, A. Douvas, C.D. Diakoumakos, US Patent 7,608,389 B2, Oct 27, 2009

Project I. 2: LITHOGRAPHY AND PLASMA PROCESSES FOR ELECTRONICS, MICROFLUIDICS AND SURFACE NANO-ENGINEERING

Key researchers: E. Gogolides, A. Tserepi

Permanent Researcher: V. Constantoudis

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

Collaborating researchers: K. Misiakos, I. Raptis, P. Argitis

PhD candidates: M.Vlachopoulou, G.Boulousis, K.Tsougeni, A.Malainou, D.Kontziampasis, D.Drygiannakis

MSc Students: D. Papageorgiou, K. Ellinas, H. Christoyianni, A. Zeniou, A. Smyrnakis

Engineer: A. Zeniou

Marie Curie Fellows: Three Marie Curie International Fellows joined our project this year

External collaborators: A. Boudouvis and M. Kalantzopoulou (NTUA, Greece), N. Hadjichristidis and E. Iatrou (UoA, Greece), S.Garbis and A. Vlahou (IIBEAA, Greece), S. Kakabakos and P. Petrou (IRRP, NCSR-Demokritos, Greece), G. Kaltsas (TEI Athens Greece), K. Beltsios and I. Panagiotopoulos (U. Ioannina, Greece), E. Gizeli and K. Mitsakakis (Univ. of Crete-FORTH, Greece) C. Cardinaud (U. Nantes, France), I. Rangelow and B. Volland (Univ. Ilmenau Germany), M. Cooke and A. Goodyear (Oxford Instruments Plasma Technology, UK), S. Daniels (DCU, Ireland), A. Erdmann (Fraunhofer, Germany), S. Tedesco, E. Pargon (CEA-LETI, France), A. Speliotis (IMS, NCSR-D)

Objectives:

Lithography and plasma etching are used as enabling fabrication technologies not only for traditional sectors, such as electronics and MEMs, but also for microfluidics, microarrays and lab-on-a-chip. We aim in developing deterministic and stochastic microfabrication processes for a broad range of applications including life sciences using top-down fabrication as well as plasma directed assembly:

- For nano-electronics using e-beam and Double Exposure 193nm lithography, our work focuses on Line Edge Roughness (LER) prediction using molecular simulation. We have combined our plasma simulation and lithography expertise to predict the LER transfer during plasma etching (see section A).
- For microfluidics, we use Deep Plasma Etching to fabricate PDMS, PMMA, PEEK and Si microfluidic devices. We demonstrated “smart” microfluidics incorporating capillary pumping and hydrophobic valving using our “plasma toolbox” technology. We also fabricated on chip affinity chromatography columns using TiO2 as stationary phase for phosphopeptide separations (see section B).
- In addition using our plasma processes for stochastic nano-texturing of polymers, we demonstrated high density protein microarrays both on PDMS and on PMMA, with almost 10fold higher binding capacity of proteins, and 100fold increased sensitivity compared to flat substrates. We have also optimized novel self aligned processes for protein microarrays on prepatterned substrates (see section B).
- We unveiled the mechanisms of plasma nanotexturing and identified the plasma reactor wall as the major factor for nanotexturing. In addition we have devised two methods to produce dual scale roughness on surfaces for control of wetting properties from hydrophilic, to hydrophobic, to oleophobic (see section C). Finally, 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.
- In order to understand the phenomena of plasma nanotexturing and organization we are also doing Monte Carlo Simulation of plasma surface interactions (see section D).

Funding:

- EU NMP2 STREP Nanoplasma, Contract No 016424, 1/4/2006-31/3/2009
- GSRT, PENED 03 ED 202, 1/12/2005-30/06/2009
- MD3, IT 214948, 1/12/2007-30/11/2009
- SPAM, Marie Curie-ITN, Contract No 215723

MAIN RESULTS IN 2009:

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

Modeling the lithography process with stochastic principles enables the consideration of resist material and process effects variability on critical dimensions and line-edge or line-width roughness of printed features. These principles are applied for a resist system where polymer and photo-acid-generator (PAG) are blended, and for the same system with the PAG molecules bonded on the main polymer chain. Three-dimensional chain-like models of resist and PAG are considered and examples of their effect on critical dimensions and on resist edge roughness were quantified, and compared with experiments from the literature. Fig.1a shows the sample molecules and their digitization scheme in the appropriate format for input to the simulator, while Fig. 1b shows a 3D example of a dissolved resist film.

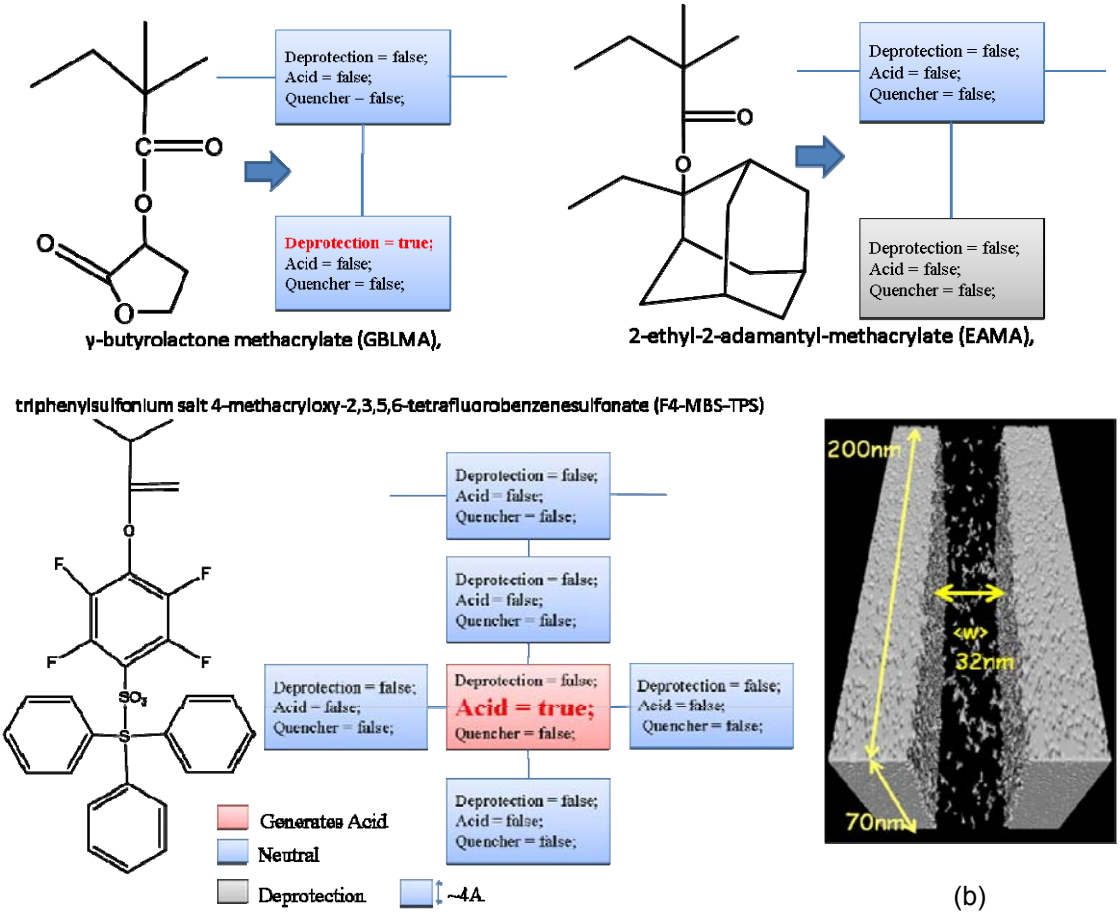


Fig. 1. *(a) Digitization schemes of the molecules used, which are modelled in the current work. (b) 3D simulation results of 32nm resist line of the resist film model. Average CD <w>=32nm.*

A2 LER transfer during plasma etching

V. Constantoudis, G. Kokkoris, E. Gogolides

The line edge roughness (LER) transfer during plasma etching is theoretically studied. After generating random fractal resist sidewalls with controlled roughness parameters, we model and contrast the nanoscale roughness phenomena for both resist and underlayer sidewalls in a two layer stack using two different plasma processes in three scenarios (Fig. 2a): a) Pattern transfer, b) resist trimming, and c) resist trimming followed by pattern transfer. In the pattern transfer process, etching is considered ion-driven and anisotropic. The protrusions of the rough, trimmed or non-trimmed, resist sidewall act as a shadowing mask for

the incident ions. It is found that shadowing of ions is enough to induce the, well-known by experiments, striations at the sidewalls of both the underlayer and the resist (see Fig. 2b). Pattern transfer induces a decrease of rms roughness but has little effect on the correlation length. In the trimming process, the evolution of the resist sidewall is modelled with an isotropic etching process not affecting the underlayer. The trimming process causes a decrease of the rms value of the resist sidewall and an increase of its correlation length and roughness exponent. In the case of trimming followed by pattern transfer, the striations of the underlayer widen with trimming time and pattern transfer further reduces all LER parameters. The effect of trimming on the rms roughness of the underlayer is important in the case of initially anisotropic resist sidewall.

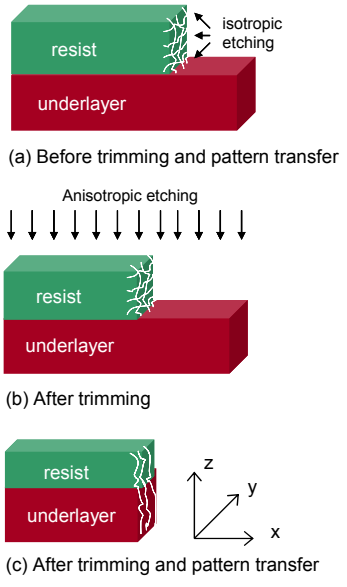


***Fig. 2a**. The setup of the model and processes. The stack a) after lithography and before (optional) trimming, b) after trimming (isotropic etching) and before pattern transfer, and c) after trimming and pattern transfer (anisotropic etching).*

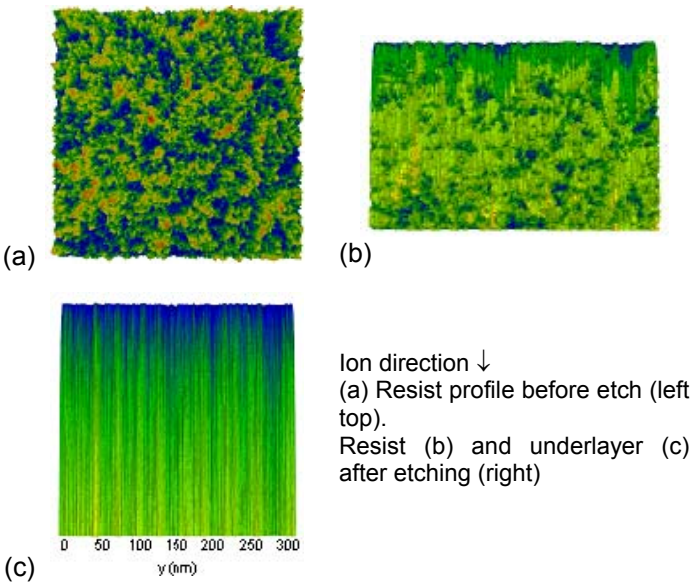


***Fig. 2b**. The morphology of the resist sidewall after litho (a), and etch (b), and the underlayer sidewall after etch (c)]. The roughness parameters of the initial resist sidewall before trimming (a) are $w_{R,initial}$=2nm, $\xi_{R,initial}$=5nm, and $\alpha_{R,initial}$=0.5. Notice the isotropic character of the initial resist surface as well as the anisotropy of the resist and underlayer after pattern transfer.*

A3 LER/LWR metrology: Updated version of our software LERDEMO (LERDEMO12)

V. Constantoudis, G.P. Patsis

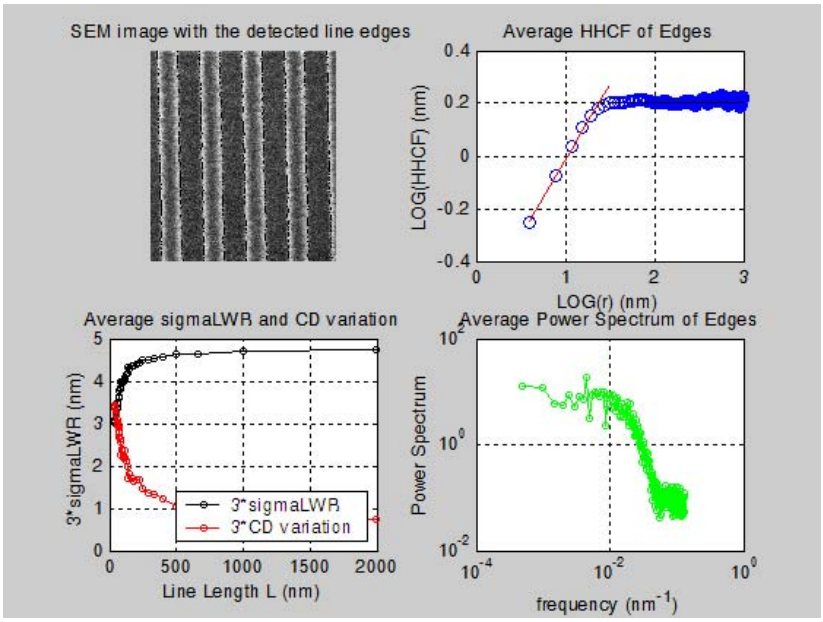


***Fig. 3.** The output sheet of the updated version LERDEMO12 with the diagram of the Power Spectrum.*

We proceeded to the circulation of a new version of the software LERDEMO developed in our group for LER/ LWR metrology from top-down SEM images taking into account the needs and requests of our client (IMEC, Belgium). The new features added in this version are the following:

1. Calculation of the c-factor, which quantifies the correlations between the edges of a line. This quantity is very useful in double patterning and directed self-assemply techniques, where correlations between the edge fluctuations of a line can be observed.
2. LER/LWR analysis and estimation of LER/LWR parameters for SEM images with anisotropic magnification in which the pixels are asymmetric (rectangular), i.e. x-edge pixel dimension is different than y-dimension.
3. Calculation and presentation in the output sheet of the Power Spectral Density (PSD) of the line widths variation and verification of the Parceval's theorem for the relation between LWR and the area under PSD.

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

B1 Plasma etching for "smart" PMMA and PEEK microfluidics with capillary filling and hydrophobic valving

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

We use plasmas for nanotexturing polymeric and silicon surfaces and for selective chemical modification. The combination of both nanotexturing and chemical modification leads to smart surfaces with nice properties such as self-cleaning. The integration of such surfaces in microchannels creates smart microfluidic devices with hydrophilic or hydrophobic patches, which may induce capillary pumping, or superhydrophobic passive valving. Figure 4 shows three types of surfaces in a microchannel with different wetting properties (see the water contact angle on the hydrophobic, superhydrophobic and super hydrophilic stripes in the microchannel inner surface).

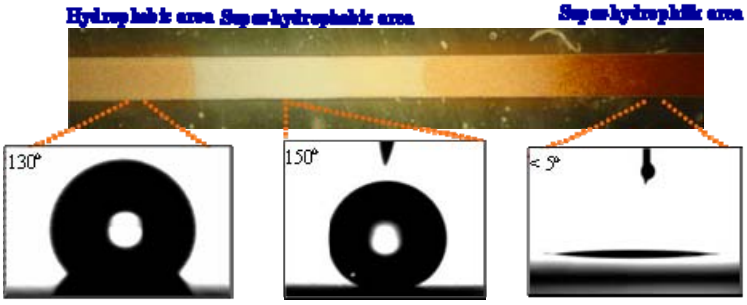


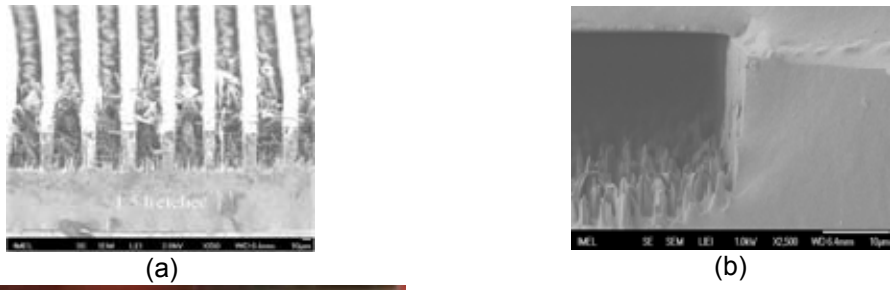
Fig. 4. *Three types of surfaces in a microchannel with different wetting properties (see the water contact angle on the hydrophobic, superhydrophobic and super hydrophilic stripes in the microchannel inner surface). The superhydrophobic stripe functions as a passive valve preventing capillary pumping of fluid from one superhydrophilic area to another.*

B2 Fabrication of PDMS microfluidics by plasma etching and plasma-based sealing of the etched structures

M.–E. Vlachopoulou, A. Tserepi

In the past 5 years, plasma etching of PDMS by SF_6 plasma has been explored as a route, alternative to replica molding (soft lithography), for the fabrication of microfluidic devices made of PDMS. We have optimized the process to achieve high etch rates and vertical profiles, necessary for rapid fabrication of deep structures in PDMS. Simultaneously, control of etched surface properties (chemistry and topography) has been achieved, through proper tuning of plasma processing conditions or using wet etching.

Using the optimized PDMS etching process, the fabrication of deep PDMS structures was demonstrated during last year. Al was used as etching mask, which, after plasma etching, was removed in BHF. PDMS microstructures as deep as 50 μm (and of aspect ratio as high as 6:1) were fabricated after 90 min etching [Fig. 5a]. The etched microchannels exhibit good anisotropy and significant nanoroughness on their bottom (almost equal to their depth). This roughness was severely reduced (4-fold) during the removal of the Al mask in BHF. Subsequently, the plasma-etched open microchannels were irreversibly bonded to a PDMS cover plate after O_2 plasma treatment of both surfaces, to result in a closed microchannel [Fig. 5b]. Finally, the sealed plasma etched PDMS microchannel was tested for leakage and found to withstand a maximum liquid flow of 100 μl/min [Fig.5c].



(a) (b)

(c)

Fig. 5. *SEM images of microchannels plasma-etched in PDMS, before (a) and after (b) being sealed with a smooth PDMS cover plate. (c) Optical image of two sealed PDMS microchannels with a red dye flowing through for testing hermetic sealing and maximum fluid flow.*

B3 Pressure drop in rough, plasma nanotextured, hydrophilic and superhydrophobic PMMA microfluidics

D. Papageorgiou, E. Gogolides

We introduce the idea of one-step randomly structured microchannels in wetting control; an easy way of producing super-hydrophobic walls inside microchannels. We use high-density plasma processing to nanotexture PMMA microchannels to achieve controllable friction properties. We studied the influence of the wall roughness and wetting properties on water flow, and demonstrate the effect of super-hydrophobic walls on the reduction on pressure drop compared to hydrophilic walls.

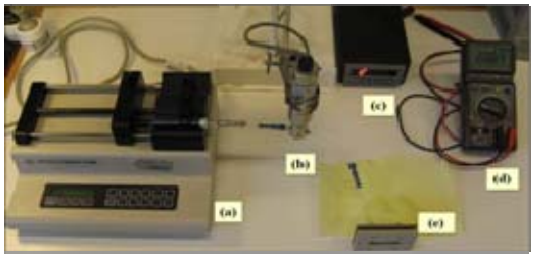
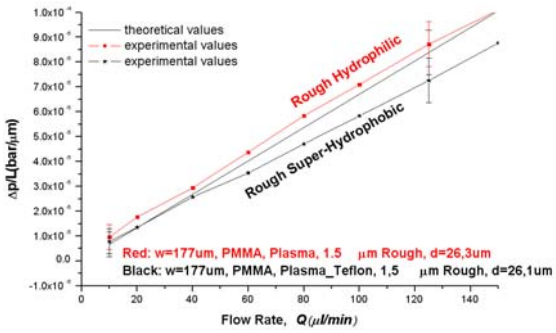


Fig. 6. *The pressure measurement setup: (a) syringe pump, (b) pressure transducer, (c) temperature sensor (d) voltage meter (e) chip holder.*



B4 Silicon and Plastic Microfluidics for chromatographic separations

K. Tsougeni, G. Boulousis, S. Garbis, A. Speliotis, E. Gogolides

The fabrication of a chromatographic column in a Silicon chip or in a PMMA chip to separate phosphopeptides with known sequence and a complex peptide mixture was undertaken. For the design of the micro-chromatographic column the geometry of parallel channels was chosen. The chips consisted of 32 parallel microchannels with common input and output and were fabricated by direct lithography and plasma etching on the Silicon and the polymeric substrates (see Fig. 7a, 7c), and sealed with lamination film. As a chip holder we selected the 'Lab-on-a-Chip Kit 4515' device from Micronit Microfluidics BV Company. The TiO_2-ZrO_2 or TiO_2 films were deposited by two methods (a) with rf magnetron sputtering, or (b) with liquid phase deposition, and were used as stationary phase in the affinity column. The method of rf magnetron sputtering can be applied only to Si substrates because high temperatures are needed in order to create crystalline forms. The method of liquid phase deposition is quick and easy to implement and can be easily applied to polymeric substrates without applying high temperatures in order to create crystalline forms (see Fig. 7d). The TiO_2-ZrO_2 or TiO_2 films had a crystalline structure as determined by X-Ray Diffraction (see Fig. 7b, 7e). Chromatographic experiments are under way.

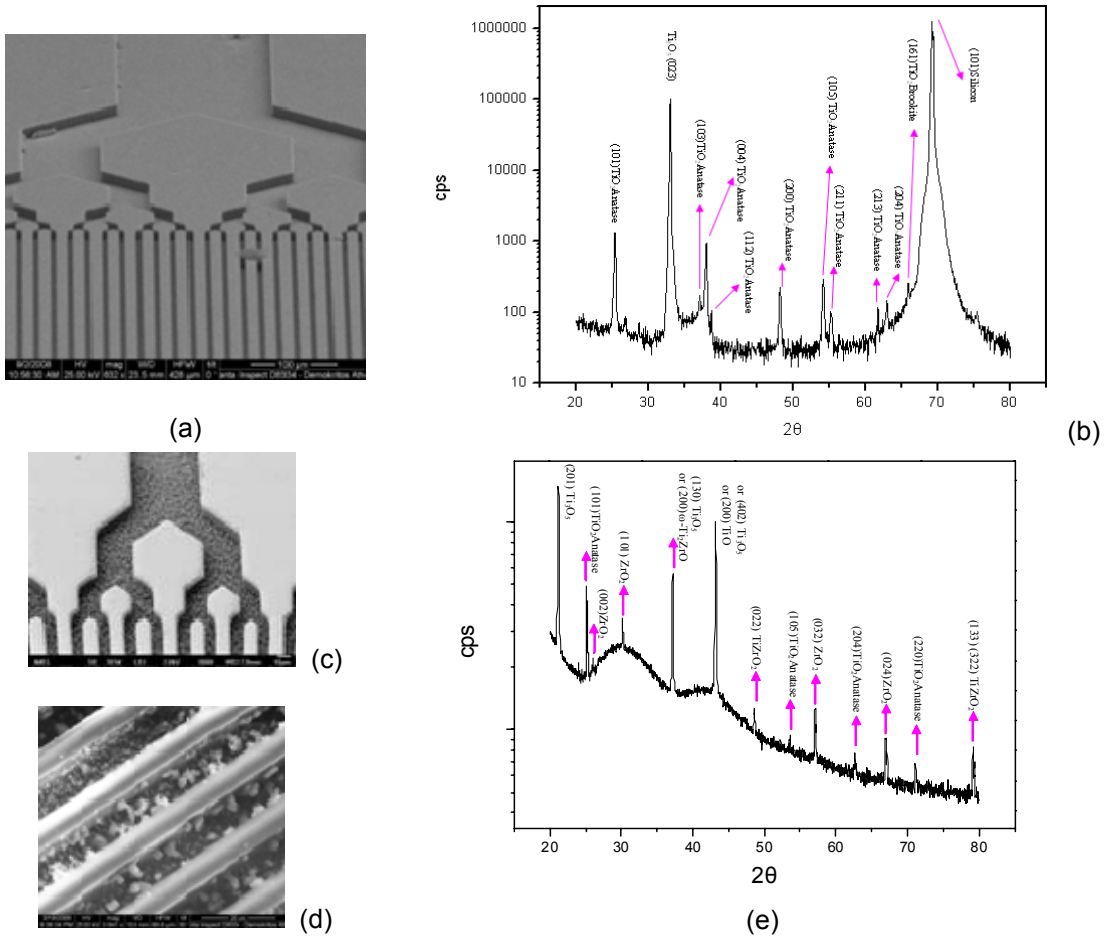


Fig. 7. *(a) SEM of 4 micron wide / 10micron deep / 3.8 cm long Si chromatography microchannels after plasma etching. (b) X-ray diffraction pattern of TiO_2 film sputtered on the Si substrate after heating at 600 ◦C (b). (c, d) SEMs of 7 micron wide / 10micron deep / 3.8 cm long PMMA chromatography microchannels in (c) after plasma etching, and in (d) after deposition of TiO_2-ZrO_2. (e) X-ray diffraction pattern of TiO_2-ZrO_2 film deposited on the PMMA plate.*

B5 Plasma nanotexturing of PMMA for microarrays

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

Poly(methyl methacrylate) (PMMA) substrates were nanotextured through treatment in Oxygen plasma to create substrates with increased surface area for protein microarray applications. Conditions of plasma treatment were found for maximum and uniform protein adsorption on these nanotextured PMMA surfaces. The protein binding was evaluated by studying the adsorption of two model proteins, namely biotinylated bovine serum albumin and rabbit gamma-globulins. The immobilization of these proteins onto the surfaces was quantitatively determined through reaction with fluorescently labelled binding molecules. It was found that adsorption of both proteins was increased up to 6-times with plasma treatment compared to untreated surfaces. The sensitivity of detection was improved by 2 orders of magnitude. Moreover, highly homogeneous protein spots were created on optimized plasma-nanostructured surfaces through deposition with an automated microarray spotter revealing the potential of plasma nanotextured surfaces as protein microarray substrates (see Fig. 8).

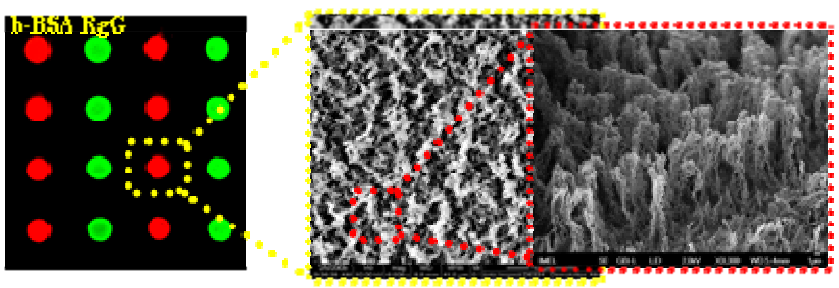


Fig. 8. *Fluorescence image of b-BSA and RgG spots microarray deposited by a nanoplotter on 20-min O_2 plasma treated PMMA surfaces. See the creation of a highly porous surface.*

B6 Protein patterning on plasma nanotextured PDMS-coated glass slides

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

Treatment of poly(dimethylsiloxane) (PDMS) surfaces with SF_6 plasma under anisotropic conditions results in the creation of nanotextured surfaces that considerably favor protein adsorption with respect to untreated surfaces, due to modified surface chemistry and increased surface area (see 2007 and 2008 Annual Reports). In order to employ such nanotextured surfaces as substrates for microarrays created and analysed using standard instrumentation, we deposited thin PDMS films on top of standard low-cost microscope glass slides. Spotting of model proteins (b-BSA and RgG) was performed by means of commercial instrumentation (spotter) using two types of spotting pins (solid and quill) and was evaluated, after reaction with fluorescently-labeled counterpart proteins, in terms of spot intensity, uniformity, size, and shape. Scannings of microarrays are shown in Fig. 9 created on untreated (a), 20-s (b) and 6-min (c) plasma treated PDMS-coated glass slides using b-BSA solutions with concentrations ranging from 25 to 500 μg/mL. It is seen that the 6-min plasma-treated PDMS-coated glass slides provide highly homogeneous spots (mean intra-spot variation 7.6%) with spot signal intensity 6-fold higher than that on untreated surfaces.

Aged 6-min plasma treated PDMS-glass slides were spotted with the quill pin (see Fig. 9d, 9e) and spots whose shape and size (~65 μm) depicted that of the spotting pin were obtained. This finding opens new capabilities towards the creation of dense arrays using the commercially available spotting tips in combination with the plasma nanotextured PDMS-coated slides.

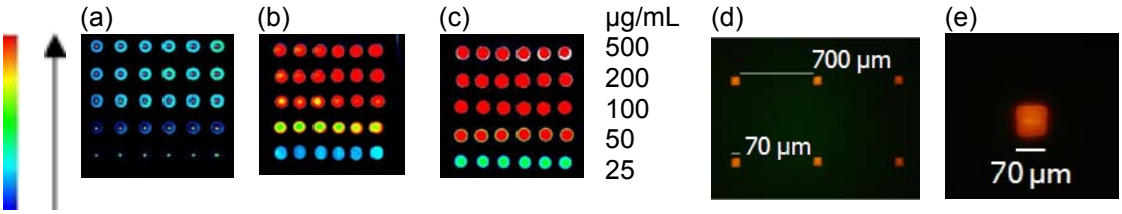


Fig. 9. *(a-c) Scannings of microarrays created on untreated (a) 20-s (b) and 6-min (c) treated PDMS-coated glass slides using b-BSA solutions with concentrations ranging from 25 to 500 μg/mL. (d-e) Epifluorescence microscope images of b-BSA (200 μg/mL) arrays printed with the quill pin on aged 6-min plasma-treated PDMS-coated glass slides*

B7 Method for fabrication of protein microarrays through plasma treatment of patterned substrates

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

Extending our previous method for fabrication of protein microarrays on Si, we evaluated SiO_2 and glass as substrates for selective and high density protein patterning. For such evaluation, immobilization of model proteins, biotinylated bovine serum albumin (b-BSA) and rabbit IgG (RgG), was performed on patterned plasma-treated substrates and detection through standard binding assays was demonstrated. SiO_2 spots were patterned on silicon oxide substrate through optical lithography with AZ5214 photoresist, and after optimized plasma (c-C_4F_8) treatment of the surface, selective protein adsorption on SiO_2 spots with respect to AZ5214 was achieved with spot to background fluorescence intensity ratio values as high as 100:1 (Fig. 10a). Spots were also defined on glass microscope slides with SU-8, a commercial photoresist capable of enhanced protein adsorption. After exposure of such patterned substrates in SF_6 plasmas, high selectivity (up to 60:1) in protein adsorption was achieved. Immobilization of two different proteins was demonstrated through fluorescence detection using a standard microarray scanner (Fig. 10b). Furthermore, the treatment was proven very stable in time (for ageing up to three months). To conclude, on both types of substrates examined and treated here, selective and enhanced protein adsorption is demonstrated, proving them suitable for dense protein microarray fabrication, useful for a wide range of bioanalytical applications.

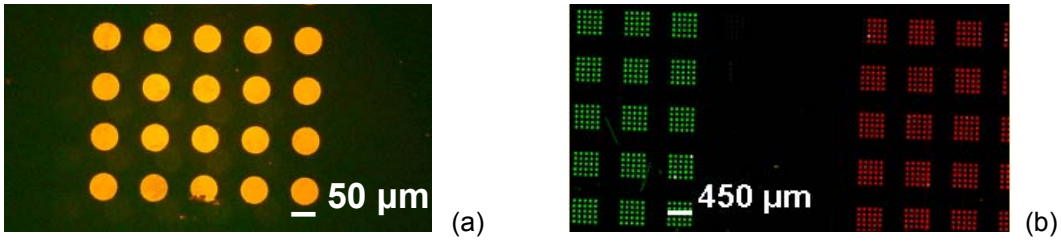


Fig. 10. *(a) b-BSA immobilization on SiO_2 spots (50μm) defined through AZ photolithography, after c-C_4F_8 plasma selective modification of the substrate (b) Immobilization of two proteins, b-BSA (red) and RgG (green), on SU8 spots (50μm) defined through lithography on glass substrates, after SF_6 plasma treatment of the substrates*

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

C1 Mechanisms of polymer nanotexturing in plasmas

K. Tsougeni, A. Tserepi, E. Gogolides

Plasma processing is used to fabricate super hydrophilic or super hydrophobic polymeric surfaces by means of O_2 plasma etching of two organic polymers namely Poly (methyl methacrylate) (PMMA) and Poly (ether ether ketone) (PEEK); a C_4F_8 plasma deposition follows O_2 plasma etching, if surface hydrophobization is desired. We demonstrate high aspect ratio pillars with height ranging from 16 nm to several microns depending on the processing time, and contact angle (CA) close to 0^o after O_2-plasma treatment or CA of 153^o (with CA hysteresis lower than 5^o after fluorocarbon deposition) (see Fig. 11b). Super hydrophobic surfaces are robust and stable in time; in addition ageing of super hydrophilic surfaces is significantly retarded due to the beneficial effect of the nanotextured topography (see Fig. 11a). The mechanisms responsible for the plasma-induced PMMA and PEEK surface nanotexturing are unveiled through intelligent experiments involving intentional modification of the reactor wall material and X-ray Photoelectron Spectroscopy, which is also used to study the surface chemical modification in the plasma. We prove that control of plasma nanotexture can be achieved by carefully choosing the reactor wall material.

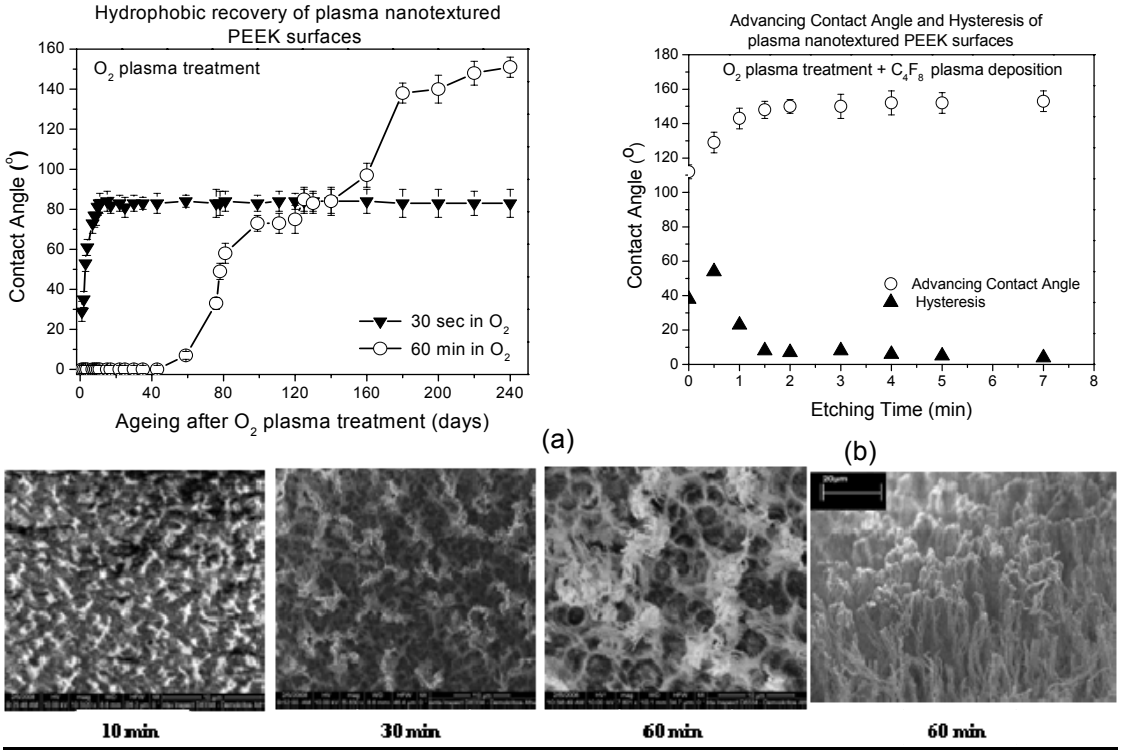


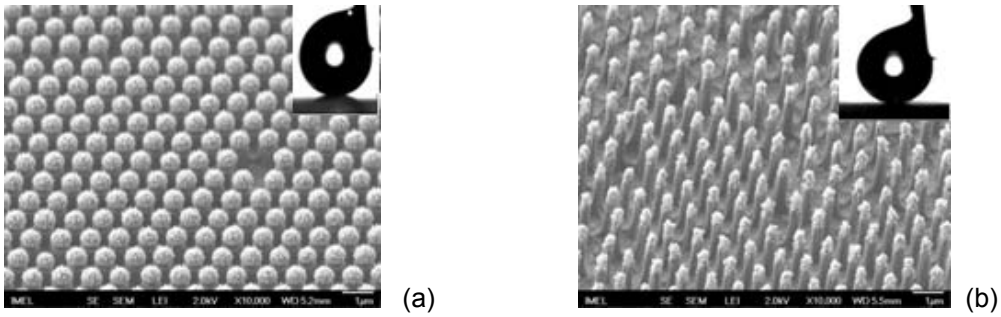
Fig. 11. *(a) Hydrophobic recovery of PEEK plates after nano-structuring in O_2 plasmas for 30 s (▼), and 60 min (○). (b) Advancing CA and hysteresis of Teflon-like coated PEEK plates versus oxygen plasma treatment time. Conditions: oxygen plasma, 1900 W, 0.75 Pa, 100 sccm, -100 V, -20°C.*
(c) Topography of PMMA after etching for 10, 30, and 60 min in O2 plasma

C2 Dual scale Nanopatterning of polymeric surfaces using colloidal lithography and plasma etching: Applications in wetting control

K. Ellinas, E. Gogolides

We have established a method to produce stable superhydrophobic and simultaneously oleophobic surfaces on polymer substrates using colloidal lithography to assemble the microparticles, followed by plasma etching to transfer the pattern on the PMMA substrate. These surfaces, that exhibit special wetting behavior, have attracted a lot of interest due to their potential practical applications e.g. self cleaning. The two key factors to achieve superhydrophobicity are: the use of coating materials of low surface energy (chemical term) and the creation of roughness on the surface (physical term). To have both mechanically robust, as well as energy favorable superhydrophobic states dual scale roughness is preferred. Oxygen based plasma is applied to etch the colloidal particles (micro scale features) and create nanoscale surface roughness (nano-texturing). Different shape and size can be fabricated according to the voltage bias and etching time, pillar size can be 10% of its initial diameter which makes the method really flexible.

In Fig. 12 two different surfaces fabricated, using different voltage bias and etching time, are shown. The maximum water contact angle is 165^0, while for pump oil the maximum contact angle is 120^0.



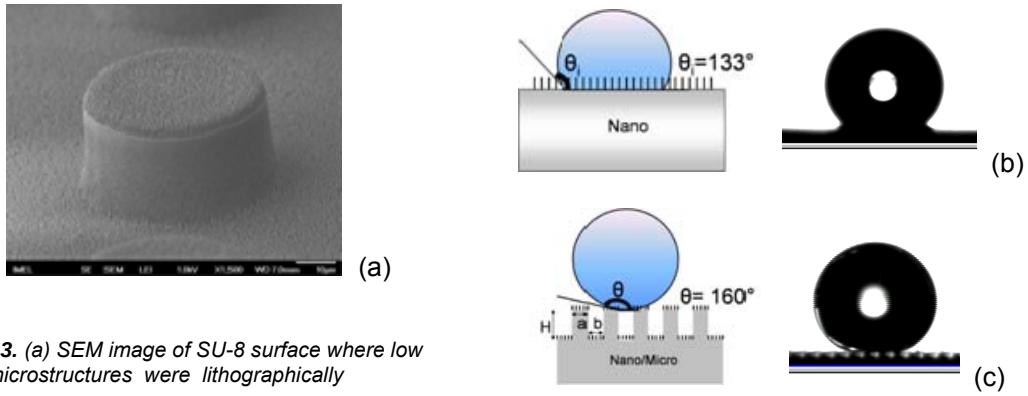
(a) (b)

Fig. 12. *(a) 700nm diameter pillars 1min etching, (b) 500nm diameter pillars 2 min etching. Dual scale topography is created in both surfaces. On the top of each picture the water contact angle is shown.*

C3 Dual scale patterning of SU-8 surfaces with robust superhydrophobicity using photolithography and plasma etching

J. Marquez-Velasco, M.-E. Vlachopoulou, A. Tserepi

Superhydrophobicity was demonstrated on SU-8 surfaces where hierarchical (dual scale) roughness was created (Fig. 13a), by combining micro- and nano-sized structures formed by means of lithography and plasma etching, respectively. It was found that plasma nanotexturing of the micropatterned SU-8 surfaces was essential in enhancing surface hydrophobicity (see Fig. 13c), after deposition of a Teflon-like film, and rendering the surfaces water repellent (i.e. minimizing contact angle hysteresis). The proposed method produced mechanically stable and robust superhydrophobic surfaces on SU-8, even with low aspect ratio microstructuring (see Fig. 13a, AR <1).



(a) (b) (c)

Fig. 13. *(a) SEM image of SU-8 surface where low AR microstructures were lithographically defined and O_2 plasma-nanotextured to result in dual-scale topography. Images of water droplets on (b) 30 s O_2 plasma nanotextured and (c) micro/nanotextured SU-8 surfaces. A superhydrophobic surface is demonstrated in (c) with water contact angle of 160º and low hysteresis (10 º).*

C4 Nanodot formation with plasma etching: Towards plasma directed assembly

N. Vourdas, D. Kontziampasis, E. Gogolides

Fabrication of periodic nanodot or nanocolumn arrays on surfaces is performed by top-down lithographic procedures or bottom-up self-assembly methods, which both make use of plasma etching to transfer the periodic pattern. Could plasma etching alone act as an assembly-organization method to create the pattern and then transfer it to the substrate? We proposed a lithography-less, plasma directed organization / assembly method to produce nanodots, and demonstrated some control over their order and dimensions. An ion-enhanced etching mechanism with simultaneous deposition of etch inhibitors is proposed to be responsible for the phenomenon. We envision applications in several diverse fields requiring inexpensive nanopatterning of moderate periodicity (order) on any substrate, or creation of Si masters for nano-imprinting, or creation of high surface-area. Our method opens up a road for fast, accessible and affordable nanopattern formation and also proves that plasma etching is not only a valuable top-down fabrication process, but also a bottom-up process for directed assembly / organization.

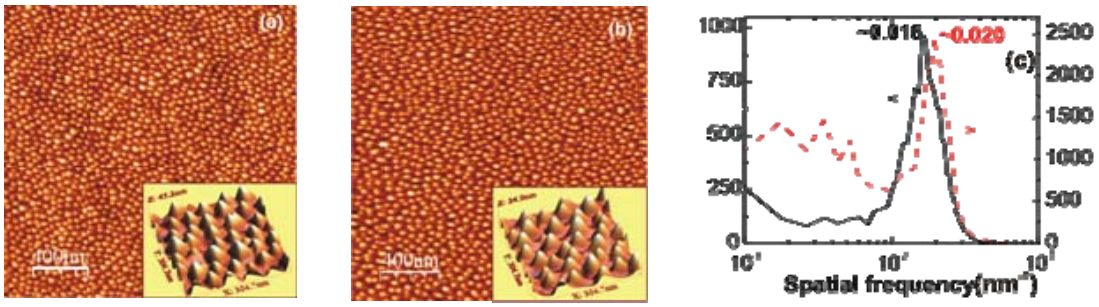


Fig. 14. *(a) 2x2 um^2 (512x512 points) AFM image (Nanoscope III AFM) of PMMA plate surface after 2 min Oxygen plasma treatment. RMS is ~9.0 nm. A 3D zoom view of a part of the image is embedded. (b) 2x2 um^2 (512x512 points) AFM image (CP-II AFM from Veeco) of PMMA film surface after 46 s Oxygen plasma etching down to Silicon substrate. RMS is ~5.2 nm. A 3D zoomed view of a part of the image is embedded. (c) Circularly averaged PSD of the AFM images of figures (a) and (b). The sharp peaks are indicative of the order of the nanodots formed. The peak at 0.020 corresponds to Fig. 14a and to a period of ~50 nm (ω=2). The peak at 0.016 corresponds to Fig. 14b and to a period of ~62 nm (ω=1.8).*

D. Plasma processes simulation

D1 Simulation of plasma directed assembly of nanostructures

G. Kokkoris, V. Constantoudis, D. Kontziambasis, E. Gogolides

In order to understand the mechanism of order formation and during plasma etching we made a hypothesis that etching with simultaneous limited co-deposition can induce order on an etched surface. We implement this idea to a (2+1)D stochastic simulator. The etched film is represented by cells; a schematic of a cellular topography in (1+1)D is shown in Fig. 15c.

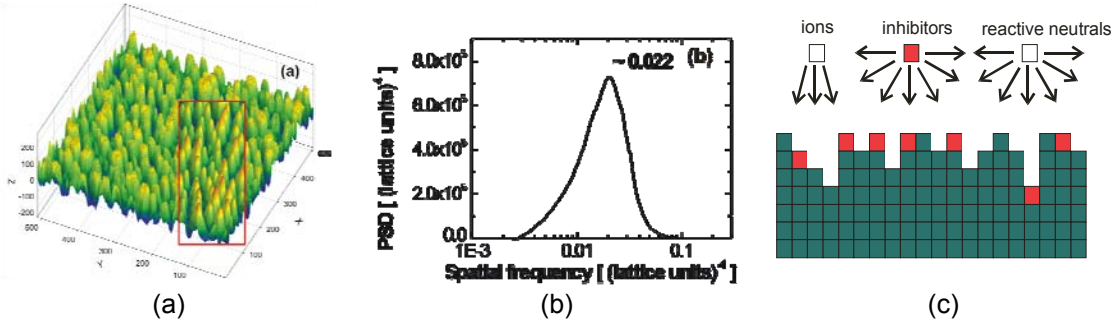


Fig. 15. *(a) 3D view of a surface produced by the Monte Carlo simulator (3600 monolayers have been etched and the fraction of depositing particles is 5%). Note the similarity with part of the surface in Fig. 15a, shown embedded. b) Average PSD of 10 simulated surfaces after removal of 3600 monolayers. The period is ~45 lattice units and the order parameter ω is ~1. (c) Schematic of the stochastic simulation framework for surface topography evolution in (1+1)D during plasma etching. The particles arriving on the surface can be ions, reactive neutral species, or depositing neutral species (etch inhibitors).*

The simulation results showed that the combination of non-reflecting ions, arriving at the surface at almost normal incidence (standard deviation from normal < 5^{o}) and causing ion-enhanced etching, with a small amount (<10%) of depositing particles (etch inhibitors), arriving at the surface isotropically, was found to induce periodicity on the etched surface. Fig. 15a shows a simulated surface in a 3D view which reveals a similarity with part of the experimental surface of Fig. 14a, shown embedded. Fig. 15b shows the circularly averaged PSD of the simulated surface, where the periodicity of the surface is manifested in the peak.

D2 LER transfer during plasma etching

The work for plasma etching transfer of LER is described in lithography, see A2 above.

D3 Kinetic Monte Carlo simulation of polymer sputtering using a random walk representation of the polymer chains

A. Anastasopoulos, V. Constantoudis, G. Patsis, E. Gogolides

Aiming in understanding the development and evolution of surface roughness on polymers during ion-enhanced plasma etching or sputtering, we use a simulation code initially developed for dissolution of polymer chains during the development process of photoresists. Our basic idea is that etching is caused from plasma ions breaking polymer chains and separating them in two pieces: If the number of monomers of one piece is smaller than a threshold then this piece is removed. The simulation is two dimensional. The first result of our simulation is that this etch-mechanism results in slow increasing of roughness with the time: RMS roughness increases with a power law with time having an exponent of 0.2 – 0.3; a power law is also valid for correlation length increase with etching time, while roughness exponent stays constant. Examination of the exponents of power laws, led us to the conclusion that roughness follows the Family-Visczek scaling hypothesis.

RESEARCH RESULTS in 2009:

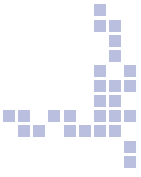
Publications in International Journals and Reviews

Microfluidics – Bioapplications

1. “Evaluation of a microfluidic sensor fabricated on polymeric material”, Petropoulos, A., Kontakis, K., Kaltsas, G., Gogolides, E., (2009) DTIP of MEMS and MOEMS - Symposium on Design, Test, Integration and Packaging of MEMS/MOEMS, art. no. 4919510, pp. 398-401.
2. “A flexible capacitive device for pressure and tactile sensing”, Petropoulos, A., Kaltsas, G., Goustouridis, D., Gogolides, E., (2009) Procedia Chemistry, 1 (1), pp. 867-870.
3. “High-density protein patterning through selective plasma-induced fluorocarbon deposition on Si substrates”, Bayiati, P., Malainou, A., Matrozos, E., Tserepi, A., Petrou, P.S., Kakabakos, S.E., Gogolides, E., (2009) Biosensors and Bioelectronics, 24 (10), pp. 2979-2984.
4. “A novel microfluidic integration technology for PCB-based devices: Application to microflow sensing”, Kontakis, K., Petropoulos, A., Kaltsas, G., Speliotis, T., Gogolides, E., (2009) Microelectronic Engineering, 86 (4-6), pp. 1382-1384.
5. “SAW device integrated with microfluidics for array-type biosensing”, Mitsakakis, K., Tserepi, A., Gizeli, E., (2009) Microelectronic Engineering, 86 (4-6), pp. 1416-1418.
6. “A low temperature surface modification assisted method for bonding plastic substrates”, Vlachopoulou, M.-E., Tserepi, A., Pavli, P., Argitis, P., Sanopoulou, M., Misiakos, K., (2009) Journal of Micromechanics and Microengineering, 19 (1), art. no. 015007.

Plasma Nanostructuring, Plasma Processing, Plasma Simulation

7. “Mechanisms of oxygen plasma nanotexturing of organic polymer surfaces: From stable super hydrophilic to super hydrophobic surfaces”, Tsougeni, K., Vourdas, N., Tserepi, A., Gogolides, E., Cardinaud, C., (2009) Langmuir, 25 (19), pp. 11748-11759.
8. “Effect of surface nanostructuring of PDMS on wetting properties, hydrophobic recovery and protein adsorption”, Vlachopoulou, M.-E., Petrou, P.S., Kakabakos, S.E., Tserepi, A., Beltsios, K., Gogolides, E., (2009) Microelectronic Engineering, 86 (4-6), pp. 1321-1324.
9. “Nano-texturing of poly(methyl methacrylate) polymer using plasma processes and applications in wetting control and protein adsorption”, Tsougeni, K., Petrou, P.S., Tserepi, A., Kakabakos, S.E., Gogolides, E., (2009) Microelectronic Engineering, 86 (4-6), pp. 1424-1427.



10. “Nano-textured polymer surfaces with controlled wetting and optical properties using plasma processing”, Vourdas, N.E., Vlachopoulou, M.-E., Tserepi, A., Gogolides, E., (2009) International Journal of Nanotechnology, 6 (1-2), pp. 196-207.
11. “A global model for SF6 plasmas coupling reaction kinetics in the gas phase and on the surface of the reactor walls”, Kokkoris, G., Panagiotopoulos, A., Goodyear, A., Cooke, M., Gogolides, E., (2009) Journal of Physics D: Applied Physics, 42 (5), art. no. 055209.
12. “Modeling of roughness evolution during the etching of inhomogeneous films: Material-induced anomalous scaling”, Constantoudis, V., Christoyianni, H., Zakka, E., Gogolides, E., (2009) Physical Review E - Statistical, Nonlinear, and Soft Matter Physics, 79 (4), art. no. 041604.
13. “Integrated plasma processing simulation framework, linking tool scale plasma models with 2D feature scale etch simulator”, Hauguth, M., Volland, B.E., Ishchuk, V., Dressler, D., Danz, T., Rangelow, I.W., Kokkoris, G., Gogolides, E., Goodyear, A., Cooke, M., (2009) Microelectronic Engineering, 86 (4-6), pp. 976-978.

Lithography and Line Edge Roughness

14. “Nanoscale roughness effects at the interface of lithography and plasma etching: Modeling of line-edge-roughness transfer during plasma etching”, Kokkoris, G., Constantoudis, V., Gogolides, E., (2009) IEEE Transactions on Plasma Science, 37 (9 SPEC. ISS. PART 1), pp. 1705-1714.
15. “Noise-free estimation of spatial Line Edge/Width Roughness parameters”, Constantoudis, V., Gogolides, E., (2009) Proceedings of SPIE - The International Society for Optical Engineering, 7272, art. no. 72724B.
16. “Line Edge Roughness transfer during plasma etching: Modeling approaches and comparison with experimental results”, Constantoudis, V., Kokkoris, G., Xydi, P., Gogolides, E., Pargon, E., Martin, M., (2009) Proceedings of SPIE - The International Society for Optical Engineering, 7273, art. no. 72732J.
17. “Line-edge-roughness transfer during plasma etching: modeling approaches and comparison with experimental results”, V. Constantoudis, G. Kokkoris, P. Xydi, E. Gogolides, E. Pargon, M. Martin, J. Micro/Nanolith. MEMS MOEMS 8, 043004 (2009)
18. “Modeling of line edge roughness transfer during plasma etching”, Constantoudis, V., Kokkoris, G., Xydi, P., Patsis, G.P., Gogolides, E., (2009) Microelectronic Engineering, 86 (4-6), pp. 968-970.
19. “Advanced lithography models for strict process control in the 32 nm technology node”, Patsis, G.P., Drygiannakis, D., Raptis, I., Gogolides, E., Erdmann, A., (2009) Microelectronic Engineering, 86 (4-6), pp. 513-516.
20. “Materials for lithography in the nanoscale”, Argitis, P., Niakoula, D., Douvas, A.M., Gogolides, E., Raptis, I., Vidali, V.P., Couladouros, E.A., (2009) International Journal of Nanotechnology, 6 (1-2), pp. 71-87.

Other Collaborative Work

21. “Cycle-averaged phase-space states for the harmonic and the Morse oscillators, and the corresponding uncertainty relations”, Nicolaides, C.A., Constantoudis, V., (2009) European Journal of Physics, 30 (6), pp. 1277-1294.
22. “Magnetic properties of Co films and Co/Pt multilayers deposited on PDMS nanostructures”, Markou, A., Beltsios, K.G., Panagiotopoulos, I., Vlachopoulou, M.-E., Tserepi, A., Alexandrakis, V., Bakas, T., Dimopoulos, T., (2009) Journal of Magnetism and Magnetic Materials, 321 (17), pp. 2582-2586.

International Conference Presentations

Microfluidics – Bioapplications

1. “Oxygen Plasma Nanotexturing of PS surfaces for Fabrication of DNA Arrays” (poster), K. Tsougeni, P. Petrou, A. Tserepi, S. Kakabakos, E. Gogolides, NanoBio Europe 2009, 16-18 June, Grenoble, France (2009)
2. “Plasma-Induced Nanotexturing of Polymers for the Fabrication of Protein and DNA Arrays” (oral), K. Tsougeni, M.E. Vlachopoulou, P. Petrou, S. Kakabakos, A. Tserepi, E. Gogolides, International Symposium on Plasma Chemistry - ISPC 19, 26-31 July 2009, Bochum, Germany (2009)
3. “Plasma Etching Technology for Fabrication and Surface Modification of Plastic Microfluidic Devices” (poster), M.-E. Vlachopoulou, K. Tsougeni, K. Kontakis, N.Vourdas, A. Tserepi, E. Gogolides, *International Symposium on Plasma Chemistry - ISPC 19, 26-31 July 2009, Bochum, Germany (2009)*
4. “Protein patterning on plasma-modified PDMS and PMMA surfaces for bioanalytical applications” (poster), M-E. Vlachopoulou, K. Tsougeni, K. Tserepi, E. Gogolides, P. Petrou, S. Kakabakos, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)
5. “Pressure drop on water flow in PMMA microfluidics with controllable wetting characteristics” (poster), D. Papageorgiou, K. Tsougeni, A. Tserepi, E. Gogolides, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)
6. “Micro-fabricated TiO2-ZrO2 Affinity Chromatography Micro-Column on PMMA for Phosphopeptide Analysis”, Tsougeni K, Boulousis G,Roumeliotis T, Zorpas K, SpeliotisT, Botsialas A, Raptis I, Tserepi A,Garbis SD, Gogolides E, IMA 2009, 4 - 8 October 2009, Athens, Greece (2009)

7. "Protein Arrays on SF6 Plasma Nanostructured PDMS Surfaces", Vlachopoulou M-E, Tserepi A, Gogolides E, Petrou P, Kakabakos S, IMA 2009, 4 - 8 October 2009, Athens, Greece (2009)
8. "Protein Patterning Through Selective Plasma–Induced Modification of Glass Substrates" (oral), A. Malainou, A. Tserepi, P.S. Petrou, S.E. Kakabakos, E. Gogolides, IMA 2009, 4 - 8 October 2009, Athens, Greece (2009)

Plasma Nanostructuring, Plasma Processing, Plasma Simulation

9. "A multi-scale computational framework for plasma etching processes: Application to the investigation of surface kinetics on the reactor walls" (oral), G. Kokkoris, A. Goodyear, M. Cooke, E. Gogolides, PESM-Plasma Etch and Strip in Microelectronics 2nd International Workshop, 26-27 February 2009, Leuven, Belgium (2009)
10. "Plasma-Directed, Organized Nanodot Formation on Polymeric Surfaces" (oral), D. Kontziampasis, N. Vourdas, G. Boulousis, V. Constadoudis, A. Tserepi, E. Gogolides, NSTI Nanotech 2009, 3-7 May 2009, Houston, Texas (2009)
11. "Plasma-Directed Organized Nanodot Formation on Polymeric Surfaces" (poster), D. Kontziampasis, E. Gogolides, V. Constantoudis, N. Vourdas, M. Cooke, A. Goodyear, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)
12. "Stable superhydrophobic surfaces induced by dual-scale topography on SU-8" (poster), M-E. Vlachopoulou, J.M. Velasco, A. Tserepi, E. Gogolides, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)
13. "Plasma etched nano-pillar arrays on polymer surfaces using colloidal lithography: Dual scale robust super hydrophobic and super hydrophilic wetting behaviour" (poster), K. Ellinas, A. Tserepi, E. Gogolides, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)

Lithography and Line Edge Roughness

14. "Modeling of Line Edge Roughness Transfer during Plasma Etching" (oral), G. Kokkoris, V. Constantoudis, P. Xydi, G. P. Patsis, E.Gogolides, PESM-Plasma Etch and Strip in Microelectronics 2nd International Workshop, 26-27 February 2009, Leuven, Belgium (2009)
15. "The role of gate width in transistor performance: Effects of sidewall roughness" (poster), V.Constantoudis, G.P.Patsis, E.Gogolides, ESSDERC 2009, 14-18 September 2009, Athens, Greece
16. "Detailed Resist Film Modelling in Stochastic Lithography Simulation for Line-Edge Roughness Quantification" (oral), G. Patsis, D. Drygiannakis, E. Gogolides, I. Raptis, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)
17. "Simulation of Shot Noise effect on CD and LER of Electron Beam Lithography in 32nm Designs" (poster), G. Patsis, N. Tsikrikas, D. Drygiannakis, E. Gogolides, I. Raptis, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)

Greek Conference Presentation

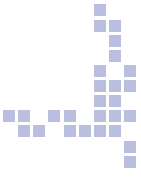
1. "The role of gate width in transistor performance: Effects of gate sidewall roughness" (oral), V.Constantoudis, G.P. Patsis, E. Gogolides, XXV Panhellenic Conference: Solid State Physics and Materials Science, 20-23 September 2009, Thessaloniki, Greece
2. "Plasma-Directed Organized Nanodot Formation on Polymeric Surface" (oral), D. Kontziampasis, N. Vourdas, V. Constantoudis, E. Gogolides, Nanosciences & Nanotechnologies 2009, 13-15 July 2009, Thessaloniki, Greece
3. "Emergence of periodic structures on treated films at nanoscale: Mechanism and modeling demonstration" (poster), V. Constantoudis, H. Christoyianni, E. Gogolides, Nanosciences & Nanotechnologies 2009, 13-15 July 2009, Thessaloniki, Greece

Ph.D Theses

1. "Roughness formation during etching of Silicon and Polymers, and its use in microfabricated chromatography columns", George Boulousis, Chemical Engineer, MSc, PhD Thesis supervisors: E. Gogolides, A. Boudouvis, National Technical University of Athens, Dept of Chemical Engineering.
2. "Study of physicochemical properties of thin polymer films and their effect in lithography", Dimitrios Dygiannakis, School of Chemical Engineering, National Technical University of Athens

MSc Theses

1. "Fabrication of polymeric microfluidic channels with nanostructured walls: Characterization of the nanostructure and measurements of the pressure drop on water flow",Dimitrios Papageorgiou, Physicist, MSc, Thesis Advisor-Supervisor: Evangelos Gogolides, Masters Programme in Microelectronics, National and Kapodistrian University of Athens, Department of Informatics and Telecommunications
2. "Dual scale superhydrophilic, superhydrophobic, and oleophobic surfaces fabricated by colloidal lithography and plasma etching",Kosmas Ellinas, Physicist, MSc,Thesis Advisor-Supervisor: Evangelos Gogolides, Masters Programme in Microelectronics, National and Kapodistrian University of Athens, Department of Informatics and Telecommunications



3. "Monte Carlo simulation of ion enhanced etching of polymers using a random walk representation of the polymer chains", Antreas Anastasopoulos, Physicist, MSc Thesis Advisor-Supervisor: Evangelos Gogolides, Masters Programme in Microelectronics, National and Kapodistrian University of Athens, Department of Informatics and Telecommunications

Practical Training

1. "Fabrication of dual scale roughness on SU-8 for stable superhydrophobic surfaces", Jose Marquez-Velasco, Universitat de Sevilla, Spain, Research Supervisor: Angeliki Tserepi, Thesis supported by the "Erasmus" program

Seminars

1. "Microfluidic devices and systems for biochemical analysis" (invited), E. Gogolides, Workshop Micro&Nano 2009, November 6-7, 2009
2. "Patterning and nanotexturing of substrates at the micro- and nano- scale for the fabrication of protein microarrays", Workshop "Evaluation of results of Demoereyna 2005 Program", A. Tserepi, December 1, 2009
3. "Micro-nano fabrication meets chemical engineering: nanostructuring of polymers with plasmas" (invited), E. Gogolides, FORTH/ICE-HT Patras, Greece
4. "Micro and nano fabrication meets chemistry: Microfluidics and lab-on-chip systems for chemical analysis and physicochemical processes" (invited), E. Gogolides, Chemistry Department, UOA, December 2009

Schools and Courses

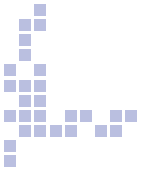
1. During the advanced summer school "Methods in Micro-Nano Technology and Nanobiotechnology", June 22-26, 2009 we tought the following labs: "Fabrication of microfluidic devices on plastic substrates by Soft lithography", A. Tserepi, M.-E. Vlachopoulou and "Fabrication of plastic microfluidic devices by Lithography and deep polymer plasma etching techniques, E. Gogolides, K. Tsougeni, See video on Nano2Life Site: http://n2lvip.tau.ac.il/
2. "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
3. "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
4. "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
5. "Micro & Nano Fabrication", S. Logothetidis, A. Nassiopoulou, E. Gogolides, Postgraduate Program on Nanosciences & Nanotechnologies of the Aristotle University of Thessaloniki
6. "Fabrication of integrated circuits: Laboratory courses", E. Tsoi, D. Kouvatsos, A. Tserepi, Postgraduate Program on Microelectronics of the National and Kapodistrian University of Athens
7. "Computational methods", P. Trohidou, G. Kokkoris, Postgraduate Program on Microelectronics of the National and Kapodistrian University of Athens

Organization of Schools

1. 5th Summer School "Methods in Micro-Nano Technology and Nanobiotechnology", an activity of NaBiA, 22-26 June 2009,http://imel.demokritos.gr/SummerSchool2009/index.htm

Patents

1. "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. Greek patent Application number: 20080100404,13.06.2008, PCT Application number: PCT/GR2009/000039, International Filing Date: 15.06.2009, Publication number: WO/2009/150479, Publication date: 17.12.2009
2. "Method for making a micro-array", A. Tserepi, E. Gogolides, P. Petrou, S. Kakambakos, P. Bayiati, E. Matrozos, PCT Application number: PCT/GR2008/000048, International Filing Date: 20.06.2008, Greek patent Application number: 20070100394, 20.06.2007, Publication number: WO/2008/155585, Publication date: 24.12.2008, US Patent & Trademark Office, App. No. 12/665817 Filing date: 21-12-2009



Project: I. 3: FRONT-END PROCESSES FOR MICRO- AND NANODEVICES

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)

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

Funding:

- GSRT-PENED-03ED496, 28/12/2005-30/6/2009

MAIN RESULTS IN 2009

A. 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)

The formation of a reliable dielectric layer on strain-Si substrates is a key point in achieving enhanced device performance, taking advantage of the beneficial effect of strain to carrier mobility. Therefore, the study of the oxidation of strained Silicon is a necessary step in understanding the physical phenomena involved in dielectric formation and electrical performance of the MOS device, as well as the limitations in s-Si processing. This is the main goal of this work. Additionally, the well-established method of nitridation of SiO_2, was extended to strained-Silicon substrates in order to address a number of phenomena related with reliability problems when performing standard oxidation on s-Si.

A systematic study has been carried out on the oxide formation of s-Si at various oxidation and oxynitridation conditions. Nitrogen-enriched thermal oxides fabricated by oxynitridation in N_2O and oxidation of N_2^+ implanted s-Si have been examined. Additionally, thermal oxides were fabricated by conventional dry oxidation. A wide range of process temperatures was studied in order to examine physical phenomena involved, to improve dielectric quality and propose a process window for strain-Silicon substrates. Towards this scope, electrical characterization, structural characterization and RAMAN spectroscopy has been implemented. Computer simulations were performed using Synopsys -Taurus software. Two different s-Si substrates of different strain level and Germanium concentration in the SiGe layer (10% and 22%) were examined. These, were denoted as S1 and S2. Standard Silicon substrates were used as reference (S0).

It was shown that the oxidation rate of s-Si does not depend on strain – level, within the accuracy of electrical and optical measurements and as confirmed by high resolution TEM images. The incorporation of Nitrogen can further reduce significantly the oxidation rate (Fig. 1), especially in the case of Nitrogen – implanted samples where all oxidation conditions led to ultrathin oxides (less than 3 nm). Raman spectroscopy at 325 nm (UV) made possible the isolation of the s-Si mode and revealed the preservation of strain after the processes (Fig. 2).

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. This effect is dependent on the geometrical characteristics of the MOS structure, as predicted by simulation (Fig. 3). 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. ~ 10^{10} $ev^{-1}cm^{-2}$) for a variety of oxidation conditions and total thermal budget induced. Instead, when performing an extensive RCA cleaning treatment and thermal oxidation, a significant part of the s-Si layer is consumed during the cleaning process and another one for the formation of the oxide. This leads to a significant degradation of the electrical properties (increased interface trap density and fixed charges) manifested with significant frequency dispersion in the C-V characteristics of the MOS s-Si structures, which overshadows the hump effect (Fig. 4).

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 can 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 due to inter-diffusion of Ge. Further degradation and eventually elimination of the second interface (s-Si/SiGe) leads to a significantly smaller interface trap density and frequency dispersion effect. A great part of the interface trap respond mechanism originates from the heterointerface of s-Si with SiGe and therefore, both interfaces contribute to the interface trap density when in close proximity. This result is confirmed by TCAD simulation analysis and by experiments with post-oxidation annealing time as a parameter. Additional parallel conductance measurements at various frequencies $G_p(\omega)$ and temperatures show the existence of two contributions to the conductance loss. Elaborate analysis of the evolution of this phenomenon with temperature, revealed Arrhenious – type reactions. 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 and could be attributed to defect mechanisms located at the back interface.

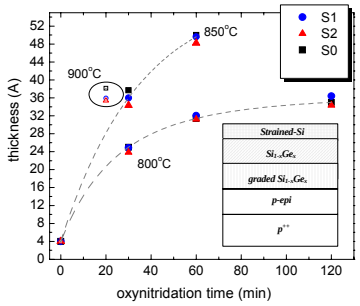


Fig 1. *Oxide growth of s-Si as a function of time and temperature when performing oxynitridation in N_2O. Inset: s-Si structure.*

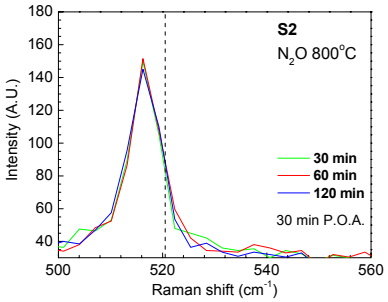


Fig 3. *Raman (UV, 325nm) measurements.s-Si peak has been isolated, no shift of Raman peak is observed*

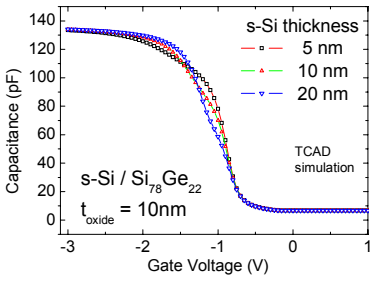


Fig 3. *The effect of s-Si thickness on C-V curves: TCAD simulation for a constant gate oxide thickness for S2 substrates.*

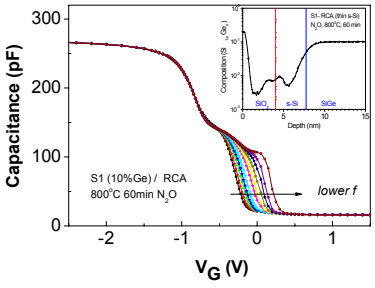


Fig 4. *Intentionally thinned S1 sample oxidized at 800°C for 60 min and frequency dispersion effect. Inset: SIMS measurements and Ge diffusion.*

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

B. Dopant diffusion in Germanium*

N. Ioannou, V. Assimakopoulos and C. Tsamis
**In collaboration with Physics Dept., Univ. of Patras (D.Skarlatos, C. Krontiras, R. Georga) and Physics Dept., Univ. of Thessaloniki (N. Z. Vouroutzis)*

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.

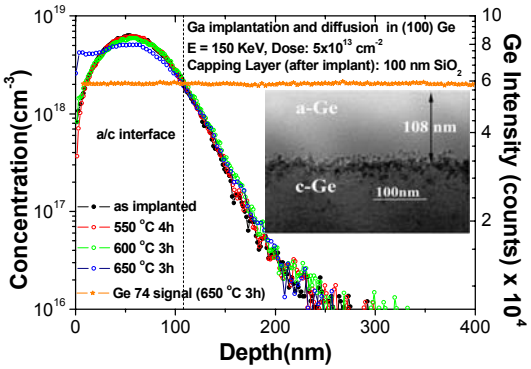


Fig 5. *Ga profiles in Ge, after low dose – high energy implantation and annealing at 550-650°C. A TEM image of the as-implanted sample is also shown as inset.*

During this year we continued our investigation on the diffusion of Ga in Ge substrates, for high as well low implantation doses, using furnace annealing in the temperature range 550-650°C and for times up to 240min. Moreover, following previous studies, the possible influence of Ge surface passivation on Ga diffusion was also investigated. Figure 5 shows Ga ToF-SIMS profiles in the case of low dose Ga implantation and annealing for samples covered with SiO_2. The maximum concentration of the as-implanted profile is Cp= $6.3x10^{18}$ cm^{-3} at a projected range Rp ~56 nm. Representative TEM image of the as-implanted substrate is shown as an inset. The amorphous layer extends to 108 nm from the surface. We observe also the absence of a honeycomb subsurface structure reported in the literature for the case of high dose implants of heavy ions in Ge. No significant Ga diffusion has been observed at 550°C. Negligible diffusion has been observed also at 600°C. By increasing the temperature at 650°C a trend of Ga diffusion (in particular out-diffusion towards the SiO2/Ge interface) is clearly observed, which leads to a change of the profile shape and height in the near - peak (now Cp ≈$5x10^{18}$ cm^{-3}) region. Selected SIMS measurements have been performed also in samples covered with 100 nm Si_3N_4. The overall picture remained the same. This means that the change of the capping layer did not affect, in any way, the point defect kinetics in the substrate and consequently the dopant diffusion under the present experimental conditions.

Figure 6 shows Ga ToF–SIMS profiles in the case of high dose Ga implantation and annealing at 550-650°C. The maximum concentration of the as-implanted profile is now Cp=$1.4x10^{20}$ cm^{-3}. However, we observe that Ga profiles of the annealed samples are completely different from the corresponding of the low dose case under the same annealing conditions. Two different regions can be identified in each profile: An almost immobile region, located around the peak of the profile, where no diffusion is observed, and a second region, in the tail of the profile, where Ga diffusion can be seen. Similar profiles have been obtained also for B at dose range $3x10^{13}$-$6x10^{14}$ cm^{-2} indicating a possible clustering phenomenon.

Simulations were performed using Synopsys Sentaurus process simulator. A constant diffusivity model has been used in order to simulate the diffusion of the tail regions of the profiles, keeping the high concentration regions immobile in order to represent the possible clustering phenomenon. The best fitting of the tail regions has been obtained using a diffusivity value of $1x10^{-16}$ cm^2s^{-1} for 550 and 600°C and a value of $3x10^{-16}cm^2s^{-1}$ for 650°C. A surprisingly high Ga diffusivity has been estimated at 550°C, which is equal to the corresponding at 600°C. This could have its origin to the small differences between the corresponding profiles, which are below the SIMS resolution limit. However a possible physical origin, being under investigation, cannot be excluded. Figure 7 shows the diffusivity values obtained at 600 and 650°C compared to literature data. The obtained values are in good agreement with previously reported results taking into account the different experimental methodologies used.

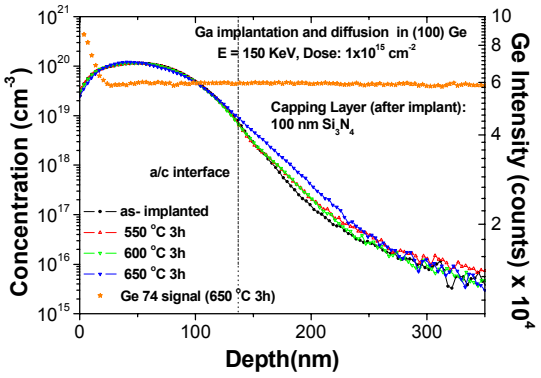


Fig 6. Ga profiles in Ge, after high dose – high energy implantation and annealing at 550-650 °C.

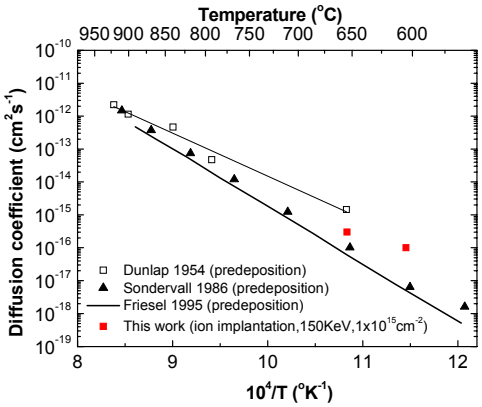


***Fig 7.** Ga diffusion coefficients obtained at 600°C and 650°C in the case of 150KeV, 1x10^15 cm^-2 implantation.*

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

PROJECT OUTPUT IN 2009

Publications in International Journals and Reviews

1. "Study of interfacial defects induced during the oxidation of ultrathin strained silicon layers", V. Ioannou-Sougleridis, N. Kelaidis, C. Tsamis, D. Skarlatos, C. Krontiras, S. N. Georga, Ph. Komninou , B. Kellerman, M. Seacrist, Journal of Applied Physics, Vol. 105, Issue 11, 2009, No 114503
2. "Gallium Implantation and Diffusion in Crystalline Germanium", N. Ioannou, D. Skarlatos, N. Z. Vouroutzis, S. N. Georga, C. A. Krontiras and C. Tsamis, Electrochemical and Solid-State Letters, 13 (3) H70-H72

PhD Thesis

1. "Study of the influence of nitrogen on the electrical characteristics of devices fabricated on strained silicon substrates", N. Kelaidis, Physics Dept., Aristotle Univ. of Thessaloniki, September 2009, Supervisors : Dr C. Tsamis (NCSR"D") and Prof. C. Dimitriadis (Aristotle Univ. of Thessaloniki)
2. "Diffusion and activation of p-type dopants in IV semiconductors for novel nanoelectronic devices", N. Ioannou, Physics Dept. Univ. of Patras, November 2009, Supervisors: Dr C. Tsamis (NCSR"D") and Prof. C. Krontiras (Univ. of Patras)

Purchase of new equipment

Update of software for Process and Device modeling (Synopsys TCAD Tools 2009)

Project: I. 4: THIN FILMS by CHEMICAL VAPOR DEPOSITION (CVD)

Project leader: D. Davazoglou

Ph.D. students: I. Kostis

Master students: L. Zambelis (Master Programme: Micro and Nano Systems, NTUA), G. Rokadakis (Master Programme: Microelectronics, UoA)

Collaborating scientists: Dr. G. Papadimitropoulos, 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)

Objectives:

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

- Process and material development
- Characterization of CVD films
- Applications

MAIN RESULTS in 2009

A. Hot-Wire Atomic Layer Deposition System

I. Kostis, G. Papadimitropoulos

An atomic layer deposition (ALD) system was designed and developed. The system is equipped with a hot wire (HW-ALD) permitting the separate heating of the gas phase in order to create activated species with special characteristics such as, for example, high surface mobility on the substrate, etc.

Fig. 1. Photo of the HWALD system that was developed. The reactor and various electronic sub-systems are shown left while on the right a part of the gas line.

Except of “classical” depositions, heating of the wire only at a pressure of the order of 0,1-1 Torr, under certain conditions, gives deposits composed of oxides of the metallic wire. More precisely, a native oxide is grown on the surface of every wire. If the vapor pressure of this oxide is higher than that of the metal, heating of the wire produces a vapor of oxides which is deposited on a cold substrate. Typical examples are W and Mo whose oxides have much higher vapor pressures than that of the corresponding metals.

In Fig. 2 SEM micrographs taken on the surfaces of a tungsten oxide (left) and a molybdenum oxide (right) film deposited in the HW-ALD system are shown. It can be observed that the obtained films are porous. As shown by spectroscopic ellipsometry measurements their porosity being near 60%. As shown by TEM measurements (Fig. 3), films

are composed by grains with dimensions of the order of 10 nm. The stoichiometry of films depends on the gas phase composition during deposition: in a nitrogen ambient stoichiometric oxide films were obtained while when hydrogen was added into the reactor reduced films with optical constants very near to those of the corresponding metals were obtained. The last were easily crystallized by heating at temperatures of the order of 150 ^{o}C to give films composed by well crystallized grains with dimensions of the order of 5 nm as shown in Fig. 3 (right).

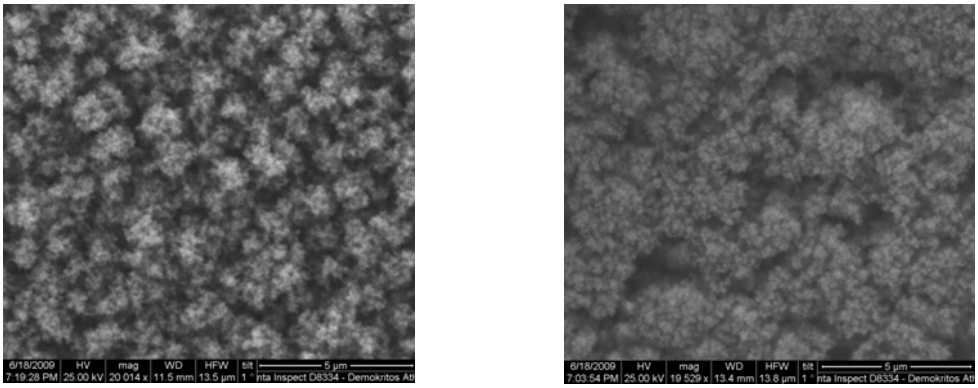


Fig. 2. SEM micrographs taken o the surface of porus WO_3 (left) and MoO_3 (right) thin films deposited by heating the corresponding wires in a vacuum of 0,1 Torr. Grains with dimensions of the order of 30-40 nm are shown, which are composed by smaller ones with dimensions near 5 nm (see Fig. 3).

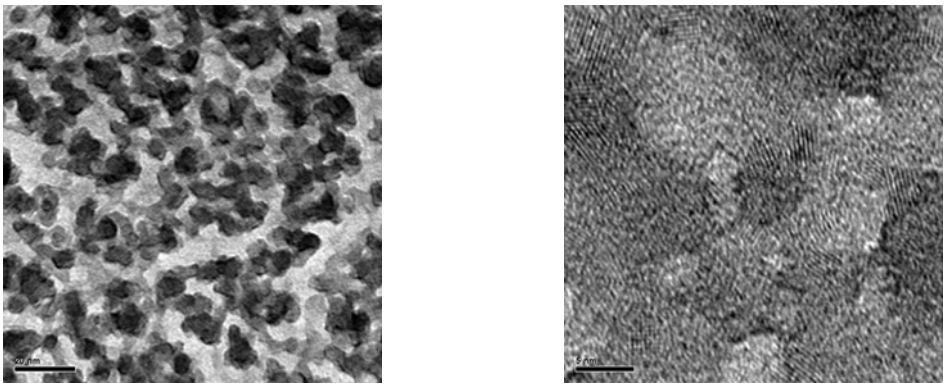


Fig. 3. TEM micrographs taken o porous WO_3 films deposited in a vacuum of 0,1 Torr of oxygen (left) and hydrogen (right) at a substrate temperature of 100 ^{o}C.

The above films were used in organic light emitting diodes (OLEDs) and organic photovoltaic devices (see Project I 1, Functional molecular materials for lithography and organic-molecular electronics).

B. Miniature Concentration Silicon Solar Cells

G. Rokadakis

Miniature photovoltaic (PV) cells with dimensions of 0,5X0,3 cm^2 were formed on Si (Fig. 4). After an initial run it turned out that only 50% approximately of PV cells were operating after dicing saw and cutting form the Si wafer. This was attributed to the poor passivation of the edges. After these initial efforts, a second run was made introducing a passivating oxide between cells so sawing was done on this oxide. The introduction of this oxide increased yield to 100 %.

Fig. 4. Miniature PV Silicon cells with dimensions of 0,15 (0,5X0,3) cm^2 before (left) and after cutting (right).

Miniature cells were operated under a moderate concentration (X20) of sun light packed to form modules and panels as seen in Fig. 5. The optical parts of modules have been fabricated by poly-dimethyl siloxane (PDMS), which is an advanced material with optical properties conformal with the operation of Si PV cells. Moreovefr, this material is easily cast to form semi-spherical lenses. It is noted that because of the hemispherical shape of these concentration lenses an accurate sun tracking is not necessary for the proper operation of modules; an accuracy of ±1 degree from the vertical is enough. Cells, modules and panels were tested at real conditions yielding efficiencies of 16%.

Fig. 5. Modules (left) and a panel (right) made of miniature concentration Si cells.

PROJECT OUTPUT in 2009

Publications in Refereed Proceedings

1. Initial Stages of Thermally and Hot-Wire Assisted CVD Copper on SiLK® and LTO Substrates Activated with Mercaptopropyl Triethoxysilane Self-Assembled Monolayers G. Papadimitropoulos, T. Speliotis, A. Arapoyianni and D. Davazoglou, **EUROCVD 17**, ECS Transactions. V25, No 8, p 893 (2009)
2. Memory Structures Based on the Self-organization of Cu Nanoparticles Deposited by Hot-Wire CVD on Polythiophene Layers P. Dimitrakis, G. Papadimitropoulos, L.C. Palilis, M. Vassilopoulou, P. Normand, P. Argitis and D. Davazoglou, **EUROCVD 17** ECS Transactions. V25, No 8, p 893 p. 1073 (2009)
3. Fabrication of Micro- and Nano-Electrodes by Selective Chemical Vapor Deposition of Cu on Si Substrates Patterned with AZ5214™ and PMMA, G. Papadimitropoulos, S. Cibella, R. Leoni, A. Arapoyianni and D. Davazoglou, **EUROCVD 17** ECS Transactions, 25 (8) 1285-1292 (2009)

Conference Presentations

1. “Inorganic metal oxides as cathode interfacial layers for polymer electronic devices”, M. Vasilopoulou, L. C. Palilis, D. G. Georgiadou, P. Argitis, I. Kostis, G. Papadimitropoulos, N. A. Stathopoulos, A. Iliadis, N. Konofaos and D. Davazoglou, 2nd International Symposium on Flexible Organic Electronics, 8-10 July 2009, Halkidiki Greece
2. Initial Stages of Thermally and Hot-Wire Assisted CVD Copper on SiLK® and LTO Substrates Activated with Mercaptopropyl Triethoxysilane Self-Assembled Monolayers G. Papadimitropoulos, T. Speliotis, A. Arapoyianni and D. Davazoglou, EUROCVD 17, ECS Transactions. V25, No 8, p 893 (2009)
3. Memory Structures Based on the Self-organization of Cu Nanoparticles Deposited by Hot-Wire CVD on Polythiophene Layers P. Dimitrakis, G. Papadimitropoulos, L.C. Palilis, M. Vassilopoulou, P. Normand, P. Argitis and D. Davazoglou, EUROCVD 17 ECS Transactions. V25, No 8, p 893 p. 1073 (2009)
4. Fabrication of Micro- and Nano-Electrodes by Selective Chemical Vapor Deposition of Cu on Si Substrates Patterned with AZ5214™ and PMMA, G. Papadimitropoulos, S. Cibella, R. Leoni, A. Arapoyianni and D. Davazoglou, EUROCVD 17 ECS Transactions, 25 (8) 1285-1292 (2009)

Ph.D Thesis

1. “Development and characterization of thin films of Cu and copper oxides and application in electronic devices”, G. Papadimitropoulos, University of Athens

Master Theses

1. “Selective chemical vapor deposition of vanadium oxides on Cu features made by colloidal lithography”, L. Zambelis, NTUA
2. “Micrographic concentration silicon photovoltaic cells”, G.L. Rokadakis, Univ. Of Athens

PROGRAM II

NANOSTRUCTURES and NANOELECTRONIC DEVICES

PROJECTS II.1 : NANOSTRUCTURES FOR NANOELECTRONICS, PHOTONICS AND SENSORS

Project leader: A. G. Nassiopoulou

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

Post-doctoral: M. Hourdakis, G. Gantzounis

Phd students: V. Gianneta, F. Zacharatos, A. Petropoulos, P. Manoussiadis, E. Αλμπάνης

Others: E. Michelakaki, H. Katsogridakis, A. Dragoneas

Objectives:

B. Nanostructure growth, characterization and applications

The activity on semiconductor nanostructures started within this research group at the early nineties and it was conducted within different EU projects. Examples of such projects are: 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, ICT NoE NANOSIL, contract No 216171 and other. 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. Two electrochemically grown materials are investigated, porous Si and porous anodic alumina thin films on Si. Their growth and properties are studied, as well as their applications in nanoelectronics, photonics and sensors. Porous Si is currently investigated as a local substrate for the on-chip integration of RF passives or as a local thermal insulator on Si for thermal devices. Porous Si free standing membranes are also developed for different applications.

Nanowires on Si are grown by electrochemistry. Si or metal nanowires are developed for different applications. Metal-assisted Si etching is also developed for Si nanowire growth.

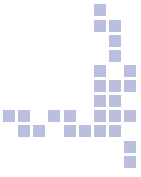
The theoretical group focuses on the investigation of ballistic transport in nanostructures, surface plasmons in thin metallic films, classical molecular dynamics and nanoscale heat transport.

B. Sensors using porous silicon technology

A material platform based on porous Si technology has been developed for applications in different sensor devices, microfluidics, lab-on-chip, on-chip integration of passives etc. Porous Si is a material with versatile properties. Its structure is either mesoporous or nanoporous/macroporous. 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 has different properties and is useful in some of the applications. Macroporous silicon is developed for use in via technology, in device cooling and in particle filtering.

Funding:

- EU IST I_3 ANNA, Contract N^o: 026134 1/12/2006–1/12/2010
- FP7-IST-NoE NANOSIL, Contract N^o: 216171, 1/1/2008-1/1/2011
- FP7 TAILPHOX, Contract N^o: 233883, 1/5/2009-30/4/2012

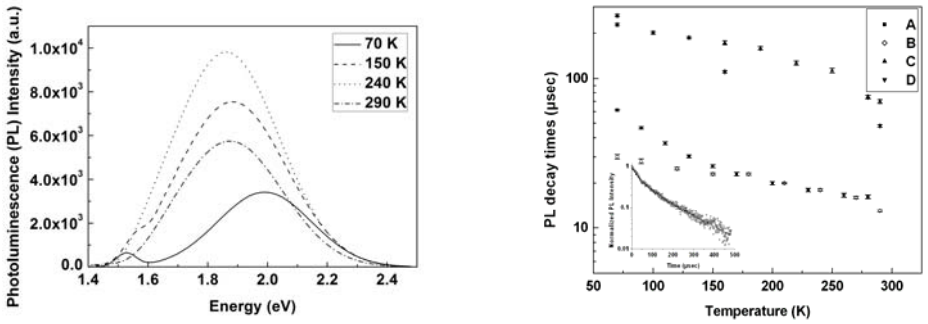


MAIN RESULTS IN 2009

A. Effect of exciton migration on the light emission properties in silicon nanocrystal ensembles

We investigated the effect of exciton migration on the light emission properties in silicon nanocrystal (Si NC) ensembles. Different Si NC systems in which Si NCs were either entirely isolated or loosely interconnected were studied by photoluminescence (PL) and time-resolved PL decay measurements in the range between 70 K and room temperature. Specifically, two light emitting mesoporous Si films grown on p-type Si substrate with different porosities (sample A= porosity 85%, sample B =porosity 62%), a light emitting heavily oxidized mesoporous Si film grown on a p+-type Si substrate (sample C) and a superlattice composed of six Si NC/SiO_2 bilayers grown by low pressure chemical vapor deposition (LPCVD) of Si and subsequent annealing/oxidation (sample D) were investigated. We observed that:

- In samples A and B, where Si NCs were loosely interconnected, PL characteristics such as energy position of PL peak, PL intensity and FWHM of the PL spectrum changed in correlation with migration of excitons away from their generation site to sites of lower energy as temperature increased.
- In samples C and D, composed of effectively isolated Si NCs surrounded by SiO_2, exciton migration could not occur and as a result PL characteristics remained almost unchanged with temperature. Only PL intensity decreased monotonically with temperature, as nonradiative recombination becomes important at higher temperatures.
- In samples C and D exciton lifetime τ was by one order of magnitude larger than in the samples A and B. This effect was attributed mainly to the fact that exciton migration introduced a component, τ_M, to the total measured exciton τ, resulting in the observed reduction of τ.



(a) (b)

Fig. *(a) PL spectra obtained at different temperatures from sample B. The PL characteristics changed considerably due to exciton migration. (b) Temperature dependence of PL decay times, τ, for samples A, B, C, and D. Insert:Typical PL decay curve following the stretched exponential law:*

$$I_{PL}(t) = I_0 \exp\left[-\left(\frac{t}{\tau}\right)\right]^{\beta}$$

Ref. S. Gardelis, A.G. Nassiopoulou, N. Vouroutzis, N. Frangis, *J. Appl. Phys. 105,* 113509 (2009). Also published in Virtual Journal of Ultrafast Science, vol. 8, issue 7, Condensed Matter Physics (2009)

B. Growth and properties of porous anodic alumina thin films on Si at large and micrometer areas

A thorough investigation of the growth and properties of porous anodic alumina (PAA) thin films of thickness in the range of few nm to few μm, directly grown on a Si substrate by electrochemical oxidation of Al thin films was undertaken, compared with similar films grown on an Al foil. It was shown that for a film thickness below ~1μm pore size and density increase with increasing film thickness. It was also shown that pore density increases when the anodized area is confined in the micrometer range. The alumina/Si interface and the Si surface after alumina dissolution were also examined and the mechanism of Si oxidation through the alumina film was explained. Pore widening was investigated for the three different

electrolytes. Finally, it was shown that by using a two- or three-step anodization process, perfect long range hexagonal pore ordering is obtained, as in the case of alumina films on an Al foil. This was achieved for the first time for PAA films on Si of thickness below 1 μm (500nm).

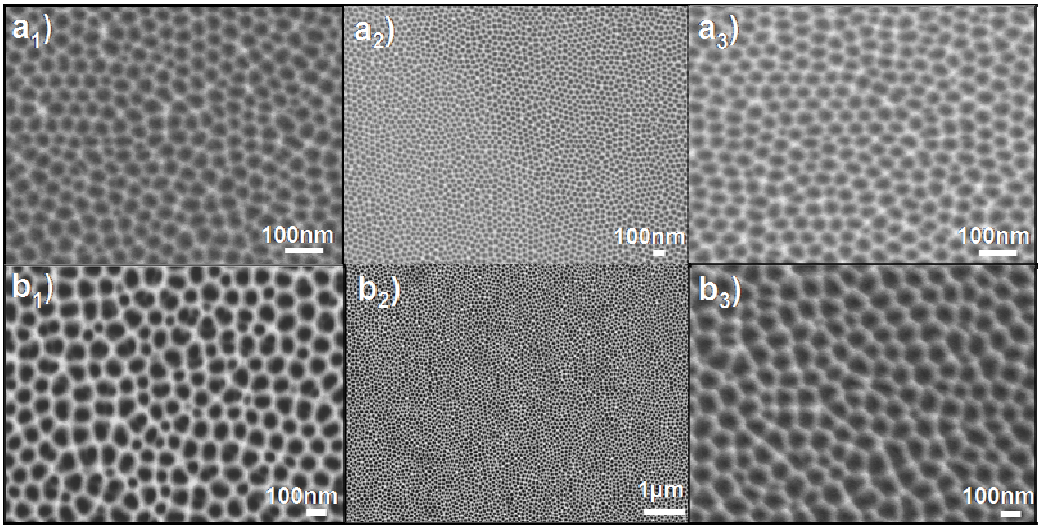


Fig. *Examples of plane view SEM images of PAA films after a two step (a1 a2, b1, b2) and three step (a3, b3) anodization of an Al film of an initial thickness of 1.3μm in sulfuric acid (a1, a2, a3) and oxalic acid (b1, b2, b3). The final film thickness after the two-step anodization was ~1.1μm and after the three-step anodization ~0.5μm.*

Ref. PhD thesis of V. Gianneta

C. Formation of porous anodic alumina templates in selected micrometer-sized areas on a Si substrate. Application for growing ordered Ti nanopillars

The local formation of porous anodic alumina (PAA) thin films on confined in SiO_2 areas measuring few μm^2 on the silicon substrate has been developed. The locally grown porous anodic alumina thin films showed highly symmetric vertical cylindrical pores with a pore density that was much higher than that of films on non-confined areas. Pore density as high as 6 x 10^{10} pores/cm^2 was achieved, compared to ~10^{10} pores/cm^2 in corresponding large-area samples. Pore diameter was as small as 30-50nm. Alumina thin films on confined areas on a Si substrate are very interesting for use as masking layers for local Si nanopatterning or as templates for local growth of different nanostructures, e.g. nanowires of different materials, on wafer level. In this work, we used the PAA films as sacrificial templates to grow regular arrays of Ti nanopillars on pre-selected areas on the Si wafer.

Table 1 *Pore size and density of PAA films in confined areas on Si. The surface area of confined regions is indicated in the first column.*

confined surface area (μm^2)	pore size (nm)	pore density (pores/cm^2)
non confined area	50	10^{10}
5 x 5	40	2 x 10^{10}
3 x 3	30	5 x 10^{10}
2 x 2	>30	6 x 10^{10}

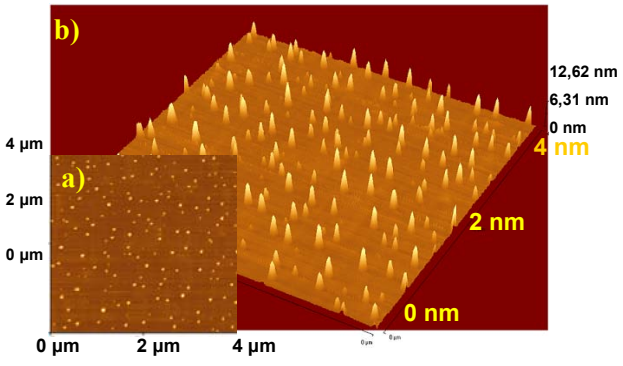


Fig. *(a) 2-D and (b) 3-D atomic force microscopy (AFM) images of 2-D arrays of Ti nanopillars on Si, fabricated by sputtering on a PAA film. The Ti nanostructures are revealed after PAA film dissolution.*

Ref. "Formation of porous anodic alumina templates in selected micrometer-sized areas on a Si substrate. Application for growing ordered Ti nanopillars", V. Gianneta, M. Huffman, and A. G. Nassiopoulou, Phys. Status Solidi A, pp.1-4 (2009).

D. Photoluminescence properties of porous silicon/fluorene dye composites

The fabrication and the photoluminescence (PL) study of hybrid nanocomposites formed by embedding fluorene dye molecules in the vertical cylindrical nanopores of a nanoporous silicon layer were investigated. The pores had a diameter of ~20nm and were homogeneously filled with the fluorene molecules as evidenced by scanning electron microscopy images. Efficient PL in the blue spectral region, attributed to the fluorene dyes embedded into the pores, was obtained from the composites. The PL spectrum of the dyes in porous silicon is blue-shifted compared to their PL spectrum in solution due to the confinement and isolation of the molecules into the pores. This blue-shift was enhanced when the dyes were initially dissolved in an aromatic solvent.

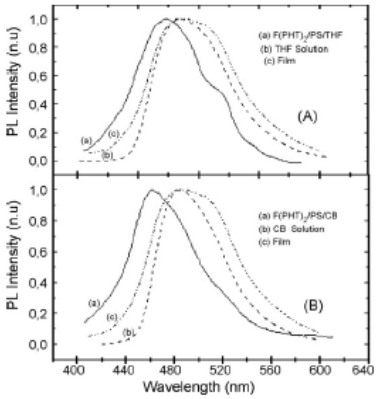


Fig. *Photoluminescence spectra of (A) $F(PHT)_2$/PS/THF and (B) $F(PHT)_2$/PS/CB composites. The spectra of $F(PHT)_2$ in solution and film are also shown for a comparison.*

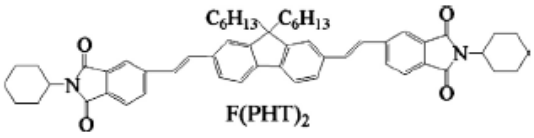


Fig. *The chemical structure of the fluorene molecule used in this study.*

Ref. "Photoluminescence properties of porous silicon/fluorene dye composites", M. Fakis, F. Zacharatos, V. Gianneta, P. Persephonis, V. Giannetas, A. G. Nassiopoulou, Materials Science and Engineering B 165, pp. 252-255 (2009)

F. Optimized Porous Si Microplate Technology for On-Chip Local RF Isolation

We developed porous Si microplates as low loss substrates for the integration of RF passives on an Si wafer. The porous microplates were grown on heavily doped p-type Si wafers with a resistivity of 0.005 Ω·cm that show similar RF response to the p/p^+ epi-wafers, commonly used by complementary metal-oxide-semiconductor (CMOS) industry. Broadband electrical characterization of thick mesoporous silicon layers used as RF microplates for on-chip integration of high-Q passive devices was performed in a CMOS-compatible process. To measure the RF losses of the microplate several designs of co-planar waveguides (CPWs) were fabricated on mesoporous Si layers (RF microplates) of various thicknesses, for form-factors relevant to the sizes of on-chip passive RF devices (Fig. 1). We showed that this specific porous material has a complex permittivity ε=3.05 (1+i0.029), which is much superior to that obtained by the authors for porous Si grown on a p-type substrate. Five different thicknesses of PS membranes were tested and it was found that, for the 5-mm CPWs used and for the WLAN frequencies of 2.5 and 5 GHz, increasing the thickness from 10 to 50 μm reduces the loss from 16% to 8% and from 25% to 10%, respectively, for these two frequencies, while the effect is almost saturated at thickness above 100 μm. The commercial finite-element simulator HFSS was used to analyze the structures shown in fig. 1 below by feeding the complex permittivity of the PS substrate with constant values until the best match of the simulated *S*-parameters to the measured data is obtained. The corresponding value of the complex permittivity is then the extracted value characterizing the material (fig. 2). It is expected that this promising effect of substrate isolation produced by PS will be much more pronounced when applied to on-chip passives with significantly smaller dimensions than those of the CPWs used in this work.

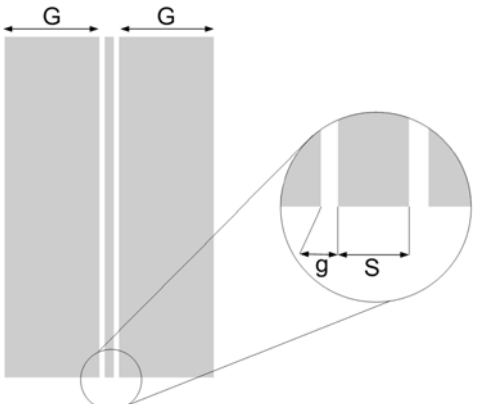


Fig. 1 *Schematic illustration of the CPW fabricated on PS dies.*

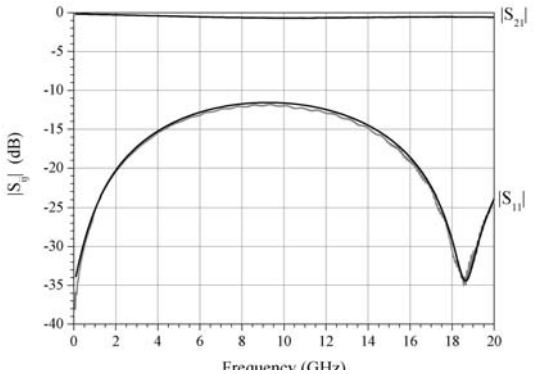


Fig. 2. *Measured vs. theoretical S-parameters of a CPW on a 150-μm-thick porous Si layer on p+ Si substrate. Gray = Measurements; Black = Simulations.*

Ref. F. Zacharatos, H. F. Contopanagos and A. G. Nassiopoulou, IEEE Transactions on Electron Devices, vol. 56, no. 11, November 2009

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

Macroporous Si membranes on p-type Si (resistivity 6–8 Ω cm) with pore size down to 180 nm and membrane thickness up to 1 μm were grown for the first time by electrochemical dissolution of Si, after pre-patterning the Si surface through a porous anodic alumina (PAA) mask, electrochemically self-assembled on the Si substrate. The formed macropores were highly ordered and arranged on the surface in a hexagonal lattice, following the hexagonal arrangement of the pores of the PAA film. At small pore height (few hundreds of nm), the pore walls were smooth, but fully developed pores showed rough walls. The obtained pore density was defined by that of the PAA film and was in general higher than in a macroporous structure with non-ordered macropores, fabricated under the same electrochemical conditions, but without pre-patterning of the Si surface. Fig. 1 is an example of plane view SEM image of a macroporous Si membrane fabricated as above. The crystal lattice (pitch) for this specific structure remained at 200 nm as in the alumina film, but pore size was larger than in the template. Fig. 2 shows shallow pores, formed through porous anodic alumina by reactive ion etching, that serve as pore initiation sites. The maximum pore depth achieved after anodization was of the order of 1 μm. 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.

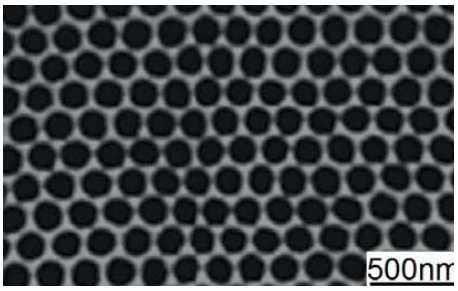


Fig. 1. *SEM plan view image of hexagonally arranged macropores fabricated on Si using pre-patterning through a PAA masking layer. Pore diameter is ~ 180 nm and the lattice constant 200 nm.*

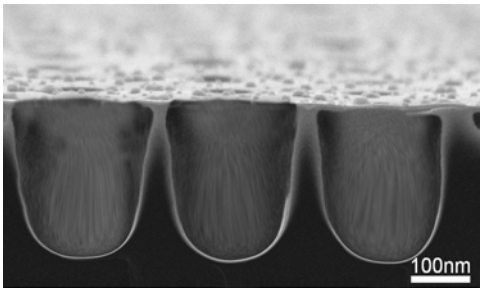
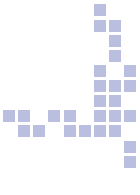


Fig. 2. *SEM cross sectional view of shallow pores formed through porous anodic alumina. These pores served as pore initiation sites for further Si porosification.*

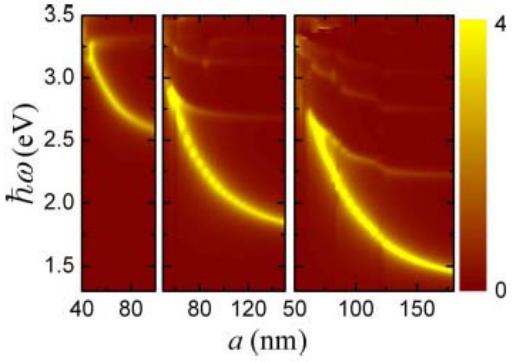
Ref. F. Zacharatos, V. Gianneta, and A. G. Nassiopoulou Phys. Status Solidi A, 1– 4 (2009)



H. Surface plasmons, metamaterials

N.Papanicolaou, C. Terkezis*, N. Stefanou*
**Univ. of Athens*

Metallic nanoparticles were used since ancient times to color glass. Their optical properties are due to the interaction of the electromagnetic field with the metallic electrons, which is called surface plasmon. Nowadays, isolated metallic nanoparticles are usually chemically synthesized as colloidal suspensions and come in a variety of shapes and sizes. One of the most attractive features of plasmon excitation is that it is accompanied with local field enhancement and subwavelength focusing. Metallic nanoparticle arrays are considered for biological and chemical sensors since their plasmon resonance is rather sensitive to the enviroment. We have made a thorough theoretical study of the optical response of two- and three-dimensional periodic assemblies of metallic nanorods by means of full-electrodynamic calculations using the extended layer multiple-scattering method. Our results show that these systems support various types of resonant and bound collective plasmon modes, which are tunable over a broad spectral range. In particular, we reveal the existence of slab plasmon modes with zero group velocity, which can cause evanescent-wave enhancement and enable subwavelength imaging.



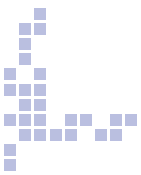
Extinction spectra for p-polarized light incident at an angle 45° on hexagonal arrays (lattice constant α) of aligned silver nanorods with diameter D=20 nm and length L=50 nm (left-hand diagram), L=100 nm (middle diagram) and L=150 nm (right-hand diagram). The plasmon resonance is highly tunable with the size of the nanorods.

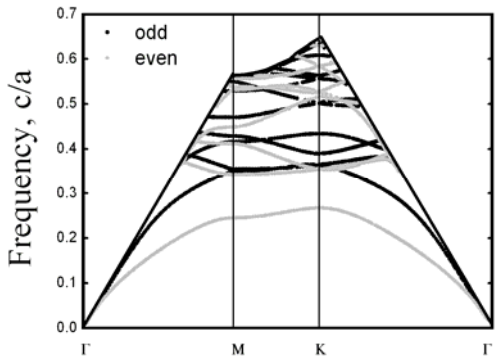
I. Si phoXonic crystals

N. Papanicolaou, N. Stefanou*
**Univ. of Athens*

Propagation of photons (electromagnetic waves) and phonons (sound waves) in periodic structures has sometimes unexpected consequences, like appearance of forbidden frequency regions, negative index of refraction, localization in cavities or even creation of slow waves with reduced propagation velocity. Light interacts weakly with sound, since the change in density induced by a propagating elastic wave changes the refractive index of the medium locally. This light-sound interaction is called acousto-opic effect. An interesting question is: what will happen if we manage to confine both light and sound for a long time in a small region in space and thus increase their interaction? This is the main focus of the European research project TAILPHOX (www.tailphox.org)

Our efforts are first focused on the creation of phoxonic crystals. These are structures that exhibit band gaps, i.e., they block propagation of both light and sound in (different) regions of frequency. Essentially, we are looking for structures which operate simultaneously as photonic and as phononic crystals. The design of such crystals will allow the fabrication of channels (waveguides) inside the phoxonic crystal where light and sound travel in a controlled manner and can also be localized in a very small cavity with dimensions smaller than 1 μm, which is one thousand times smaller than a human hair. Such a localization of light and sound would provide new, impressive opportunities to control light with sound and vise versa, and could lead to a new generation of acousto-optical devices. Moreover, it might become possible to control light emission efficiency of silicon, which is the main material of semiconductor industry and has a huge technological importance.





Photonic band diagram of the guided modes for a free-standing Si slab perforated with a hexagonal array of air holes. The radius or the air holes is 0.3a and the thickness of the slab is 0.5a, where a is the lattice constant of the hexagonal lattice. Even (gray) TE-like modes and odd (black) TM-like modes are shown. The structure exhibits a band gap for the even bands of about 0.076 in scaled units c/a, between the first and second even bands (c is the speed of light in vacuum), and a smaller gap of 0.034, for the odd bands at higher frequencies, between the fourth and fifth odd bands.

PROJECT OUTPUT IN 2009

Publications in International Journals and Reviews

1. "Optimized porous Si microplate technology for on-chip local RF isolation", F. Zacharatos, H. Contopanagos, A. G. Nassiopoulou, IEEE Transactions on Electron Devices, 56 (11), pp. 2733-2738 (2009)
2. "Investigation of Auger recombination in Ge and Si nanocrystals embedded in SiO2 matrix", M. Mahdouani, R. Bourguiga, S. Jaziri, S. Gardelis, A. G. Nassiopoulou, Physica E: Low-Dimensional Systems and Nanostructures, 42 (1), pp. 57-62 (2009)
3. "Dynamic charge transfer effects in two-dimensional silicon nanocrystal layers embedded within SiO_2", V. Ioannou-Sougleridis, A. G. Nassiopoulou, J. of Appl. Phys., 106 (5), art. no. 054508 (2009)
4. "Ultrafast time-resolved spectroscopy of Si nanocrystals embedded in SiO2 matrix", E. Lioudakis, A. Emporas, A. Othonos, A. G. Nassiopoulou, Journal of Alloys and Compounds, 483 (1-2), pp. 597-599 (2009)
5. "Photoluminescence properties of porous silicon/fluorene dye composites ", M. Fakis, F. Zacharatos, V. Gianneta, P. Persephonis, V. Giannetas, A. G. Nassiopoulou, Materials Science and Engineering B, 165 (3) 2009
6. "Photoluminescence in the blue spectral region from fluorene molecules embedded in porous anodic alumina thin films on silicon", M. Fakis, V. Gianneta, P. Persephonis, V. Giannetas, A. G. Nassiopoulou, Optical Materials, Optical Materials, 31 (8), pp. 1184-1188, 2009
7. "Effect of exciton migration on the light emission properties in silicon nanocrystal ensembles", S. Gardelis, A. G. Nassiopoulou, N. Vouroutzis, N. Frangis, Journal of Appl. Phys., 105 (11), art. no. 113509, 2009 (Selected for the July 2009, Issue (vol. 8, issue 7) of Virtual Journal of Ultrafast Science, 2009)
8. "Formation of porous anodic alumina templates in selected micrometer-sized areas on a Si substrate. Application for growing ordered Ti nanopillars", V. Gianneta, M. Huffman, A. G. Nassiopoulou, Physica Status Solidi (A) 206 (6), pp. 1309-1312, 2009
9. "Highly ordered hexagonally arranged sub-200 nm diameter vertical cylindrical pores on p-type Si using non-lithographic pre-patterning of the Si substrate", F. Zacharatos, V. Gianneta, A. G. Nassiopoulou, Physica Status Solidi (A) 206 (6), pp. 1286-1289, 2009
10. "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, Physica E: Low-Dimensional Systems and Nanostructures, 41 (6), pp. 986-989, 2009
11. "Laterally ordered 2-D arrays of Si and Ge nanocrystals within SiO_2 thin layers for application in non-volatile memories", A. G. Nassiopoulou, A. Olzierski, E. Tsoi, A. Salonidou, M. Kokonou, T. Stoica, L. Vescan, International Journal of Nanotechnology, 6 (1-2), pp. 18-34 (2009)
12. "Calculated optical transitions in a silicon quantum wire modulated by a quantum dot", X. Zianni and A. G. Nassiopoulou, Journal of Materials Science: Materials in Electronics 20, S68-S70 (2009)
13. "Tailoring plasmons with metallic nanorod arrays", C. Tserkezis, N. Papanikolaou, E. Almpanis, and N. Stefanou, Phys. Rev. B 80, art. no. 125124 (2009)

Publications in Conference Proceedings

1. “Comparison of electrical measurements with structural analysis of thin high-k Hf-based dielectric films on Si”, E. Hourdakis, M. Theodoropoulou, A. G. Nassiopoulou, A. Parisini, M. A. Reading, J. A. van den Berg, T. Conard, and S. Degendt, ECS Trans. 25 (3) 363-372 (2009)
2. “Preparation and characterization of nanocrystals using ellipsometry and X-ray diffraction”, P. Petrik, S. Milita, G. Pucker, A. G. Nassiopoulou, J. A. van den Berg, M. A. Reading, M. Fried, T. Lohner, M. Theodoropoulou, S. Gardelis, M. Barozzi, M. Ghulinyan, A. Lui, L. Vanzetti, A. Picciotto, ECS Trans. 25 (3) 373-378 (2009)
3. “Negative effective permeability of multilayers of ordered arrays of metal-dielectric nanosandwiches”, C. Tserkezis, N. Stefanou, G. Gantzounis, and N. Papanikolaou, Proc. SPIE 7353, 735305 (2009)

International Conference Presentations

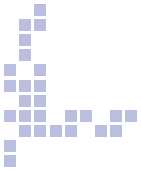
1. "Porous Si as a local substrate technology platform for on-chip electronic and sensor applications", (invited talk) A. G. Nassiopoulou, TUAT/TEL International Workshop “Innovations of Silicon, by Silicon, for Silicon”, 18.9.2009, Tokyo
2. "Ordered arrays of SiO_2 nanodots with embedded Si nanocrystals: Fabrication and characterization", A. G. Nassiopoulou, (invited talk), 216th ECS Meeting – Vienna, Austria, E1 – Analytical Techniques for Semiconductor Materials and Process Characterization, 6.10.09
3. “Comparison of electrical measurements with structural analysis of thin high-k Hf-based dielectric films on Si”, E. Hourdakis, M. Theodoropoulou, A. G. Nassiopoulou, A. Parisini, M. A. Reading, J. A. van den Berg, T. Conard, and S. Degendt, 216th Meeting of the Electrochemical Society, Vienna, Austria, 5-7 October 2009
4. “Preparation and characterization of nanocrystals using ellipsometry and X-ray diffraction”, P. Petrik, S. Milita, G. Pucker, A. G. Nassiopoulou, J. A. Van den Berg, M. A. Reading, M. Fried, T. Lohner, M. Theodoropoulou, S. Gardelis, M. Barozzi, M. Ghulinyan, A. Lui, L. Vanzetti, A. Picciotto, 216th Meeting of the Electrochemical Society, Vienna, Austria, 5-7 October 2009
5. "Highly ordered porous alumina and porous Si films for electronic, photonic and sensor applications", A. G. Nassiopoulou (invited talk), REGMINA Workshop on MEMS and NEMS technologies, Belgrade, June 4-5 2009
6. "Silicon nanostructuring through self-assempbed masking layers", A. G. Nassiopoulou (invited talk), EMRS 2009_Symposium M, Strasbourg, 9-13 June 2009.
7. “Negative effective permeability of multilayers of ordered arrays of metal-dielectric nanosandwiches”, C. Tserkezis, N. Stefanou, G. Gantzounis, and N. Papanikolaou, SPIE Europe Photonics (2009)

Presentations in National Conferences

1. "Nanoelectronics at the Center of Leading Edge Technologies", A. G. Nassiopoulou (invited talk), Workshop on Nanotechnology, organized by the Greek National Physics Society, 9 May 2009
2. "Porous Si technology for on-chip RF passives and other Si devices” A. G. Nassiopoulou, Symposium organized by the National Scientific Society “Micro&Nano” in the field of “New challenges in Microelectronics, Nanoelectronics, Optoelectronics and Sensors”, NCSR Demokritos, 6-7 November 2009
3. “Coupled Plasmons and Resonant Effective Permeability of Metal-Dielectric-Metal Nanosandwich Assemblies”, C. Tserkezis, N. Stefanou and N. Papanikolaou, 25th Panhellenic Conf. on Solid State Physics & Materials Science, Thesaloniki 2009
4. “Optical Response of Plasmonic Nanoantenna Arrays”, E. Almpanis, N. Papanikolaou, C. Tserkezis and and N. Stefanou, 25th Panhellenic Conf. on Solid State Physics & Materials Science, Thesaloniki 2009
5. “Confined photons and phonons in nanopatterned silicon films” E. Almpanis, N. Stefanou, N. Papanikolaou, 2nd Mediteranean Conference on Nanophotonics, MEDINANO-2, Athens, October 26-27, 2009
6. “Raman studies (SERS) of rhodamine 6G on random and periodic arrays of silver nanoparticles”, A. Gabriileli, I. Theodorakos, T. Jun, I. Raptis, A. Gerardino, Th. Speliotis, N. Papanikolaou, I. Zergioti, D. Tsoukalas, Y. Raptis, Emerging Trends and Materials in Photonics ICO-PHOTONICS-DELPHI2009 October 7-9, 2009

Edition of special issues of International journals and Conference Proceedings

1. Special issue on "Nanotechnology in Greece", published in the International Journal of Nanotechnology, vol. 6 (Nos 1/9) 2009, Edited by A. G. Nassiopoulou, C. Fotakis
2. Edition of the Proceedings of the 6th International Conference on Porous Semiconductor Science and Technology (PSST 2008). Special Issue of Physica Status Solidi. Edited by: A. G. Nassiopoulou, L. T. Canham, M. Sailor and P. Schmuki, Wiley-VCH (2009)



Organization of Conferences, Symposia, Workshops

1. Organization of the National Scientific Symposium on “Recent Developments in Microelectronics and MEMS, organized by A. G. Nassiopoulou, under the auspices of Micro&Nano Scientific Society, 6-7 November 2009, NCSR Demokritos

PhD Theses

1. “Macroporous Si as a dielectric for local electrical isolation of Si and as a template for electrical interconnections through the wafer”, PhD thesis by F. Zacharatos, supervised by A. G. Nassiopoulou, defended at NTUA (2009)
2. “Self - assembled porous anodic Al_2O_3 films on Si substrate and applications", PhD thesis by V. Gianneta, supervised by A. G. Nassiopoulou, defended at the University of Patras (2009)
3. “Hybrid sensor devices in the mesoscopic scale”, PhD Thesis by A. Petropoulos, defended at NTUA (2009)

Master and diploma Theses

1. “Characterization and testing of a flow using porous Si thermal isolation”, MSc thesis by P. Doukeris, Supervisor: A.G. Nassiopoulou, defended at the University of Athens (2009)
2. "Growth and investigation of thermally oxidized thin porous silicon films embedded in MOS devices", MSc Thesis by A. K. Michelakis, supervised by S. Gardelis and defended at the University of Athens 2009
3. “Macroporous Si membranes for Si pressure sensors”, diploma thesis by A. Ganatsiou, supervised by A.G. Nassiopoulou, defended at the University of Thrase (2009)

Courses taught

1. Lectures on the “CMOS devices and processes” by A. G. Nassiopoulou, for the MSc programme on Nanosciences and Nanotechnologies, Univ. of Thessaloniki, 2nd semester 2009
2. Lectures on “CMOS devices and processes” by A. G. Nassiopoulou for the MSc programmes on Microelectronics (University of Athens) and Nanoelectronic devices and MEMs (National Technical Univ. of Athens), 1st semester 2009-2010
3. “Optoelectronics and Applications”, S. Gardelis, Summer School, NCSR Demokritos, July 2009
4. “Microelectronic Materials and Device Technology”, S. Gardelis, 5th Nano2life International Summer School on Methods in Micro-Nanotechnology and Nanobiotechnology, 22-26 June 2009, Athens, Greece
5. Lectures on “Sensor technology” for the MSc program on Microelectronics (University of Athens)

Project II.2: MATERIALS AND DEVICES FOR MEMORY APPLICATIONS

Project leader: P.Normand

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

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

Post-doctorals: E. Makarona, D. Velessiotis

PhD candidate: P. Goupidenis, N. Nikolaou

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

- ESA - Sub-Contract FORTH-NCSRD- RFQ No 3-12083, 14/4/2008-14/4/2009

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/SiO_2 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 Si NCs in thin SiO_2 layers by Plasma Immersion (Clrs: CEMES/CNRS, Ion-Beam-Services (IBS, FR)), (e) Wet oxidation of silicon nitride implanted with low-energy Si ions for ONO memory stacks (Clrs: CEMES/CNRS, MDM-INFM (IT)), (f) MOS structures with low-energy Ge-implanted thin gate oxides (Clr: LETI/CEA (FR)), (g) Proton radiation tolerance of nanocrystal memories (Clr: NTUA (GR)), (h) Fabrication and characterization of SiO_2 films with Si NCs obtained by stencil-masked LE-IBS (Clrs: CEMES/CNRS and INSA Toulouse (FR)), (i) Fluorene-based cross-bar organic memory device (Clrs: NTUA and Durham Univ.)

In 2009, our main activities described hereafter were focused on the following tasks: (A) Molecular storage elements for proton memory devices (Clrs: IMEL's projects I.2 & II.3, TEI Crete, Ioannina Univ.), (B) Formation of Ge nanocrystals in high-k dielectric layers for memory applications formation (Clrs: CEMES/CNRS, FZR Dresden, Cambridge NanoTech (USA)), (C) High-k dielectrics stacks for advanced non-volatile memory devices (Clrs: Helsinki Univ. (FI), IMS/NCSR'D'), (D) III-Nitrides quantum dots-resonant tunneling diodes as tunable wavelength UV-VIS phototodetectors (Clr: MRG/FORTH (GR)), (E) Oxide/nitride/oxide dielectric stacks with Si nanocrystals embedded in nitride (Clr: CEMES/CNRS), (F) Hybrid organic thin film transistor by laser-induced-forward-transfer (Clrs: NTUA, IMS/NCSR'D), (G) Fabrication and characterization of Ge diodes (Clr: IMS/NCSR'D').

MAIN RESULTS IN 2009

A. Molecular storage elements for proton memory devices

E. Kapetanakis[1], A.M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Dimitrakis, K. Beltsios[2], P. Goupidenis, P. Normand

**Assistant Professor at the Department of Electronics, TEI Crete*
*** Assistant Professor at the Department of Materials Science Engineering, University of Ioannina*

We recently demonstrated the concept of bi-functional molecular ionic dielectric stacks combining ion transport with ion trapping/detrapping functions for the further development of reprogrammable non-volatile single-OFET memory devices (see Kapetanakis et al. Adv. Mater. 20, 4568, 2008). The information carriers were in the form of protons and the dielectric stacks consisted of a proton-conducting layer (PCL) and a proton-trapping layer (PTL). The PCL was a poly(methyl methacrylate) (PMMA) film with embedded molecules of 12-tungstophosphoric acid ($H_3PW_{12}O_{40}$), while the PTL was a PMMA film containing 2-aminoanthracene molecules.

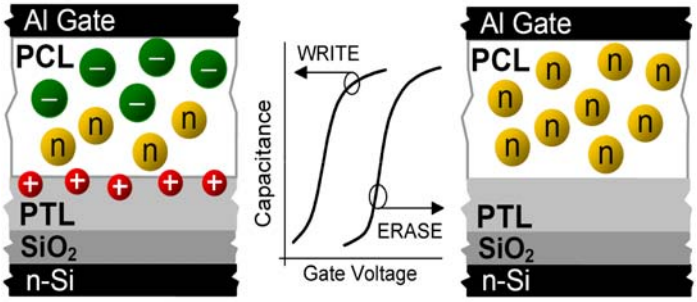


Fig. 1: *Schematic illustrating the structure and the operation principle of a non-volatile bistable MIS memory device with a molecular-based proton storage element consisting of a PCL / PTL stacked structure.*

The concept of using a PCL/PTL-type stack for the realization of non-volatile proton memory devices is quite simple (see figure 1) and many materials are possible candidates. The materials' selection is primarily guided by requirements of memory performance and process compatibility that strongly depend on the physicochemical properties of the candidate materials. This year, we focused our efforts on the optimization of the thermal processing parameters (temperature and duration) used in preparation of the above PCL-PTL materials. FTIR investigations resulted in the successful prevention of two undesirable phenomena for the device stability and performance: (a) the reaction between HPW and PMMA matrix inside the PCL, and (b) the intermixing of the PCL and PTL layers (see Kapetanakis et al., organic electronics 10, 711, 2009).

Moreover, a combination of UV spectroscopy studies and transient current (TC) experiments on MIS structures provided a comprehensive picture about the protons involved in the memory effect and their motion through the PCL. The concentration of the HPW molecules within the PCL was estimated to approximately 1.9×10^{20} HPW molecules cm^{-3} while a proton density of ~3.8×10^{17} protons/cm^3 was extracted from TC measurements under full polarization conditions, indicating that the main part of the dissociated protons which are attached to polymer basic sites is mainly immobile.

Finally, the material features of a generic PCL/PTL stacked structure, which affect the operation of a molecular proton memory device, were examined from a theoretical point of view. Results indicate that the write characteristics of this type of memory such as the magnitude of the memory window and the write speed depend on the thickness, the proton mobility and the proton concentration of the PCL, while the write voltage is mainly determined by the thickness of the PTL. In light of these analyses, it appears that memory windows as large as 2.8V might be obtained for a 1ms / 3V write operation regime even in the case of relatively thick PCL/PTL. These observations suggest that a PTL/PCL storage element is appealing for low-cost low-power non-volatile single-OFET memory applications.

Our next research activities include the development of organic/inorganic single-FET memory devices using the above PTL/PCL stacks and advanced electrical characterization of the polarization / depolarization mechanisms taking place in the PCL.

B. Formation of Ge nanocrystals in high-k dielectric layers for memory applications

P. Dimitrakis, V. Ioannou-Sougleridis, P. Normand, C. Bonafos[1], S. Schamm[1], A. Mouti[1], B. Schmidt[2], J. Becker[3]

[1]CEMES-CNRS, Université de Toulouse, Toulouse, France
[2]Research Center Dresden-Rossendorf, Dresden, Germany
*[3]Cambridge Nanotech Inc, Cambridge, MA, USA**

Semiconductor nanocrystals (NCs) have been employed successfully in various demonstrators for new CMOS device applications like nonvolatile memory (NVM) cells and optoelectronic components. Ge NCs are of special interest for nano-floating gate NVM cells due to their negative conduction band offset with respect to the Si substrate conduction band; an attractive NC property for faster programming speeds and longer retention times compared to silicon NCs. Another interesting option is the use of high-k materials as tunneling dielectrics. This route has been examined to overcome the charge retention issues rising from the thinning of the injection SiO_2 layer. Based on the above, Ge-NCs embedded in high-k dielectrics provide a promising alternative in the development of NC-NVM.

In previous studies (see 2006 IMEL annual report), formation of Ge-NCs into Al_2O_3 thin layers by low-energy Ge implantation and subsequent furnace annealing at 800°C was demonstrated. In the present work, 5nm-thick Al_2O_3 and 7nm-thick HfO_2 layers were grown by ALD on Si substrates and subjected to 1keV Ge+ implantation at doses of 0.5 or $1x10^{16}$ cm^{-2}. After deposition of a 10nm-thick Al_2O_3 (or HfO_2) layer, different furnace annealing steps in N_2 ambient were carried out to examine in a more comprehensive way the effect of the annealing temperature on the structural and electrical properties of the implanted high-k materials.

TEM and Electron Energy Loss Spectroscopy (EELS) studies revealed the presence of Ge-NCs only in the annealed Al_2O_3 layers (see Fig.2). These NCs have a mean diameter of 5nm and are located at a tunneling distance of 1 to 3 nm from the Si substrate. Further analysis revealed the presence of 1 nm thick SiO_2 layer at the Al_2O_3/Si substrate interface as well as crystallization of the alumina matrix. Capacitance-to-voltage (C-V) measurements performed on Al-gate MIS capacitor structures at various test ac-signal frequencies exhibited hysteresis due to charge storage in implantation-induced-defects and NCs. In the case of the $10^{16}cm^{-2}$ implanted samples, an annealing temperature in the 800 – 950°C range defines a safe process window, i.e., without significant changes in the memory window (see Fig. 3). The reduction of memory window observed at 1050°C might be related with Ge out-diffusion and dissolution of very small Ge clusters. Current-to-voltage (I-V) characteristics suggest that the higher the temperature of post-implantation annealing the lower the conduction through the Al_2O_3 layer especially at low electric fields. Retention performance of the above samples is under investigation.

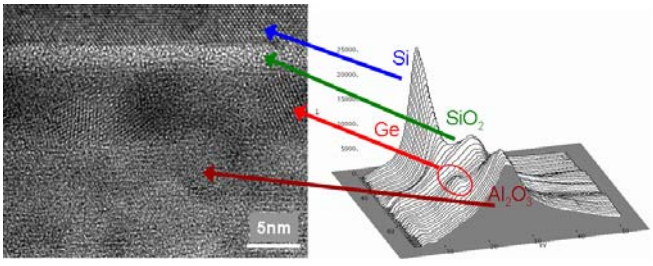


***Fig. 2**: XTEM and EELS analysis of Al_2O_3 thin film implanted with 10^{16} Ge^+ cm^{-2} and annealed at 800 °C.*

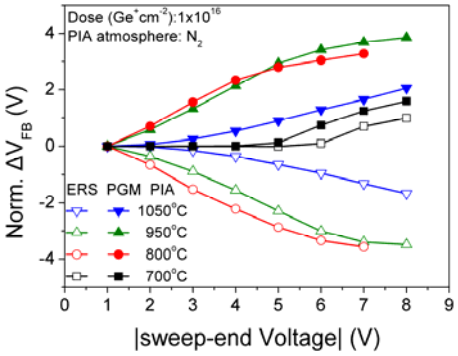


***Fig. 3**: Memory windows obtained from C-V hysteresis using MIS capacitors with Al_2O_3 gate insulator implanted with Ge and annealed in N_2 at different temperatures.*

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

N. Nikolaou, V. Ioannou-Sougleridis, P. Dimitrakis, K. Giannakopoulos[1], P. Normand, K. Kukli[2], J. Niinisto[2], M. Ritala[2], M. Leskela[2]

[1]*Institute of Materials Science, IMS-NCSR "D"*
[2]*Chemical Department of Helsinki University (FI)*

The objective of this project is to examine the influence of 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-based charge trapping memories are being considered as a promising alternative which could alleviate the serious downscaling limitations of the conventional flash memories. However, the most prominent issue of the latter devices is the inability to reduce further the vertical dimensions of the memory stack and at the same time to satisfy the 10-years retention requirement. In turn, the silicon nitride charge trapping devices must resolve a number of drawbacks and in particular the "over-erase"-saturation effect. This can be accomplished by the replacement of the standard SiO_2 tunnel and control oxides by high-k dielectrics layers. It is evident that the ALD precursor chemistry becomes gradually the critical factor which determines the physical, chemical and electrical properties of the deposited high-k dielectrics.

During the last year the main activity was focused on the examination of the structural and electrical properties of $SiO_2/Si_3N_4/ZrO_2$ or $SiO_2/Si_3N_4/HfO_2$ gate stacks with layer thicknesses of 2.5/5/10 nm respectively. Both high-k layers were deposited using zirconium and hafnium alkylamide or cyclopentadielyl precursors in combination with ozone as the oxygen source.

In the case of the ZrO_2 gate stacks and independently of the used precursor, a memory window of about 6 V was achieved after application of ±10V/100ms pulses (see Fig.4). In addition to the charging behavior, no significant differences have been detected in the I-V and C-V characteristics between the ZrO_2 layers synthesized by the two different precursors. However, in terms of reliability the alkylamide precursors provide ZrO_2 layers with higher dielectric strength. In the case of HfO_2 blocking layers the memory window and the dielectric strength are significantly affected by the precursor. The alkylamide-formed- HfO_2 and the cyclopentadienyl-formed-HfO_2 show write windows of 9 and 7V, respectively. Moreover, it appears that the alkylamide precursor provides a HfO_2 layer with a higher dielectric strength. Pulsed operation reveals that HfO_2 based gate stacks exhibit reasonable charge trapping after the application of voltage pulses 11 V at 0.1 ms.

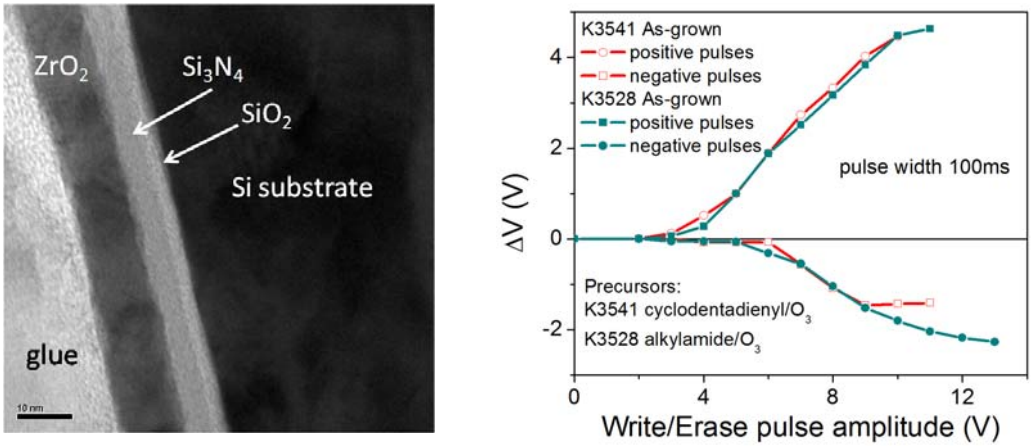


***Fig. 4**: (a) Transmission electron microscopy image of $SiO_2/Si_3N_4/ZrO_2$ gate stack on a silicon substrate where the ZrO_2 was deposited by the cyclopentadienyl precursor. (b) Flat-band voltage shift versus the amplitude of the applied write/erase pulse in the case of the $SiO_2/Si_3N_4/ZrO_2$ gate stack capacitors using alkylamide- or cyclopentadienyl-formed-ZrO_2.*

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

P. Dimitrakis, E. Iliopoulos[1], G. Deligiorgis[1], P. Normand, G. Konstantinidis[1], A. Georgakilas[1]

[1]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) structures.

Clear evidence for the functionality of our RTD devices was presented last year (see 2008 IMEL annual report). However, these devices were suffering from large leakage currents and high density of surface states that cause screening of the NDR region and unexpected switching of current to high values. These experimental findings revealed the presence of two major issues in device fabrication: (a) the optimization of the insulating dielectric surrounding the diode structure and (b) the passivation of the diode surface before insulator's deposition. This year, we focused our efforts on these issues as well as on the growth conditions of GaN QDs for optimizing their structural characteristics.

More than twenty different single/double-well RTD structures were grown using MBE and more than five processing routes were applied for device fabrication. A case study is presented hereafter. Figure 5 shows XRD measurements on a single well RTD structure. The excellent agreement between the measurements and the fitted model reveals the high quality of the grown layers and their interfaces. Utilizing this structure, several devices were fabricated following four different processing routes for surface passivation. Next, a LPCVD TEOS SiO_2 layer was used for device isolation. The I-V characteristics of these devices are shown in figure 6. Obviously, the surface passivation process affects the leakage current of the diodes and the observation of the NDR phenomenon. Only devices realized following recipes B and C exhibit resonant tunneling due to the effective passivation of the surface states. Further investigations are currently in progress to optimize the peak-to-valley ratio in the I-V characteristics of the later devices.

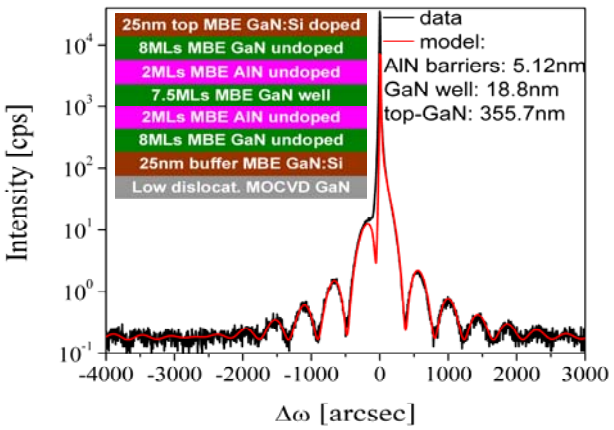


***Fig. 5**: (0002) ω-2θ scan XRD data of a single-well RTD structure (inset) and the corresponding dynamical theory simulation (red line).*

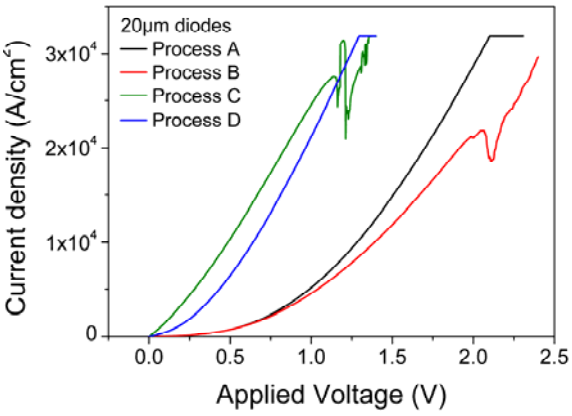


***Fig. 6**: I-V characteristics of the tested RTD devices fabricated following four different processing routes. The RTD structure is shown in Fig.5. Process B seems to be the most promising.*

E. Oxide/nitride/oxide dielectric stacks with Si nanocrystals embedded in nitride

N. Nikolaou, V. Ioannou-Sougleridis, P. Dimitrakis, P. Normand, S. Schamm[1], C. Bonafos[1], A. Mouti[1], G. BenAssayag[1]

[1]CEMES-CNRS, Université de Toulouse, Toulouse, France

Part of our last year efforts was devoted to the study of the physical phenomena that occur in memory structures consisting of $SiO_2/Si_3N_4/SiO_2$ gate stacks with silicon nanocrystals (Si-NCs) embedded within the silicon nitride material. The Si-NCs were synthesized by low-energy ion implantation into the silicon nitride layer followed by the deposition of a SiO_2 capping layer and subsequent annealing. At high Si implantation doses (1-1.5x10^{16} ions/cm^2) these structures exhibit clear current peaks followed by a negative differential resistance region, for both gate voltage polarities (see Fig.7a). Electrical examination was performed at temperatures from 20 to 100°C using constant ramp-rate I-V measurements. This approach provides a valuable tool for the determination of the origin of the observed current peaks as well as to extract useful information about the trapping location of the injected charge within the dielectric stack. The formation of the current peaks is due to a displacement current (Fig. 7b) which develops during the transfer of charge carriers from the Si substrate to the Si-NCs. Analysis of the characteristics revealed that the carriers are trapped within the Si-NCs band, (Fig. 7c and 7d) verifying this region corresponds to energy minima of the dielectric stack (see Nikolaou et al., Nanotechnology 20, 2009).

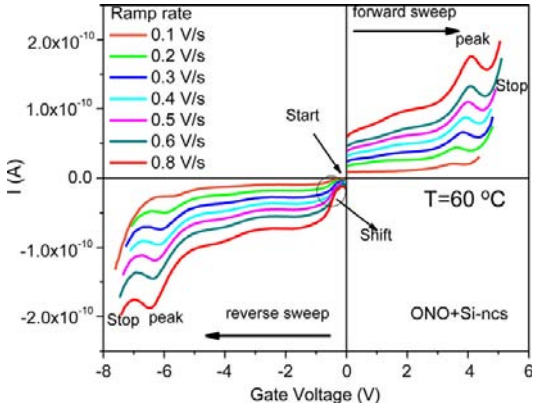


***Fig. 5a**: Constant ramp rate I-V characteristics of the implanted ONO structure showing the current peaks*

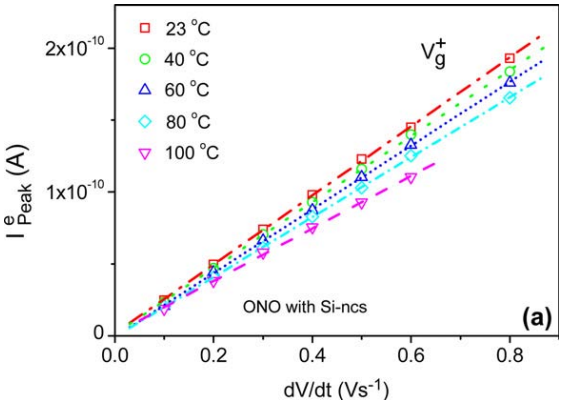


***Fig. 7b**: Electron current peak magnitude vs ramp rate. The linear relation indicates that the current peak is a displacement current.*

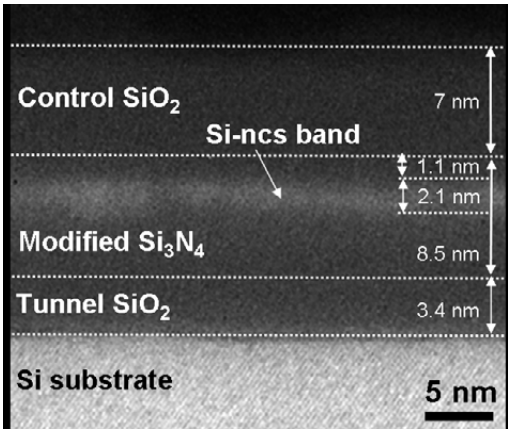


***Fig. 7c**: Cross section EFTEM image of the SiO_2/Si-Nc Si_3N_4/SiO_2 structures under study.*

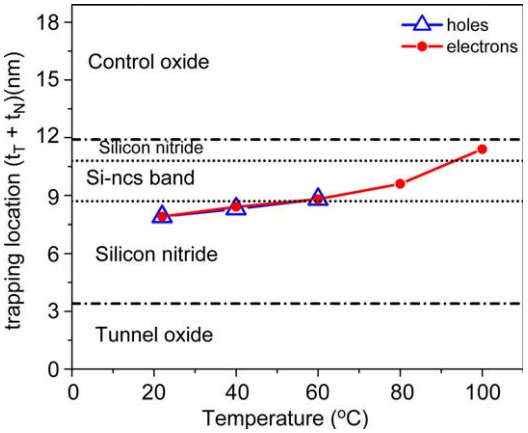


***Fig. 7d**: Variation of the trapping location of the injected carriers with temperature.*

F. Hybrid organic thin film transistor by laser-induced-forward-transfer (LIFT)

P. Dimitrakis, P. Normand, S. Chatzandroulis, M. Makriyianni[1], I. Zergioti[1], A. Speliotis[2]

[1]Department of Physics, School of Applied Sciences, NTUA (GR)
[2]Institute of Materials Science, IMS-NCSR "D"

The Laser Induced Forward Transfer (LIFT) technique is a promising alternative for maskless manufacturing of organic electronic components on flexible substrates when usual techniques, such as inkjet or roll-to-roll printing, cannot be used. Our research activities in this area were focused on the fabrication of organic thin-film transistors (OFETs) using solid phase LIFT semiconducting polymer material. The LIFT step carried-out at NTUA for the deposition of regioregular poly-3-hexylthiophene (P3HT) materials was successfully integrated to the device process flow developed at IMEL for bottom gate OFETs.

More specifically, a dry silicon dioxide layer 80-100nm thick was first grown on an implanted p-type Si substrate (receiver substrate) acting as the gate oxide and the gate electrode respectively. Au/Ti metal pads were sputtered (IMS) onto the SiO_2 layer through a shadow mask, forming the source and drain electrodes. Then, the polymer material (RR-P3HT) was transferred using the LIFT technique from a donor substrate (i.e., a quartz substrate with spin-coated P3HT materials) onto the receiver substrate placed in between the source and drain electrodes and covering partially the metal pads, as shown in figure 8. The distance between the S/D electrodes defines the gate length of the transistor which was about 100μm. Upon irradiation, the donor and the receiver substrates are located in close proximity. The resulting transistors were characterized at IMEL by parametric *I-V* measurements. It was found that the mobility of the P3HT layer is similar to that of conventional spin-coated P3HT. Furthermore, the source to drain current measurements under zero gate bias revealed that bulk conductivity of P3HT is due to a space-charge-limited-current mechanism. Figure 9 shows typical transfer characteristics, (i.e. I_{DS}-V_{GS}), at relatively low V_{DS}=-15V, of the tested OFETs from which a threshold voltage (V_T) around -20V has been extracted. Further investigations on the structural properties of the P3HT transferred layers and on the optimization of the transistor characteristics are in progress.

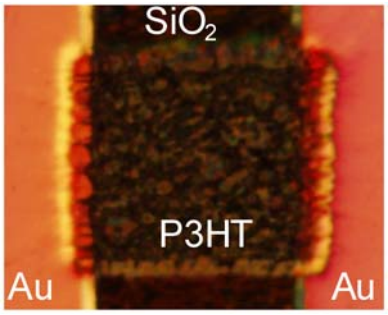


***Fig. 8**: Optical microscope image of a single P3HT layer printed using the LIFT technique on top of a SiO_2 layer and between the source/drain electrodes (Ti/Au).*

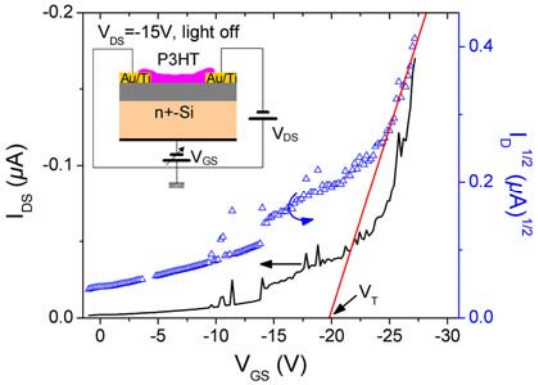


***Fig. 9**: Typical transfer characteristics of OFETs using LIFT-deposited-RR-P3HT materials.*

G. Fabrication and characterization of Ge diodes

V. Ioannou-Sougleridis, A. Golias*, A. Speliotis*, A. Dimoulas*

**Institute of Materials Science NCSR 'D'*

The objective of this research activity is the development of junction diodes on Ge substrates at temperatures lower than 400°C. The severe scaling limitations of the conventional MOSFET fabricated on a Si substrate, and especially the limited drive current, require the replacement of the channel material. Germanium constitutes an attractive technological option due to the high mobility of both electrons (two times higher than Si) and holes (four times higher than Si). Although in terms of mobility, this material is ideally suited as channel material for high-performance logic applications, the germanium substrates integration technology faces significant challenges. A critical parameter is the formation of n+/p and p+/n junction diodes using low thermal budgets and low temperatures, a requirement to preserve the high-k dielectric integrity.

The diodes were formed by phosphorus or boron ion implantation using a dose of $2x10^{15}$ ions/cm^2. In order to facilitate low temperature dopant activation, a 50nm-thick Pt layer was deposited on the diodes, followed by a thermal annealing at 350^{o}C. During annealing Pt diffuses within germanium and Ge diffuses within the Pt layer. These parallel movements lead to the formation of a platinum-germanide layer. The extent of the PtGe reaction depends mainly on the type of the implanted dopant (phosphorus or boron) and the annealing conditions. During the platinum germanide formation, process dopant activation takes place. Figure 10a shows the I-V characteristics of an n+/p diode after annealing at 350^{o}C for time intervals between 2 and 30 min. Note the high drive current of 400 A/cm^2. The characteristics exhibit a maximum value of I_{on}/I_{off} ratio of $1x10^4$. At extended annealing the quality of the diodes degrades both in the forward and the reverse bias regimes. Figure 10b shows the I-V characteristics of a p+/n diodes fabricated by the same process. In this case an excellent value of I_{on}/I_{off} ratio of $1x10^5$. These characteristics of both n+/p and p+/n diodes reveal that the metal induced dopant activation process could resolve the issue of low temperature diode formation on germanium substrates

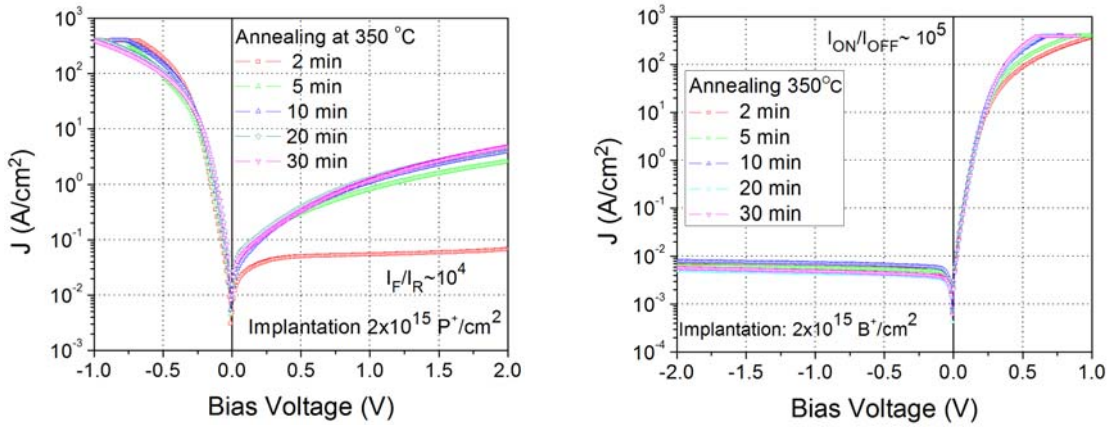


Fig. 10: *J-V characteristics of n^+/p (a) and p^+/n (b) Ge diodes as a function of annealing time at 350^{o}C. The diodes were fabricated by ion implantation, Pt deposition and annealing*.

PROJECT OUTPUT in 2009

Publications in International Journals

1. "Hybrid organic-inorganic materials for molecular proton memory devices", E. Kapetanakis, A.M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand, , Organic Electronics: physics, materials, applications 10, 711-718, 2009.
2. "Temperature-dependent low electric field charging of Si nanocrystals embedded within oxide-nitride-oxide dielectric stacks", N. Nikolaou, P. Dimitrakis, P. Normand, P., S. Schamm, C. Bonafos, G. Ben Assayag, A. Mouti, V. Ioannou-Sougleridis, Nanotechnology 20, Article number 305704, 2009.
3. "Ultra-low-energy ion-beam-synthesis of Ge nanocrystals in thin ALD Al2O3 layers for memory applications", P. Dimitrakis, A. Mouti, C. Bonafos, S. Schamm, G. Ben Assayag, V. Ioannou-Sougleridis, B. Schmidt, J. Becker, P. Normand, , Microelectronic Engineering 86, 1838-1841, 2009.
4. "Structured ZnO-based contacts deposited by non-reactive rf magnetron sputtering on ultra-thin SiO2/Si through a stencil mask", A. Barnabé, M. Lalanne, L. Presmanes, J.M. Soon, Ph. Tailhades, C. Dumas, J. Grisolia, A. Arbouet, V. Paillard, G. BenAssayag, M.A.F. van den Boogaart, V. Savu, J. Brugger, P. Normand, Thin Solid Films 518, 1044-1047, 2009.

Publications in International Conference Proceedings

1. "Memory Structures Based on the Self-organization of Cu Nanoparticles Deposited by Hot-Wire CVD on Polythiophene Layers", P. Dimitrakis, G. Papadimitropoulos, L. Palilis, M. Vasilopoulou, P. Normand, P. Argitis, and D. Davazoglou, ECS Trans. 25, 1073, 2009.
2. "Metal induced low temperature activation and La2O3 passivation of germanium n+/p and p+/n junctions", V. Ioannou-Sougleridis, A. Dimoulas, P. Tsipas and Th. Speliotis, proceedings of the 39th European Solid-State Device Research Conference (ESSDERC) September 14-18 Athens, Greece pp 367-370.

3. "Localized silicon nanocrystals fabricated by stencil masked low energy ion implantation: effect of the stencil aperture size on the implanted dose" R. Diaz, C. Dumas, J. Grisolia, T. Ondarçuhu, S. Schamm, A. Arbouet, V. Paillard, G. BenAssayag, P. Normand, J. Brugger, MRS Symp. Proc. 1160, pp. 61-66, 2009

Conference Presentations

1. "Memory Structures Based on the Self-organization of Cu Nanoparticles Deposited by Hot-Wire CVD on Polythiophene Layers", P. Dimitrakis, G. Papadimitropoulos, L. Palilis, M. Vasilopoulou, P. Normand, P. Argitis, D. Davazoglou, , EUROCVD-17 and CVD-XVII, 216th Meeting of the Electrochemical Society, 4-9 October 2009, Vienna, Austria.
2. "Ultra-low-energy ion-beam-synthesis of Ge nanocrystals in thin ALD Al2O3 layers for memory applications", P. Dimitrakis, A. Mouti, , C. Bonafos, S. Schamm G. Ben Assayag, V. Ioannou-Sougleridis, B. Schmidt, J. Becker, P. Normand, INFOS 2009, 29 June – 1 July, Cambridge, UK.
3. "Metal induced low temperature activation and La2O3 passivation of germanium n+/p and p+/n junctions", V. Ioannou-Sougleridis, A. Dimoulas, E. Golias, Th. Speliotis, 39th ESSDERC, September 14-18, Athens, Greece.
4. "High Performance Germanium n+/p and p+/n Diodes Using Low Temperature Metal Induced Dopant Activation and La2O3 Passivation", A. Dimoulas, P.Tsipas, Th. Speliotis, V. Ioannou-Sougleridis, 216th Electro-Chemical conference, October 4 - 9, 2009 , Vienna, Austria.

Invited Talks and Tutorial lectures

1. "Discrete charge storage memories", P. Dimitrakis, Workshop on Nanoelectronics and Nanophotonics, Ankara, Turkey, January 26-28, 2009 (invited talk)
2. "Nanoparticle Memories: CMOS, Organic and hybrid approaches", P.Dimitrakis, Winter School on Nanoelectronics and Nanophotonics, Bilkent University, Ankara, Turkey, January 20-25, 2009 (tutorial lecture)
3. "The Physics of Advanced and Emerging Flash Memories", P. Dimitrakis, Sympos. H, Tutorial Notes, MRS Spring Meeting, 13-18April, San Francisco 2009 (Tutorial lecture)

Edition of Conference Proceedings

1. Proceedings of the 34th International Conference on Micro- and Nano-Engineering, MNE 2008, Athens, Greece, September 15-19, 2008, edited by I. Raptis, E. Gogolides, P. Normand and A. Tserepi., Microelectronic Engineering 86 (4-6), pp. 435-1518, April-June 2009.

Conference Organization

1. 39th European Solid-State Device Research Conference (ESSDERC), Athens, 14-18 September, 2009, Program co-Chair: P. Normand, Poster Session co-Chair: P. Dimitrakis.
2. Workshop "Nanotechnology for electronic and photonic applications", Athens, 18 September, 2009

Patent

1. International patent application (PCT/GR2009/000023, 14/04/2009), Memory devices using proton-conducting polymeric materials, Inventors: E. Kapetanakis, A.M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand.

Project II.3 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), Ulf Soderval (Chalmers University), Bengt Nilsson (Chalmers University).

Objectives:

- 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.

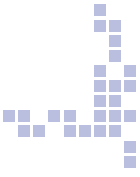
MAIN RESULTS IN 2009

A. Fabrication and electrical characterization of molecular layers for nanotransistors

D.Velessiotis, M. Douvas, N.Glezos, P.Argitis

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 such as 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) and vertical structures using an STM or cAFM tip as the upper electrode. We have investigated both quantum conductivity effects as well as charging effects. During this year we have concentrated on the investigation of planar dipole devices as well as nanotransistors. The STM system was also used fore film characterization.

The basic test circuit template contains three types of devices a) a matrix set of opposite electrodes with channel distance L=15,25,…,200nm and channel widths W=50,…,200nm. b) a matrix set of parallel electrodes with channel width W=2μm and a set of transistors with symmetric planar gates with L=50,75nm and W=50,100nm. The electrode setup was designed by our group and then fabricated using e-beam lithography at the Nanofabrication Laboratory (Chalmers) as part of the MC2Access project. The aim of the research is to study the transport characteristics of deposited POM molecular layers and distinguish the tunneling from the percolation region of the transport mechanism. More specifically we wish to fabricate a molecular transistor which is based on the control of the percolation threshold through the gate voltage.



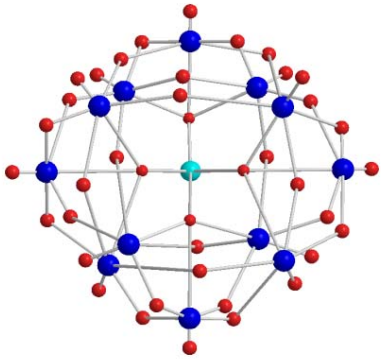


Fig1 *The Tungsten POM used in these experiments. The central Phosphorus hetero-atom binds 40 Oxygen (red) and 12Tungsten(blue):atoms.*

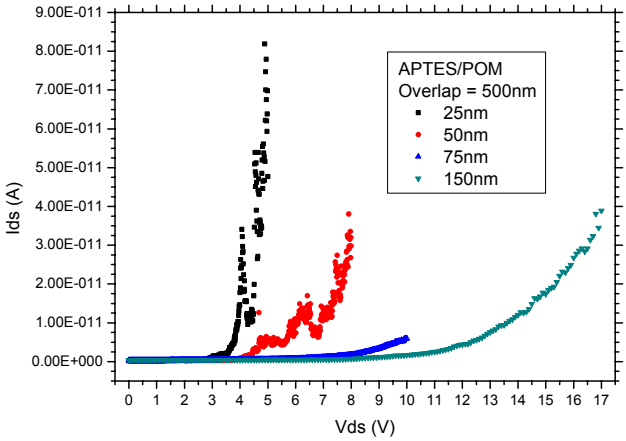


Fig2 *Electronic transport characteristics in the case of parallel nanoelectrodes with an overlapping width W=500nm and lengths L=25,50,75,150nm.*

As it may be seen in figure 2, in the case of small distances (25,50nm) the currents are higher although the small number of molecules between the electrodes cause instabilities. For example in the case of L=25nm the estimated number of molecules is smaller than 10 across a line vertical to the electrode surfaces. In the case of larger distances the tunneling distance results in much smaller currents and percolation is the basic mechanism here. The tunneling regimes were analyzed according to the discussion of Simmons , a low voltage regime and a Fowler – Nordheim regime (figure 3).

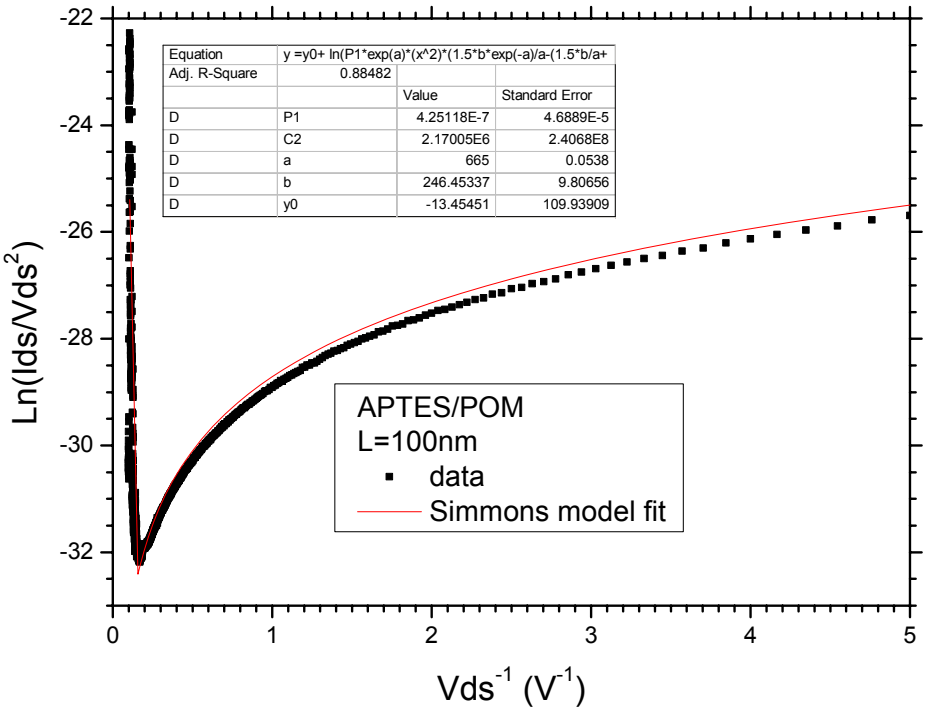


Fig 3*. An example of the Fowler – Nordheim analysis for the I-V characteristics., Since the horizontal axis corresponds to 1/V the low voltage region appears to the right of the minimum point and the Fowler – Nordheim part to the left. The minimum transition point depends on the value of the effective barrier hight.*

The transistor behavior is described in figures 4. The percolation threshold is regulated by the gate voltage.

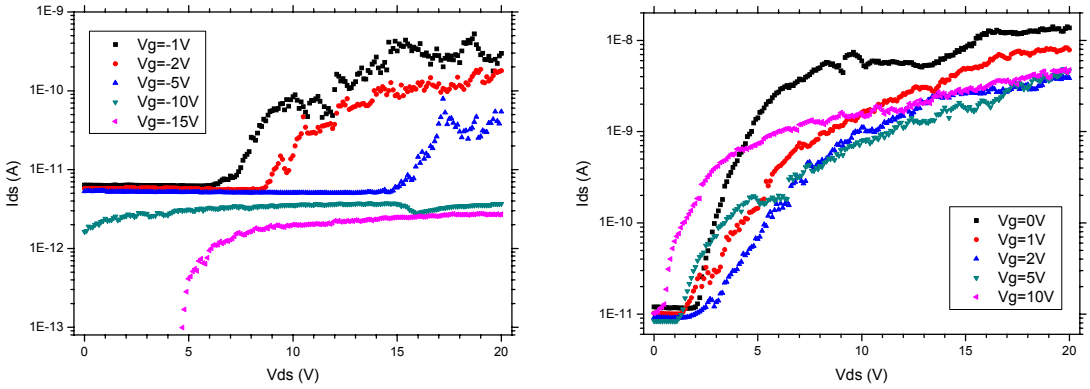


Fig 4 *Characteristics of a molecular monolayer transistor with L=50nm. When a negative gate voltage is applied (left) the result is the suppression of the percolation paths that the electrons have available and a decrease in the currents. The onset of conductance (percolation threshold shifts to larger values. A positive gate bias has no special effect as expected (right).*

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.

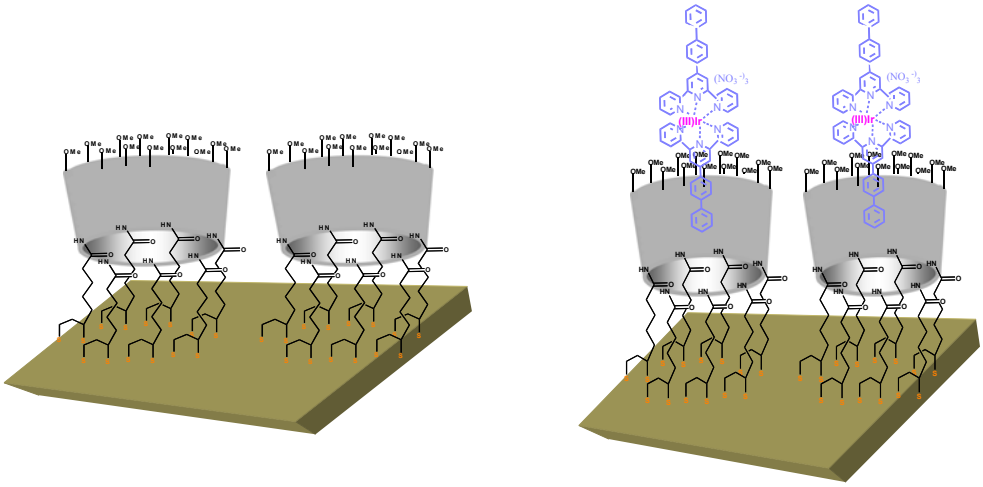


Fig. 5. *Schematic representation of the surface organization of CD* ***DMBLIP*** *and with the metalloguest* ***IrGuest .***

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 :

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

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 6). 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 φ=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.

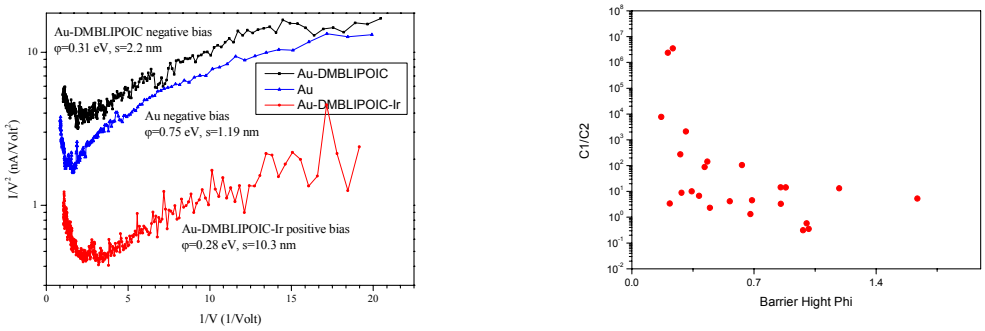


***Fig. 6**. Electronic transport properties in STM configuration as a Fowler – Nordheim plot.. The I-V characteristics are averaged over different points on the surface. Au reference: black; **DMBLIP** on Au, blue line; **IrGuest/DMBLIP** on Au, red line. The ratio of the C1., C2 coefficients as a function of the barrier height are also and measure of the effect. In the case of smaller measured voltages, the F-N region dominates over the linear region.*

PROJECT OUTPUT IN 2009

Publications in International Journals

1. Charge carrier mobility in sulphonated and non-sulphonated ni phthalocyanines: Experiment and quantum chemical calculations , Šebera, J., Nešpurek, S., Kratochvílová, I., Záliš, S., Chaidogiannos, G., & Glezos, N. (2009).. European Physical Journal B, 72(3), 385-395.
2. Low voltage operating OFETs based on solution-processed metal phthalocyanines , Chaidogiannos, G., Petraki, F., Glezos, N., Kennou, S., & Nešpurek, S. (2009).. Applied Physics A: Materials Science and Processing,96(3), 763-767.
3. Hybrid organic-inorganic materials for molecular proton memory devices., Kapetanakis, E., Douvas, A. M., Velessiotis, D., Makarona, E., Argitis, P., Glezos, N., et al. (2009). Organic Electronics: Physics, Materials, Applications, 10(4), 711-718.
4. Quantitative force and mass measurements using the cantilever with integrated actuator and deflection detector., Woszczyna, M., Zawierucha, P., Swiatkowski, M., Gotszalk, T., Grabiec, P., Nikolov, N., Glezos N. (2009). Microelectronic Engineering, 86(4-6), 1043-1045.
5. Data Modeling for Tools and Technologies for the Analysis and Synthesis of NANO structures , Giacomini, M.; Pastorino, L.; Soumetz, F. Caneva; Mielczarski, J.A.; Mielczarski, E.; Rangelow I. ; Gotszalk T.; Glezos N.; Huq, Ejaz; Ruggiero C,: Journal of Information Technology Research, Vol. 2, Issue 3 p 49-70 , 2009.

PROGRAM III

SENSORS and MICROSYSTEMS

Project III.1A MECHANICAL AND CHEMICAL SENSORS

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

Collaborating Researchers: D. Goustouridis

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), 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:

- Micro2DNA (IST-FP6-STREP) Contract No 027333, 1/2/2006-31/5/2009
- GSRT-PENED 03ED630, 11/2005-6/2009
- Lab-on-chip, Corralia, National Funds and European Regional Development Funds, NSRF 2007–2013, 1/11/2009-31/10/2012

MAIN RESULTS IN 2009 :

In 2009, our main activities were focused on the following tasks:

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

B. Polymer based chemical sensor arrays

C. Capacitive Type Sensors

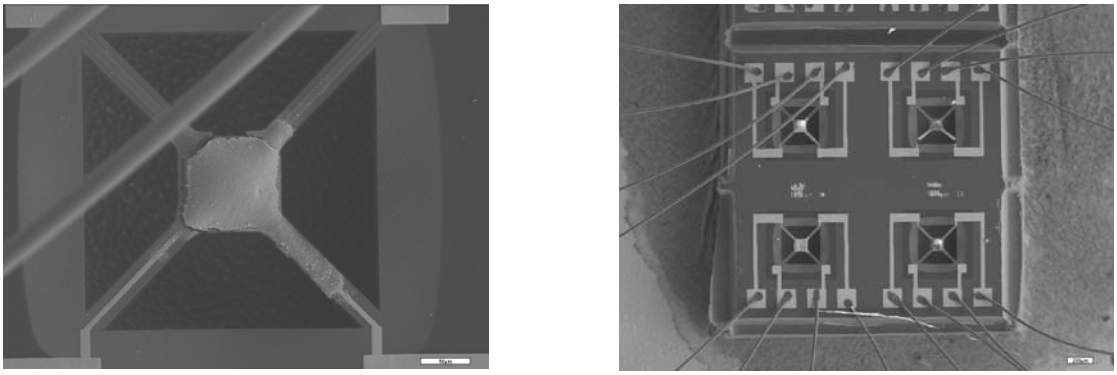
A. Low power Metal-Oxide (MOX) Chemical Sensors*

R. Triantafyllopoulou and C. Tsamis

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.

During this year, we continued and completed our research activities on gas sensors for food safety and quality applications as well as for environmental monitoring. 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.

The sensitive material was developed with two alternative technologies: (a) sputtering and (b) microdropping. In the first case thin films were prepared by reactive r.f. magnetron sputtering using a 99.9% pure SnO_2 target. 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 (Fig.1a). 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 SnO_2:Pd deposited on a micro-hotplate using micro-drop technique and (b) of a sensor array with micro-dropped nanostructured sensitive materials SnO_2:Pd and WO_3:Cr, mounted on a package.*

Sensors were characterized in various ambient (CO, NO, NH_3) using two alternative methodologies: (a) isothermal mode operation and (b) pulsed mode operation, for gas concentrations ranging from 10 to 500 ppm. Typical response of sputtered SnO_2 gas sensors towards CO is shown in fig. 2a, for isothermal mode. Operation in pulsed temperature mode, results in higher sensor sensitivity and enhanced selectivity, with reduced power consumption. 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. In Fig. 2b the response of micro-dropped SnO_2:Pd gas sensor is shown for two different cycles. Improved results are obtained compared to isothermal mode, the enhancement being larger as the low temperature of the pulsed temperature cycle reduces.

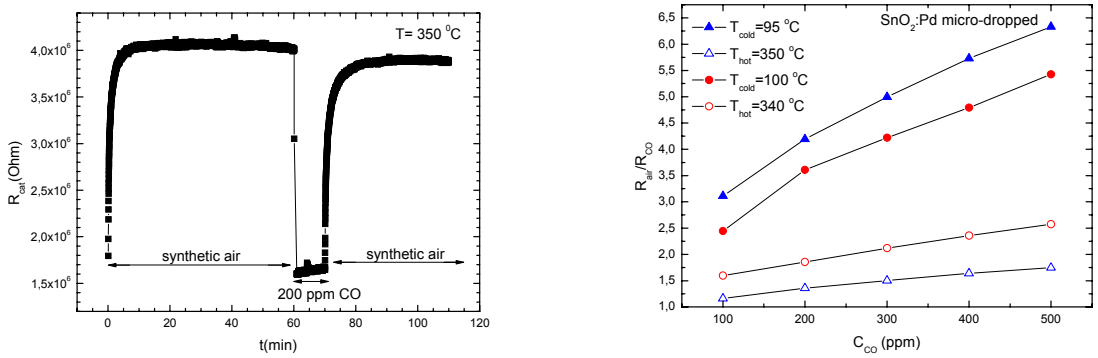


Fig. 2: *(a) Typical response of gas sensors with* sputtered SnO_2 towards detection of 200 ppm CO. *(b) Low power operation and CO detection enhancement for micro-dropped SnO_2:Pd gas sensors working at various pulsed mode cycles*.

B. Polymer based chemical sensor arrays

K. Manoli[1,2], P. Oikonomou[1,2], D. Goustouridis[1], M. Sanopoulou[2], I. Raptis[1]

[1]Institute of Microelectronics, NCSR 'Demokritos'
[2]Institute of Physical Chemistry, NCSR 'Demokritos'

Must fermentation is a complex enzymatic process where, apart from the conversion of sugars to ethanol and CO_2, a variety of organic compounds are produced in orders of magnitude lower concentrations. Control of the fermentation process is critical for the organoleptic quality of the final product. The complex characteristic aroma profile of a wine or a fermenting must, produced by a variety of alcohols, esters, organic acids etc, can be identified with instrumental chemical analysis after proper extraction techniques, which are time consuming and require expensive laboratory equipment.

Our research work deals with the challenging task to monitor the must fermentation progress, and detect possible deviations from optimum fermentation with a gas sensor array, without the use of pre-concentrator steps. To achieve this goal interdigitated capacitors (IDCs) fabricated with 2.0μm conventional microelectronic technology and coated with polymeric film were employed. IDC sensor is a mature technology capitalizes on the advances of microelectronics / microsystems processes

offering high yield and low cost systems. For the particular study arrays of 8 IDEs were fabricated and coated with hydrophilic and hydrophobic polymers through a well formatted around the capacitor. The fermentation process of a particular grape must was duplicated under laboratory conditions and monitored in terms of standard chemical analysis and the response of the gas sensor array to the headspace of must samples, on a daily basis. Finally, the sensor array signals were subjected to PCA analysis. The obtained results indicate that the PCA analysis is capable of discriminating the must from the wine. It is also shown that this discrimination is the same for the two fermentations due to same initial chemical composition of both musts at and of the wines produced at the end of the process. Furthermore there is a clear difference from the response of the standard ethanol solutions.

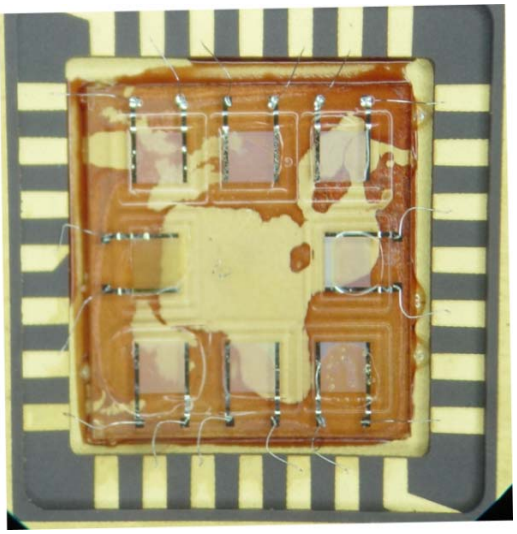


Fig. 3 *Optical micrograph of the 8-IDC sensor array coated with different polymers and packaged in a conventional DIL package.*
Thick (~50μm thickness) epoxy well (EPR resist) around every IDC allows reproducible and well defined casting of the sensing polymer layer.

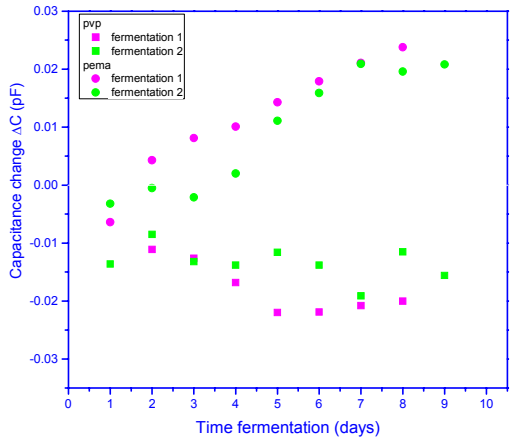


Fig. 4 *Responses of selected IDEs coated with PVP and PEMA polymer films. In general in hydrophobic polymers, the responses to the musts increase with increasing ethanol content. Difference between standard EtOH solutions and musts of the same ethanol concentration are assigned to the presence of other volatile compounds in the must*

C. 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

A capacitive type chemical/biological sensor array organized in a 16 x 16 sensor matrix has been developed. 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. The array has been tested in the detection of b-thalassemia CD19 oligonucleotides. With these tests it was proven that it is possible to detect the hybridization reaction of the CD19N oligonucleotide by converting the surface stress changes of the ultrathin silicon membrane into a change of the capacitance of the sensor. To verify this, an additional device was fabricated which has exactly the same structure as the capacitive DNA sensor with two modifications: i) no cavity was etched underneath the upper electrode

of the capacitor (this is the ultrathin silicon membrane in the sensor device) and ii) the upper electrode is fabricated out of aluminium material for simplicity. Thus the upper electrode would only check charge changes on its surface and not mechanical changes as it is not allowed to deflect. The experiments have shown that the change in capacitance during hybridization is one order of magnitude lower for the Al-electrode capacitors compared to the capacitive DNA sensors thus proving the original assumption that the capacitive sensor response is due to surface stress changes during hybridization rather than a charge accumulation/shielding effect.

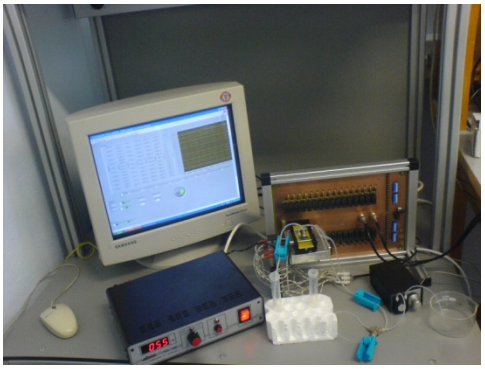


Fig.5: *In order to perform the oligo experiments tight control over the sample temperature is required. Therefore the hybridization cassette was allowed to settle on a hotplate whose temperature could be regulated to within 0.1°C. Furthermore, in order to minimize bubble formation manual pinch valves were introduced in the fluidic circuit thus increasing the control over the flow of the various fluids. Fluid control was achieved using a peristalting pump at the exit of the fluidic circuit. Finally a relay matrix undertakes the task of switching each sensor in the array to a capacitance meter.*

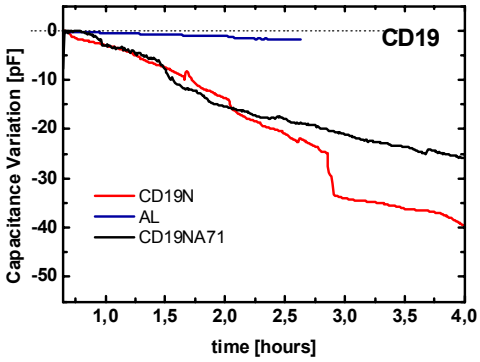


Fig. 6: *The average response of the Al capacitors when 36 nM of PCR are under analysis is depicted together with the response of two different capacitive sensor arrays for that same concentration. The change of capacitance for the Al capacitors is negligible when compared with that of the sensors thus excluding that a non mechanical effect is the reason for the DNA sensor response.*

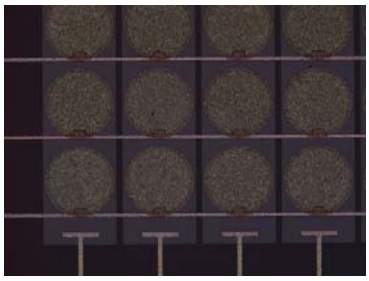


Fig. 7. *Finished close-up photo of the Al capacitor array device.*

PROJECT OUTPUT in 2009

Publications in International Journals

1. "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., vol. 86 (4-6), 1495-1498, 2009.
2. "Electrical and optical evaluation of polymer composites for chemical sensing applications", G. Dendrinos, L. Quercia, I. Raptis, K. Manoli, S. Chatzandroulis, D. Goustouridis, K. Beltsios, Microelectronic Engineering, vol. 86 (4-6), 1289-1292, 2009.
3. "Novel disposable microfabricated antimony-film electrodes for adsorptive stripping analysis of trace Ni(II)" Ch.Kokkinos, A.Economou, I.Raptis, Th.Speliotis Electrochem. Comm. 11 250-257, 2009.
4. "Polymer/$BaTiO_3$ nanocomposites based chemocapacitive sensors", P.Oikonomou, K.Manoli, D.Goustouridis, I.Raptis, M.Sanopoulou Microelectron. Eng. 86 1286-1289 2009.

Publications in International Conference Proceedings

1. “Capacitive sensor arrays with controllable deposition of the sensing polymer area for VOCs applications: Design and measurement considerations”, K. Manoli, D. Goustouridis, P. Oikonomou, S. Chatzandroulis, M. Sanopoulou, I. Raptis, Procedia Chemistry, vol. 1, issue 1, 176-179, 2009.
2. “Disposable micro-fabricated electrochemical bismuth sensors for the determination of Tl(I) by stripping voltammetry”, Ch. Kokkinos, I. Raptis, A. Economou, Th. Speliotis Procedia Chemistry, vol. 1, issue 1, 1039-1042, 2009.
3. “Monitoring of must fermentation progress by polymer coated capacitive vapour sensor arrays”, P. Oikonomou, K. Manoli, D. Goustouridis, E. Valamontes, I. Raptis, M. Sanopoulou IEEE Sensors 2009 (Christchurch, New Zealand, 10/2009)

Conference Presentations

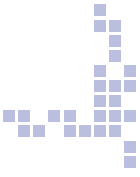
1. “Direct laser printing of polymers for gas sensing applications”, C. Boutopoulos, C. Pandis, P. Pissis, I. Zergioti, V. Tsouti, S. Chatzandroulis, , COLA 2009 10th International Conference on Laser Ablation, Singapore 22-27 November 2009.
2. “In-situ monitoring of must fermentation by polymer coated interdigitated sensor arrays”, P.Oikonomou, K.Manoli, D.Goustouridis, I.Raptis, M.Sanopoulou Instrumental Methods of Analysis (IMA 2009) (Athens, Greece, 10/2009)

PhD Theses

1. V. Tsouti, “Fabrication of Si nanocantilevers for efficient chemical detection”, conducted at IMEL and NTUA/SEMFE (June 2009)
2. R. Triantafyllopoulou, “Fabrication and characterization of Metal Oxide Chemical Sensors”, NTUA/SEMFE (October 2009)

Patents

1. Greek patent bureau (OBI), appl. no. GR20090100300 (2009), “A Capacitive Type Device for Chemical and Biological Sensing And A Method To Fabricate Same”, NCSRD, P.Normand, S.Chatzandroulis, D.Goustouridis, V.Tsouti.



Project III. 1B ENERGY HARVESTING MATERIALS AND DEVICES

Project Leader: C. Tsamis

Post-doctoral scientists: E. Makarona

PhD candidates: G. Niarchos

MSc Students: S. Katsaridis

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:

- MEMSENSE", Corralia, National Funds and European Regional Development Funds, NSRF 2007–2013, contract no. 45 (5/2009 - 4/2012)

MAIN RESULTS IN 2009

Energy Scavenging from the ambient 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.

ZnO nanorod growth for efficient energy conversion

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

*Inst. of Material Science, NCSR "Demokritos"

Over the past few years, ZnO has been the center of attention for a variety of applications, mostly due to its unique set of properties. Apart from its use in electronic and optoelectronic devices such as field-effect transistors, gas sensors, solar cells and UV emitting diodes, ZnO has showed a great potential for energy harvesting applications. Due to its coupled piezoelectric and semiconducting properties, ZnO in the form of nanostructures such as wires, rods or helices has exhibited a remarkable efficiency in the conversion of mechanical energy to electrical energy, becoming thus an excellent candidate for energy scavengers and innovative nanopiezotronic applications.

During this year, we continued our research effort on the growth of ZnO nanorods on patterned substrates using a low temperature, silicon-compatible, solution-based approach. Since accurate control of the dimensions and sizes of the resulting nanostructures was achieved by employing the ZnO seeding layer, lithographically patterned substrates were the next step towards exhibiting the potential of the ACG process to become a low-cost, environmental-friendly method for large-scale mass production. Vertically aligned nanorods were grown with high cover density and uniformity (Figures 1a,1b) onto the various patterns where the vertical alignment seemed to be further

enhanced by the physical confinement of the photoresist side-walls. It is worth noting that the growth follows even the lithographic imperfections and the undercuts of the photoresist.

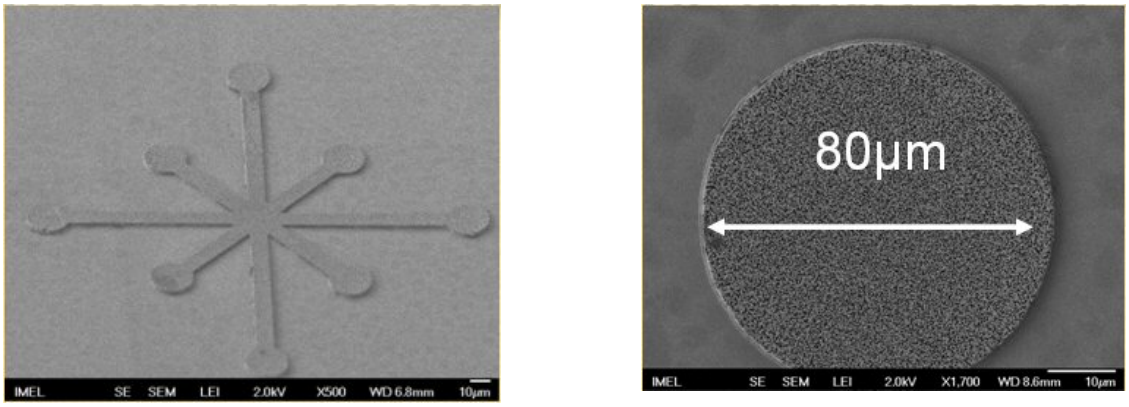


Fig. 1 *SEM images of patterned areas where ZnO nanorods have be grown using the hydrothermal technique.*

As can be seen from Figure 2a, ZnO nanorods can be classified into four different types: I) Regular Hexagonal-shaped, II) Elongated Hexagonal-shaped, III) Asymmetric Hexagonal-shaped and IV) Irregular (non-hexagonal) shaped nanorods. Statistical analysis shows that the number of hexagonal-shaped (Type I, II and III) nanorods is significantly larger (80-85%) compared to non-hexagonal (type IV) ones, indicating that the process conditions favour the growth of hexagonal based structures. The distribution between the various types of nanorods does not depend on the concentration of the aqueous solution. Further analysis reveal that as we decrease the concentration of the aqueous solution from 10mM to 5mM the percentage of regular hexagonal nanorods (Type I) decreases, while the number of enlongated (Type II) and asymmetric (Type III) nanorods increases.

Besides the shape distribution, it is important to know the size distribution of the nanorods. We observed that, increased concentrations (10mM) allow for the production of more uniform and denser arrays but with a compromise on the precision of the size control. On the other hand, however, lower concentration nutrient solutions (5mM) provide a better control over the size dispersion of the produced nanorods (Fig 2b). Knowledge of size distribution in combination with FEM modelling can provide a useful methodology for the optimization of process parameters for the fabrication of patterned nanorod arrays to be implemented in nanogenerators with improved energy conversion efficiency.

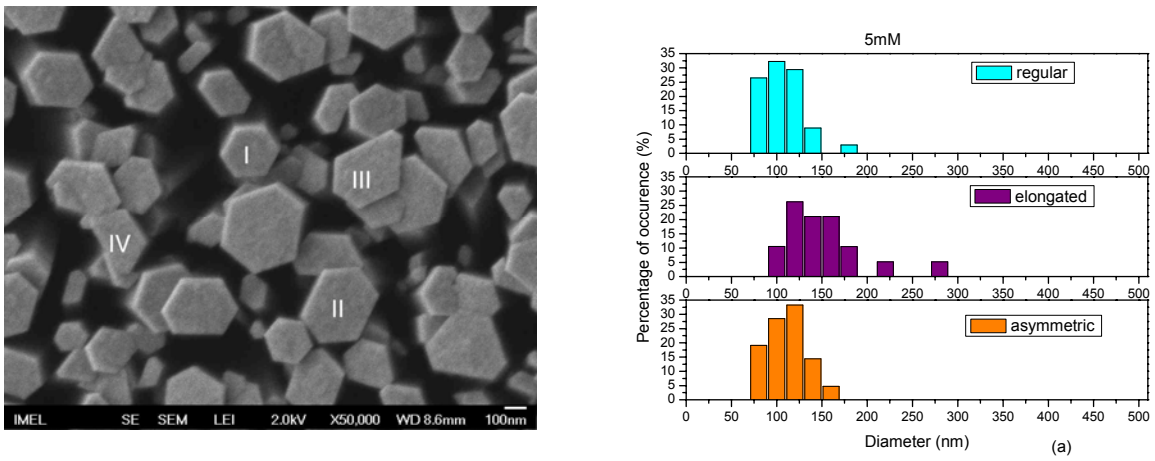


Fig. 2 (a) *SEM images of ZnO nanorods. Various shapes of hexagonal (I), (II), (III) and non-hexagonal (IV) nanorods can be identified* ***(b)*** *Size distribution of hexagonal-shaped nanorods.*

PROJECT OUTPUT in 2009

Publications in International Journals

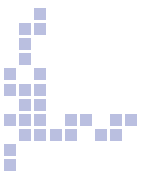
1. “Growth of ZnO nanorods on patterned templates for efficient, large-area energy scavengers”, G. Niarchos, E. Makarona and C. Tsamis , To appear in Journal of Microsystems Technology.

Publications in International Conference Proceedings

1. “Growth of ZnO nanorods on patterned templates for energy harvesting applications” , “Niarchos G., Makarona E. and Tsamis C., Proc. of SPIE Vol. 7362:73621L-1, (2009)

Conference Presentations

1. “Modeling and optimization of ZnO nanostructure arrays for improved energy conversion efficiency”, G. Niarchos, E. Makarona, C. Tsamis, Third International Conference on One-dimensional Nanomaterials (ICON), 7-9 December 2009, Atlanta, Georgia (Oral)
2. “Growth of ZnO nanorods on patterned templates for energy harvesting applications”, Niarchos G., Makarona E. and Tsamis C., Microtechnologies for the New Millennium 2009, 4-6 May 2009, Dresden, Germany (Poster)



PROJECT III.2 : 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

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", Contract No 027804, 1-1-2006-30-6-2009
- EU, FP7-ICT, STREP, "PYTHIA", Contract No 224030, 1-5-2008-30-4-2011

MAIN RESULTS IN 2009

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

Monolithic silicon optocoupler array chips are properly biofunctionalized to affinity biosensors. The optocouplers consist of silicon nitride waveguides that optically link silicon LEDs and silicon photodetectors (Fig.1). The light emitters are silicon avalanche diodes that emit light when reverse biased beyond their breakdown voltage. The optical device is transformed to biosensor by spotting the waveguides with ss DNA (Fig.2) probes and by coupling a microfluidic compartment on top to allow for the supply of the reagents and the sample. Binding of the counterpart ss DNA changes the optical coupling efficiency and the detector photocurrent and allows for simultaneous detection of a variety of molecules.

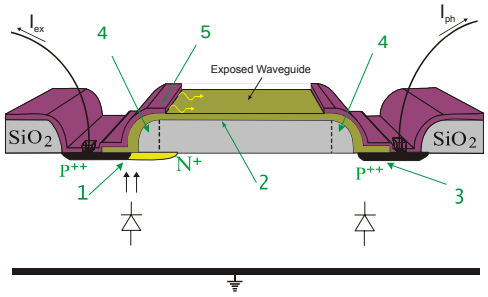


Fig. 1. *Schematic of the monolithic silicon optocoupler showing the LED on the left (1), the silicon Nitride waveguide (2) in the middle and the detector on the right (3). The thick (3 microns) silicon dioxide (4) spacers at either end of the optical link provide for the smooth fiber bending to suppress bending losses. The cladding layer (5) is removed to exposed the bioreaction waveguide surface.*

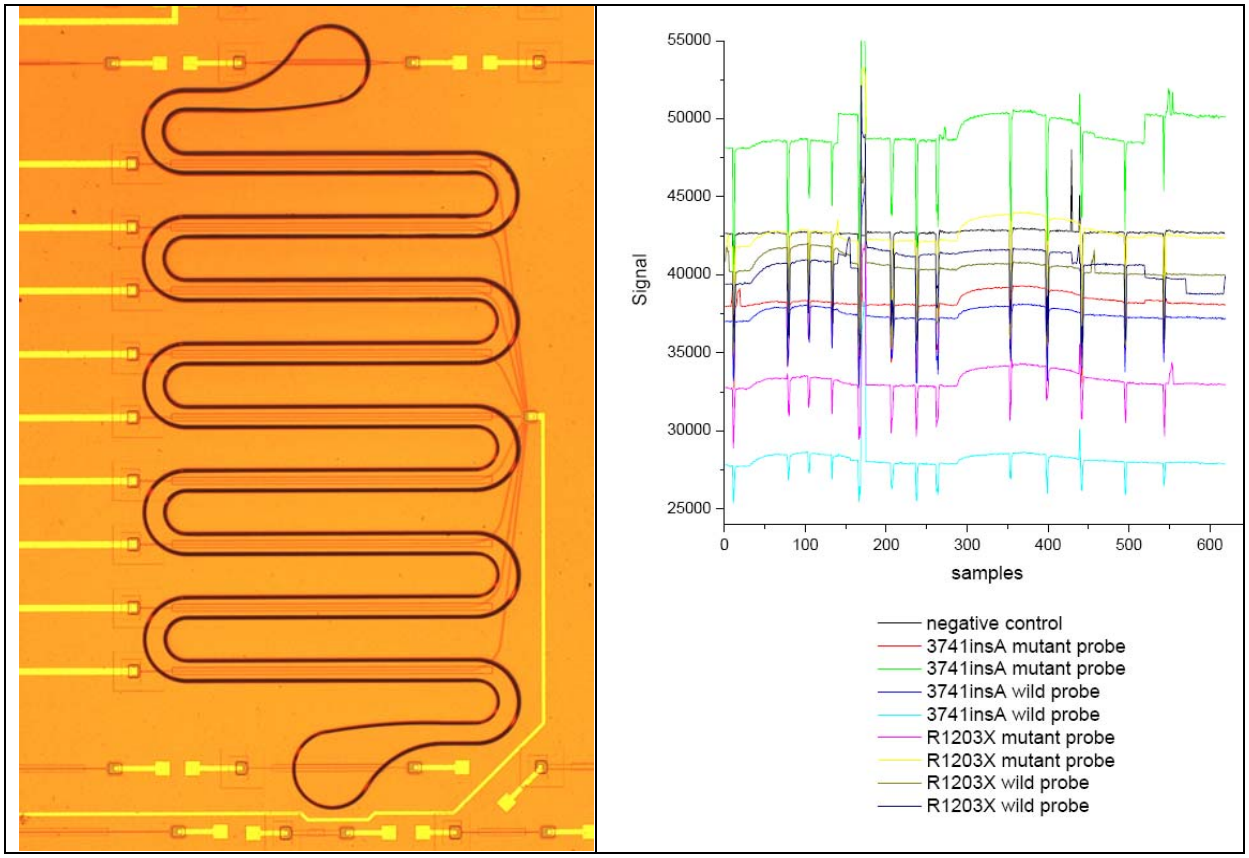


Fig. 2. View of the chip (left) and multi-analyte DNA detection sequence (right).

The chip photograph shows the nine LEDs on the left and the single detector on the right where all waveguides converge.
The middle waveguide has a length of 2400 μm, a width of 8 μm. The waveguides for most of their length are parallel with a pitch 400 μm.
Also shown is an open meandering SU-8 150 μm wide microchannel that extends over all nine waveguides and has two input-output fluidic ports
(upper-lower side). From the Al interconnect geometry it is implied that all the contact pads (not shown) are brought on the left side of the chip.
The real-time response from a chip spotted with DNA probes as indicated in the legend during hybridization reactions with PCR products.
The testing sequence was as follows (Samples=time step):
1xHEN buffer: start to sample# 25; Combined PCR products from healthy individual DNA corresponding to mutations R1203X & 3741insA:
sample# 25-100; Washing with 1xHEN: sample# 100-130; Washing with 0.5xHEN: sample# 130-160; Washing with 0.25xHEN: sample# 160-200;
Washing with 0.125xHEN: sample# 200-235; Washing with 1xHEN: sample# 235-260;
Combined PCR products from patients with the mutations R1203X & 3741insA: sample# 260-350; Washing with 1xHEN: sample# 350-400;
Washing with 0.5xHEN: sample# 400-450; Washing with 0.25xHEN: sample #450-500; Washing with 0.125xHEN: sample #500-550;
Washing with 1xHEN: sample #550-end of run. The negative spikes are due to stray light interaction following the instrument lid opening.

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.*

In the framework of the PYTHIA project, www.pythia-project.eu, a novel approach, Broad-Band Mach-Zehnder Interferometry (BB-MZI) (fig. 3a) is explored as an alternative operation principle based on a monolithically integrated biosensor array, fabricated by standard silicon technology. This

radical concept will be applied to the early diagnosis of human diseases through the label-free, multi-analyte detection of gene mutations and proteins.

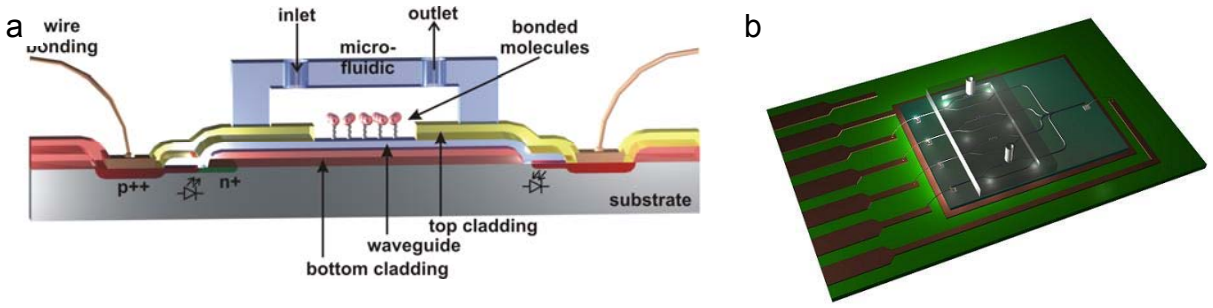


***Fig. 3**: a) Cross section of the basic sensor concept with the integrated light source, planar waveguide (sensing arm) and photodetector. b) Schematic of the fully-integrated biosensor with an array of BB-MZI devices*

The basic sensor scheme consists of a VIS-NIR light source and a waveguide monolithically fabricated on a silicon wafer, while its principle of operation is the spectroscopic interference due to the optical path difference originating by biochemical events. The signal can be recorded either via an also monolithically fabricated photodetector or via an external spectrophotometer. The integrated nature of the basic biosensor scheme allows for the development of arrays tailored to specific diagnostic applications. Each biosensor array will be comprised of individually functionalized light source/optical waveguide series coupled to a single detector for multiplexing operation. Encapsulation with an appropriately designed microfluidic system will allow for the easy delivery of the samples to be analyzed and ensure the facile contact with the external low-noise electronic components. The encapsulated array will be fixed on a cartridge (fig. 3b), ready to be manually inserted to its final position in the housing, where it will be directly connected to the optical and electrical interconnects.

Through extensive 2D and 3D optical simulation with BeamProp software (RSoft Inc.) it was proved that the suggested approach is a promising sensing concept for truly integrated highly sensitive label-free optoelectronic transducers. In addition the simulation work revealed some design considerations that may affect the sensing performance of the suggested concept. The Y junctions proved to have a significant effect on the transmitted spectrum result in a distortion away from the ideal sinusoidal shape expected from the ideal Y junctions supporting two optical paths with different lengths. Nevertheless such a distortion in no way compromises the inherently high sensitivity of the structure in detecting small changes in the effective refractive index of the exposed arm.

The first batch of un-optimized optoelectronic transducer arrays was fabricated and evaluated. The electrical and optical characterization of these optoelectronic transducers provided a solid confirmation of the BB-MZI concept and useful information for the design optimization of the biosensor chips. The transducers were functionalized and encapsulated with a microfluidic cell to be possible to evaluate them in real conditions. For the first evaluation of the PYTHIA device performance, model assays were used. For the Biotin-Streptavidin model assay, the detection of streptavidin in the picomolar range was easily demonstrated, which is comparable with the state of the art values for label-free biosensors. These preliminary results are promising for ultra sensitive detection of proteins and DNA mutations.

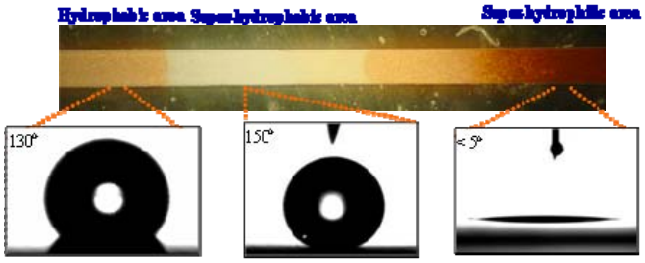
The progress in the design and fabrication of the biochip along with the preliminary results obtained so far are convincing that the PYTHIA biochip and measuring apparatus will be able to diagnose diseases at an early stage, determine whether one will suffer from hereditary diseases and provide head-up warnings for one's well-being.

C. Microfluidics and Microarrays

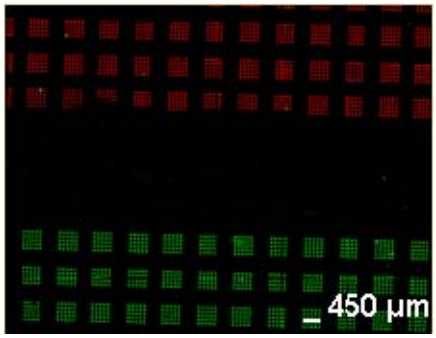
For microfluidics, we use Deep Plasma Etching and bonding to fabricate PDMS, PMMA, PEEK and Si microfluidic devices. We fabricated on chip affinity chromatography columns using TiO_2 as stationary phase for phosphopeptide separations. We also demonstrated "smart" microfluidics incorporating capillary pumping and hydrophobic valving using our "plasma toolbox" technology (see Fig. 4a).

In addition using our plasma processes for stochastic nano-texturing of polymers, we demonstrated high density protein microarrays both on PDMS and on PMMA, with almost 10fold higher binding capacity of proteins, and 100fold increased sensitivity compared to flat substrates. We have also extended self aligned processes for protein microarrays on prepatterned surfaces to cheaper substrates (see Fig. 4b).

Detailed description of the above can be found in Project I.2 Micro and Nanofabrication using lithography and plasma etching.



(a)



(b)

Fig. 4.

Three types of surfaces in a microchannel with different wetting properties (hydrophobic, superhydrophobic and super hydrophilic) in the microchannel inner surface. The superhydrophobic stripe functions as a passive valve preventing capillary pumping of fluid from one superhydrophilic area to another

Immobilization of b-BSA (red) and RgG (green) model proteins on SU8 spots (50μm) defined through lithography, after SF_6 plasma treatment of the glass substrate

PROJECT OUTPUT in 2009

Publications in International Journals

1. "Real-time label-free detection of complement activation products in human serum by white light reflectance spectroscopy", Petrou PS, Ricklin D, Zavali M, Raptis I, Kakabakos SE , Misiakos K, Lambris JD, Biosensors & Bioelectronics, 24, p.3359-3364, 2009
2. "Ultra-thin poly(dimethylsiloxane) film-coated glass capillaries for fluoroimmunosensing applications", Niotis AE, Mastichiadis C, Petrou PS, Siafaka-Kapadai A , Christofidis I , Misiakos K, Kakabakos SE, Microelectronic Engineering, 86 p. 1491-1494, 2009
3. "Bulk fluorescence light blockers to improve homogeneous detection in capillary-waveguide fluoroimmunosensors", Mastichiadis C, Petrou PS, Christofidis I, Misiakos, Kakabakos SE, Biosensors & Bioelectronics,24,p.2735-2739,2009
4. "A monolithic photonic microcantilever device for in situ monitoring of volatile compounds", Misiakos K, Raptis I, Gerardino A, Contopanagos H. Kitsara M, LAB ON A CHIP,9, p.1261-1266, 2009
5. "Real-time detection of BRCA1 gene mutations using a monolithic silicon optocoupler array", Mavrogiannopoulou E, Petrou PS, Kakabakos SE Misiakos K, Biosensors & Bioelectronics, 24,p. 1341-1347, 2009
6. "Silicon optocouplers for biosensing", Petrou PS, Kakabakos SE, Misiakos K, International Journal Of Nanotechnology, 6, p.: 4-17 Published: 2009
7. "Capillary waveguide fluoroimmunosensor with improved repeatability and detection sensitivity", Niotis AE, Mastichiadis C, Petrou PS, Christofidis I,Siafaka-Kapadai A, Misiakos K, Kakabakos SE, Analytical And Bioanalytical Chemistry,393 p.1081-1086, 2009
8. "A low temperature surface modification assisted method for bonding plastic substrates", Vlachopoulou ME, Tserepi A, Pavli P, Argitis P. Sanopoulou M. Misiakos K., Journal Of Micromechanics And Microengineering, 19, A.N.: 015007, 2009

Publications in International Conference Proceedings

1. "Ultra-miniaturized monolithically integrated polymer coated Si optoelectronic cantilevers for gas sensing applications", Misiakos K, Raptis I, Goustouridis D, Gerardino A., Contopanagos H, Valamontes E, Kitsara M, IEEE Sensors 2009 (Christchurch, New Zealand, 10/2009)
2. "A flow-through optical sensor system for label-free detection of proteins and DNA", Petrou P.S, Zavali M, Raptis I, Beltsios K,.Kakabakos S.E, Ricklin D, Lambris J.D, Misiakos K, IEEE Sensors 2009 (Christchurch, New Zealand, 10/2009)

Conference Presentations

1. "Evaluation of biomolecular film thickness using white light reflectance spectroscopy"Kitsara M, Petrou P, Beltsios K, Raptis I, Kakabakos S, Instrumental Methods of Analysis (IMA 2009) (Athens, Greece, 10/2009).

Project III. 3: THIN FILM DEVICES for LARGE AREA ELECTRONICS

Project leader: Dr. D.N. Kouvatsos

Collaborating researchers from other projects: 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), Dr. F.V. Farmakis (Heliosphera).

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.

Funding

- GRST - PENED 03ED550, 19/12/2005–30/6/2009.

MAIN RESULTS IN 2009

A. Characterization of SLS ELA TFTs

Low temperature polycrystalline silicon thin film transistors are essential for large area electronics and high performance flat panel displays. In recent years, LTPS TFT performance has substantially increased due to important breakthroughs in the field of polycrystalline silicon crystallization and also due to the optimization of the process steps that differ from those of typical MOSFETs, mainly because of the requirement for low temperature procedures. The object of the present task was the electrical characterization of polycrystalline Silicon thin film transistors, crystallized with different variations of the advanced technique SLS ELA, and the determination of process technological parameters that affect the device performance, in order to further optimize the production of such high performance transistors.

We began studying the effect of the TFT active region film microstructure, relating the film characteristics themselves with the electrical performance and reliability characteristics of the TFTs. We found a new electrical characterization parameter ($V_{g,max}$-V_{th}), offering new insight on poly-Si trap density. This parameter proved especially useful in the understanding of degradation mechanisms under dc stress, allowing us to distinguish tail state generation (Fig. 1) from interface state generation (Fig. 2). We verified and probed the reasons for the superiority of the SLS ELA crystallization technique compared to SPC. Electrical characterization of TFTs crystallized with different SLS ELA techniques revealed specific relationships between microstructural characteristics and electrical ones.

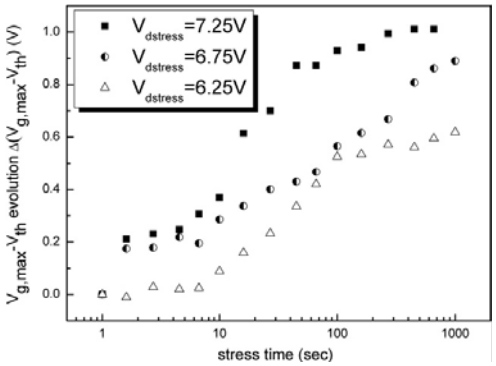


Fig. 1: Evolution of $V_{g,max}$–V_{th} (quantity proportional to the tail states density) with stress time for n-channel TFTs crystallized with the location control technique.

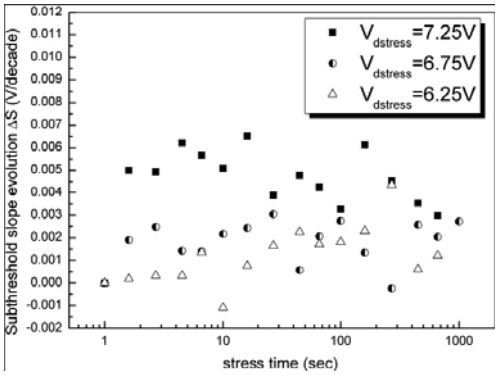


Fig. 2: Evolution of subthreshold slope S (quantity proportional to the interface states density) with stress time for n-channel TFTs crystallized with the location control technique.

Then, we examined the relationship between critical process steps and SLS ELA TFT performance. We found that the method of gate dielectric deposition significantly affects the TFT electrical parameters and also their degradation mechanisms. We also concluded that the doping and activation procedures could optimize the fabrication procedure, since a p- type doping could yield films with lower grain boundary trap densities. Channel dimensions should carefully be selected, since there are specific, technology related, narrow width and short channel mechanisms.

We also studied the role of the topology (top gate, bottom gate, double gate) on TFT performance. We observed that bottom gate structures are more likely to fail, due to the crystallization technique and the thickness of the films utilized. Even if they are operational, they will feature larger trap densities, due to the aforementioned reasons. A physically based model was developed for a double gate TFT with smaller bottom gate length than top one. The application of this model could give quantitative estimations of the oxide charge and interface trap densities.

Finally, we tried to modify the typical TFT fabrication procedure, studying the use of alternative gate dielectrics. We focused on the high-k dielectric HfO_2, fabricated capacitors using this material and studied possible, low temperature compatible gate electrodes. We concluded that the best possible gate electrode material to be used for LTPS HfO_2 TFT is tungsten (W).

To sum up, through the work within this task we extracted new characterization methodologies and new relationships between the electrical and technological characteristics of high performance LTPS TFTs, while at the same time suggesting specific optimization points for all of the critical steps in the fabrication procedure. Therefore, the work within this task is a useful tool-guide for an optimized fabrication procedure of high performance LTPS TFTs.

B. Modeling of hot carrier stress degradation mechanisms

Even though hot carrier phenomena have been widely studied in MOS poly-TFT structures, their quantitative impact in the reliability and performance characteristics of poly-TFT devices of different channel widths after electrical stressing under different stress conditions has been described only to a limited extent. Moreover, even in the models developed for the mature technologies of SOI (Silicon On Insulator) devices, typical bulk-MOSFETs and a-Si:H TFTs, the effect of subjecting devices with various channel widths under different hot carrier stress conditions has not been analyzed and mainly STI (Shallow Trench Isolation) PMOS devices have been investigated so far. Consequently, the effect of different hot carrier stressing conditions on the 1-D current-voltage characteristics as a function of the channel width needs to be further examined.

Thus, concerning the investigation of LTPS TFT degradation under DC stress, a practical model has been developed, with the key assumption being the formation of two channel regions, a defective and a non defective one. This is indicated in the schematic of Figure 3. The parameters that the model predicts are the mobility and the threshold voltage for the two regions and the extent ΔL of the degraded region. The equivalent circuit model of a device that has been subjected to electrical stress is represented by two TFTs connected in series.

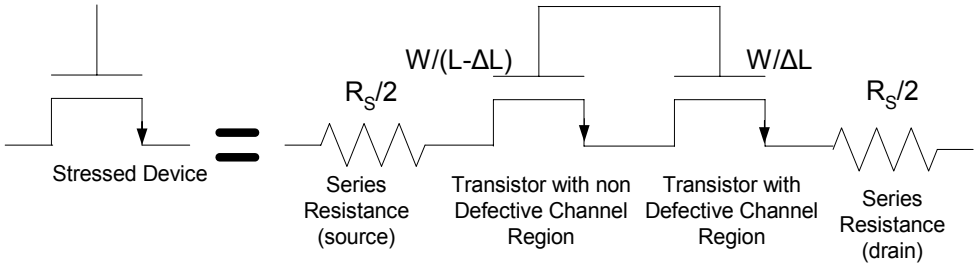


Fig 3: Schematic of TFT structure (left) and its equivalent electrical representation after electrical stressing (right). The developed model suggests the formation of two channel regions that are represented by two transistors connected in series.

In order to obtain a simple and practical expression, so as to predict the hot carrier damage for large grain size polysilicon TFTs, we use the on-current model proposed in an earlier work (Farmakis et al, IEEE Trans. Electron Dev. 2001; 48: 701-706):

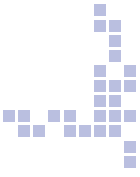
Developing the mathematical formalism of the model and assuming monoenergetic traps at the grain boundaries, we eventually arrive at an expression for I_{DS} and subsequently for the total measured resistance R_{DS} (which is equal to the $R_A + R_B + R_S$, where the indices A (or nd) and B (or d) correspond to the undamaged and damaged areas and S to the source / drain contacts) as follows:

$$\frac{g_m V_{DS} C_{ox}}{I_{DS}^2} = \left[\frac{L}{W \mu_{0,nd} \left(V_{GS} - V_{th,nd} \right)^2} - \frac{\Delta L}{W \mu_{0,nd} \left(V_{GS} - V_{th,nd} \right)^2} + \frac{\Delta L}{W \mu_{0d} \left(V_{GS} - V_{th,d} \right)^2} \right]$$

which is the fitting function of the model.

The parameter ΔL is the most critical one for the stress experiments and the fitted data that were found were in accordance with the experimental results: the extension of the degraded region for wider devices occurs faster when the channel hot electron (CHE) injection mechanism (stress condition $V_{GS,stress} = V_{DS,stress}$) is dominant and slower in the stress regime $V_{th} \leq V_{GS,stress} \leq V_{DS,stress}/2$ (where the responsible device degradation mechanism is drain avalance hot carrier, DAHC). This is shown in Figures 4 and 5, respectively.

We suggest that the model predicts the maximum value of the threshold voltage of the two devices connected in series in the circuit equivalent, as it is expected for two devices connected in series. This implies that if the degradation is uniform, the corresponding threshold voltage will be equal for the two regions (defective and non defective), whereas if the damage is non-uniform (but more or less extended along the channel) the predicted threshold voltage of the whole device is, to a good approximation, that of the one at the defective channel region (which is the maximum one). This approximation is also supported theoretically in the relevant literature. According to Tang *et al* (Solid-State Electron. 2009; 53: 225-233), in a non-uniform channel (with a different local threshold voltage), the overall threshold voltage is the weighted threshold voltage over the channel (in our case the V_{th} of each device). However, as inversion in the defective channel part is harder to achieve, reflecting a much larger weight, the overall weighted threshold voltage is very close to the average threshold voltage of the defective channel part. Indeed, the threshold voltage as a parameter illustrates the mean concentration of free carriers and not how these carriers transport between source and drain. Moreover, the damage that occurs in the defective part of the channel region is reflected in two additional parameters: the defective region length ΔL, which is proportional to the interface state and / or the oxide trap states creation, and the mobility that charge carriers exhibit in the defective channel portion that depends on the defect charge density at the Si / SiO_2 interface and / or in the bulk oxide.



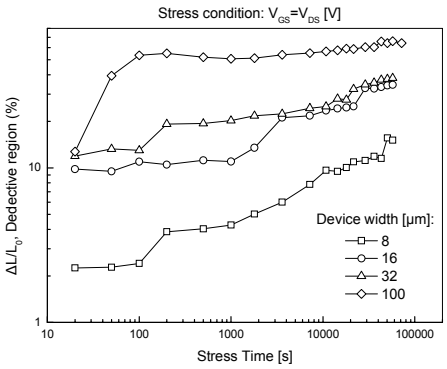


Fig. 4: Percentage variation of defective region length predicted from the model for devices of various widths W = 8, 16, 32 και 100 μm and of a common length (L = 0.8 μm). Stress condition: V_{GS} = V_{DS}.

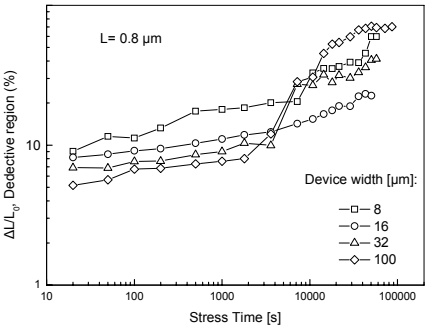


Fig. 5: Percentage variation of defective region length predicted from the model for devices of various widths W = 8, 16, 32 και 100 μm and of a common length (L = 0.8 μm). Stress condition: V_{GS} = V_{th}.

Figures 6 and 7 demonstrate the extracted threshold voltage shift (dot lines) and the overall threshold voltage shift predicted by the model (solid lines) for devices with different widths subjected to stress conditions $V_{GS,stress}$ = $V_{DS,stress}$ and $V_{GS,stress}$ = V_{th}, respectively. It is obvious (from both figures) that the model estimates the evolution of the threshold voltage of the stressed device adequately. It is noticeable that in Figure 6 the device with channel width of W = 100 μm exhibits the same behavior with the devices subjected to the stress condition $V_{GS,stress}$ = $V_{DS,stress}$ (which is an initial decrease and then an increase of the threshold voltage; it is observed both in the extracted data and in the results of the model). Moreover, in order to gain insight of the degradation mechanisms existing in each case ($V_{GS,stress}$ = $V_{DS,stress}$ and $V_{GS,stress}$ = V_{th}), the threshold voltage parameter was also extracted by using the transconductance derivative method.

Considering the mobility that charge carriers have in each region, the quality of the Si/SiO_2 interface in the defective or the non-defective portion of the channel region affects its corresponding value. By applying the model, we evaluated the mean low field mobilities $\mu_{o,nd}$ and $\mu_{o,d}$ that the model takes into account for the two stressing conditions: $V_{GS,stress}$ = $V_{DS,stress}$ and $V_{GS,stress}$ = V_{th}.

In conclusion, the two main electrical stress conditions ($V_{GS,stress}$ = $V_{DS,stress}$ and $V_{GS,stress}$ = V_{th}) favor, respectively, the two main device degradation mechanisms due to hot carriers, that is, channel hot electron (CHE) and drain avalanche hot carrier (DAHC). A simple and practical electrical model predicting the device degradation under hot carrier stress was presented. The quality characteristics of the width depended degradation were evaluated by the model. More specifically, the defective region length was found to be width depended ΔL(W), with a different dependency for each stress regime. In the application of the model, out of the I_d-V_g characteristics taken for every aging step of the devices, we fit the model function, Equation (3), derived above. From the values we obtain ($V_{th,d}$, ΔL); then, we predict the values shown in Figures 6 and 7. Thus, the V_{th} shift (ΔV_{th}) of the overall device, approximately equal to the shift in $V_{th,d}$ (the maximum of the values $V_{th,d}$ and $V_{th,nd}$), is predicted by the model (this work is included in an IEEE TED paper currently in the publication process).

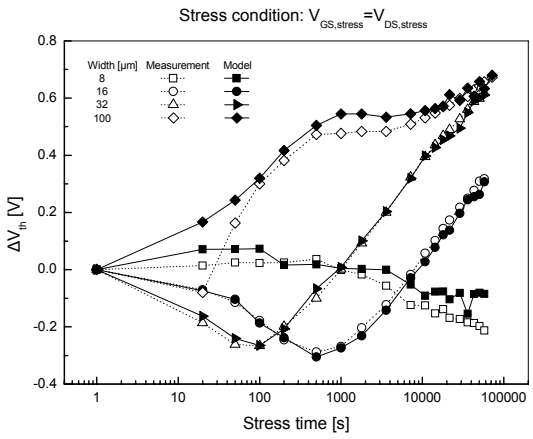


Fig. 6: Threshold voltage variation for devices of various widths W = 8, 16, 32 and 100 μm and of a common length (L = 0.8 μm). Stress condition: $V_{GS,stress}$ = $V_{DS,stress}$. Extracted threshold voltage values (dot lines and open symbols) and predicted by the model (continues solid lines and filled symbols). Experimental (measured) data.

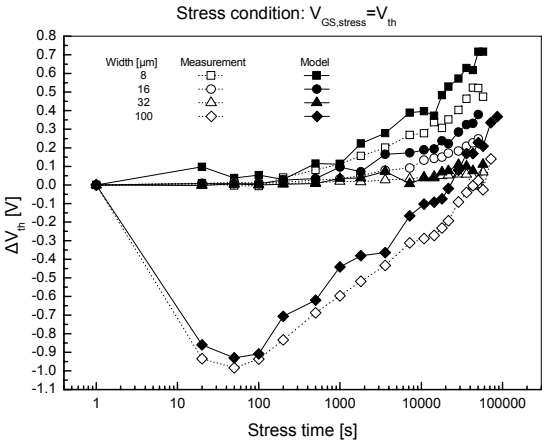


Fig. 7: Threshold voltage variation for devices of various widths W = 8, 16, 32 and 100 μm and of a common length (L = 0.8 μm). Stress condition: $V_{GS,stress}$ = V_{th}. Extracted threshold voltage values (dot lines and open symbiols) and predicted by the model (continues solid lines and filled symbols).

C. Low temperature and transient current characterization

Based on the understanding of the transient currents in polycrystalline silicon TFTs gained through investigations that culminated during the past year, a new approach for experimental determination of band gap states density (DOS), by Deep Level Transient Spectroscopy (DLTS), has been presented. An asymmetric U-shaped distribution of states in the band gap has been obtained. The results are in agreement with theoretical predictions and others experimental observations.

The influence of the longitudinal grain boundaries on thin film transistor (TFT) characteristics have also been investigated as a function of temperature. Three types of behavior have been identified: i) parameters that are not affected by the number of boundaries in the channel (swing), ii) parameters that are crucially affected (mobility) and iii) parameters that their behavior is temperature dependent (leakage current). Therefore, it is concluded that the appropriate number of boundaries in the channel, hence the channel width, must be chosen according to the needs of the corresponding application.

Finally, the role of back gate on the front channel operation of p-channel double gate devices has been investigated. The results suggest that the presence of a back gate can significantly adjust the front gate parameters and also control their temperature dependence, allowing for a desirable electrical behavior of double gate TFTs in a wide temperature range.

D. Material / optical characterization

With the work conducted within the framework of this task, during 2009 we further investigated the polysilicon film itself, as this film results from each SLS ELA technique utilized, before any transistors are fabricated in it. We characterized several advanced SLS ELA films morphologically (SEM, AFM) and optically (UV-visible spectroscopy, spectroscopic ellipsometry, XRD analysis), in order to gather detailed information on their microstructure. The XRD data revealed that the different SLS ELA techniques give a material significantly differentiated, as far as its crystallinity is concerned, from both amorphous Si and crystalline Si, probably due to its special crystalline structure, which resembles that of allo-Si. This Si crystal modification is a structure similar to graphene and consists of lamellar crystals. Therefore, the special characteristics observed in these films could be attributed to the atom arrangement itself.

PROJECT OUTPUT IN 2009

Publications in International Journals

1. “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, Thin Solid Films 517 (23), 6375, October 2009.
2. “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, Thin Solid Films **517** (23), 6364, October 2009.
3. “Degradation and lifetime estimation of n-MOS SLS ELA polycrystalline TFTs during hot carrier stressing – Effect of channel width in the region $V_{th} \leq V_{GS,stress} \leq V_{DS,stress}/2$”, Kontogiannopoulos, G.P., F.V. Farmakis, D.N. Kouvatsos, G.J. Papaioannou and A.T. Voutsas, Semiconductor Science and Technology 24 (7), 0750271, July 2009.

Publications in Conference Proceedings

1. “The effect of small geometry on the degradation performance of SLS ELA polysilicon thin film transistors”, Kontogiannopoulos, G.P., M.A. Exarchos, D.N. Kouvatsos, G.J. Papaioannou and A.T. Voutsas, Proceedings of the 29th International Display Research Conference IDRC ’09) / Eurodisplay 2009, Rome, Italy, September 2009.
2. “Short channel effects in SLS ELA polysilicon TFTs”, Proceedings of the 5th International Kontogiannopoulos, G.P., D.C. Moschou, D.N. Kouvatsos, G.J. Papaioannou and A.T. Voutsas, Thin Film Transistors Conference (ITC ’09) / 2009 Society for Information Display Europe Chapter Meeting, Paris, France, March 2009.

International Conference Presentations

1. “On the optical and structural properties of advanced SLS ELA polycrystalline silicon thin films”, Moschou, D.C. N. Vourdas, D. Davazoglou, D.N. Kouvatsos, V.E. Vamvakas and A.T. Voutsas, European Materials Research Society Spring 2009 Meeting, Strasbourg, France, May 2009.

PhD Theses

1. “Development of thin film transistor fabrication technology optimized with respect to the polysilicon film structure resulting from the crystallization process”. Despina Moschou, Ph.D. degree awarded from the Department of Informatics, University of Athens
2. “Investigation of ageing degradation effects in polysilicon thin film transistors crystallized using advanced annealing techniques”, Giannis Kontogiannopoulos, Ph.D. degree awarded from the Department of Physics, University of Athens

PROJECT III.4: CIRCUITS & DEVICES FOR SENSOR NETWORKS & SYSTEMS

Project Leaders: S.Chatzandroulis

Collaborating researcher: S. Katsafouros

PhD Candidates: P. Broutas, S. Kokorikos

External Collaborators: E.D. Kyriakis-Bitzaros

Objectives

The main objective of the activity is the development of the necessary 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

- European Space Agency (ESA) Contract No. 21339/08/NL/GLC

MAIN RESULTS IN 2009

Wireless telemetry and RF remote powering of sensor tags

Remote monitoring networks often require the development of batteryless sensor nodes that harvest energy from the environment, i.e vibration and incident RF power. RF power harvesting tags have the advantage that RF fields can be generated by controlled base stations, thus providing a more stable power supply. The block diagram of a typical batteryless sensor tag is depicted in Figure 1. It consists of the tag antenna, an impedance matching circuit, the voltage rectification unit, a microcontroller (MCU), sensors and a modulator for data transmission. The balance between the available power at the tag and the power required to operate its electronic circuitry is the most important problem in such a design.

In this task a power harvesting scheme has been proposed that reduces the minimum required level of incident RF power at the tag antenna. The power harvesting unit comprises a voltage multiplication circuit that raises voltage to a sufficient level in order to charge an array of energy storage capacitors. A low power voltage controlled switch that continuously monitors the voltage level across the capacitor array is used to activate the rest of the tag circuitry. As a result, the sensor tag can accumulate incident power that is lower than the maximum power required when it is fully active. Using the proposed scheme, a prototype has been built and tested using discrete electronic components.

The performance of the power harvester has been tested by measuring the capacitor array charging time in the near field of a resonant dipole antenna that emits 200mW at 430MHz as presented in Figure 2. In this figure the tag is continuously active for distances of 5-15cm, while charging time intervals of up to 250ms are required for distances of 15-25cm. It is evident that the accumulated energy at the capacitor array is not consumed when the incident power can directly drive the tag circuitry (distances up to 15cm). Thus, the capacitor array within this range remains fully charged after system power up and the voltage controlled switch is continuously on.

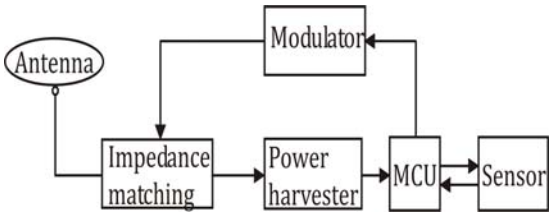


Fig. 1. *Architecture of an RF power harvesting sensor tag.*

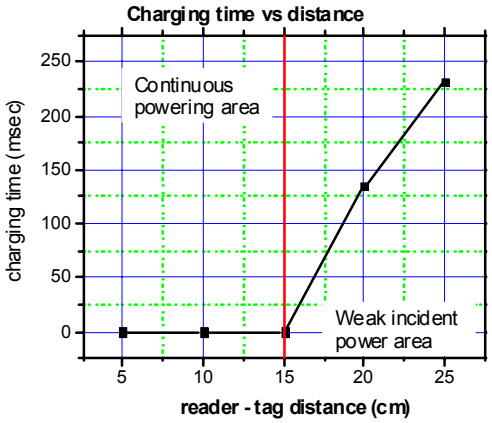


Fig. 2. *Charging time versus distance for a 70uF capacitor array. The tag operates at the near field of the base station antenna that emits 200mW at 430MHz.*

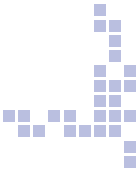
PROJECT OUTPUT IN 2009

Publications

1. P. Broutas, S. Kyriakis Bitzaros, D. Goustouridis, S. Katsafouros, D. Tsoukalas, S. Chatzandroulis, “Conceptual Design of a Wireless Strain Monitoring System for Space Applications”, “Mobile Lightweight Wireless Systems”, Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, Springer Berlin Heidelberg, Vol. 13 pp. 405-410, 2009

Conference presentations

1. P. Broutas, S. Kyriakis Bitzaros, I. Mourtsiadis, D. Goustouridis, S. Katsafouros, D. Tsoukalas, S. Chatzandroulis, “Power Harvesting Scheme for Remotely Powered Sensor Tags”, ESSCIRC, 2009. ESSCIRC '09. Proceedings of, 14-18 September 2009, Athens, Greece
2. P. Broutas, S. Kyriakis Bitzaros, D. Goustouridis, S. Katsafouros, D. Tsoukalas, S. Chatzandroulis, “Conceptual Design of a Wireless Strain Monitoring System for Space Applications”, presented in Wireless Sensor Networks for Space Applications Workshop (WiSens4Space), 1 – 2 October 2009, Santorini, Greece



PROJECT III.5: PHOTONIC CRYSTALS AND METAMORPHIC MATERIALS

Project Leaders: H. Contopanagos

External Collaborators: C. Kyriazidou, N. Alexopoulos (University of California, Irvine, USA)

Objectives

To design, optimize and fabricate photonic crystals and frequency-agile metamaterials (metamorphic materials) to be used as electromagnetically active filters and substrates/superstrates for novel embedded antenna architectures and other systems (filters, waveguides and resonators) operating in the microwave/mm-wave region, for applications in novel RF transceivers.

MAIN RESULTS IN 2009

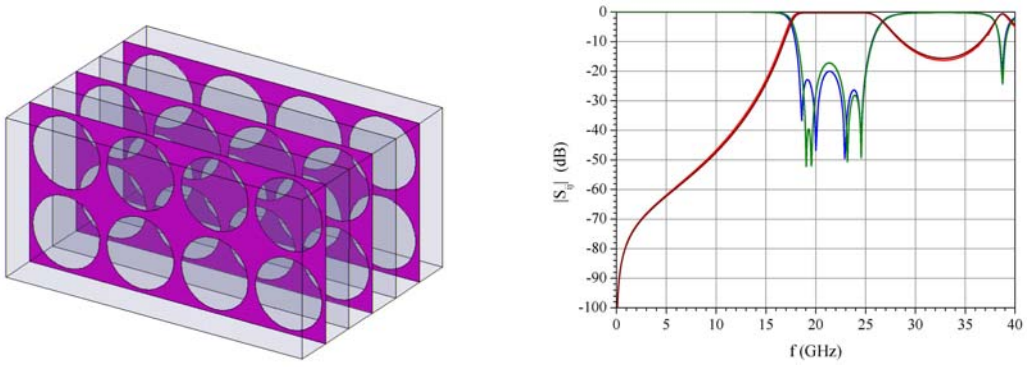
Theory and Design of Metamorphic Materials

C. Kyriazidou, H. Contopanagos and N. Alexopoulos

Composite electromagnetic media have long been the subject of interest for a variety of theoretical and practical reasons and in a variety of physical realizations as amorphous mixtures, ordered media, frequency-selective surfaces, photonic crystals etc. A wide range of interesting physical phenomena is revealed in several of these realizations, most importantly frequency-modulated reflection and transmission.

In this work we present the newly defined metamorphic materials which are artificial metallo-dielectric structures composed of passive elements and switches, that exhibit bulk electromagnetic transitions among a set of dinstinct electromagnetic states, each characterized by a specific range of values of the reflected electromagnetic field. According to the interconnect topologies of the metallic inclusions, a metamorphic material behaves, at a single frequency, as an electric conductor, a passive or active magnetic conductor, an absorber or an amplifier. Further, we have developed a completely analytical theory of scattering for these materials as well as a method of extraction of their effective permittivity and permeability at all frequencies, based on a resonant inverse-scattering theory. Detailed evaluations are given of the complex dispersive wave impedance, refractive index, permittivity and permeability functions for each metamorphic state of a specific 3-state metamorphic material and specific design rules are also derived. It is found that, as a rule, the electric and magnetic wall states are related to resonant permittivity and permeability values, respectively. Finally, it is shown that negative resonant values of the imaginary part of the resulting effective permittivities or permeabilities are consistent with energy conservation for passive electromagnetic media, despite contrary claims that exist in previous literature.

Among the many structures we have analyzed, we present the characterization of the metamorphic material when the switch topology makes it a photonic crystal composed of stacked conducting screens containing arrays of holes, scaled at microwave/mm-wave frequencies, shown in Fig. 1a in 3 monolayers.



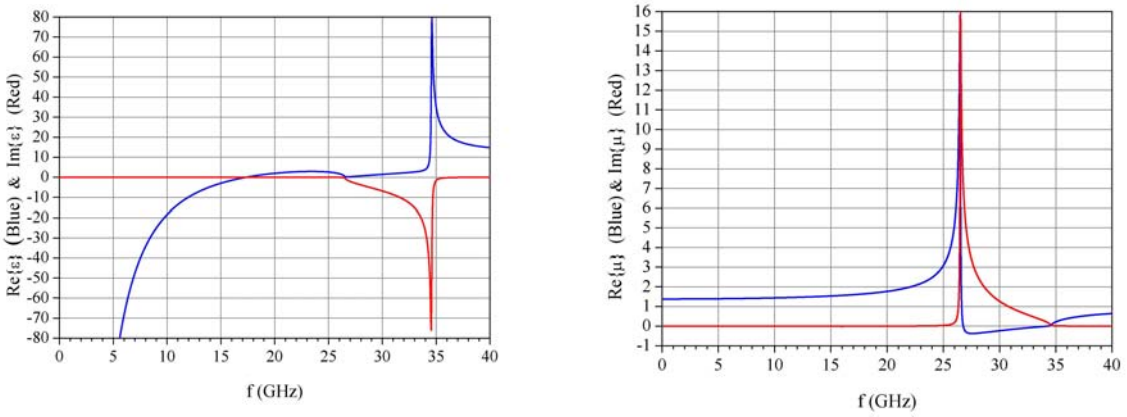
(a) (b)

Fig. 1 *a) Three stacked monolayers of metallic screens having a tetragonal lattice of large holes, immersed in a dielectric matrix. b) Reflection (Blue-Numerical/Green-Analytical) and Transmission (Red-Numerical /Brown-Analytical).*

In Fig. 1b we compare the corresponding S-matrices derived computationally through HFSS and analytically through our analytical approach. The agreement is excellent at quite high frequencies, past the plasma frequency (17 GHz) and including the multi-resonance regime.

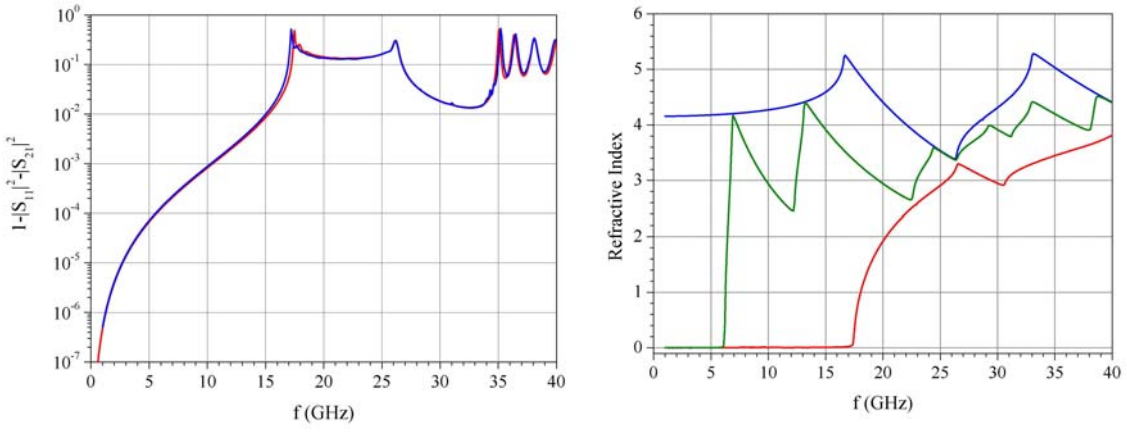
In Fig. 2a, b we present the extracted relative complex permittivity and permeability. The medium behaves as a metal up to 17 GHz, where it reaches the (artificial) plasma frequency. Thereafter it behaves as a dielectric, up to 25 GHz, and at even higher frequencies it develops very high resonant magnetization, including negative real part of the permeability, and negative imaginary part of the permittivity at select frequencies.

Contrary to the traditional view, this last property does not make the material active, provided the effective response functions are multiplexed in frequency in the way shown in Fig. 2. Indeed, we show in Fig. 3a the total power loss of a 10-monolayer metamaterial slab. The red curve is obtained analytically with input the effective functions of Fig.2, while the blue curve is a direct HFSS numerical simulation. The two results are in excellent agreement and show a positive-definite loss throughout the frequency range. Fig. 3b shows the material metamorphism of the (real part of the) refractive index as a function of frequency, for 3 switch states interconnecting the metal inclusions. This electronically adjustable dispersion reflects a corresponding reconfigurable functionality of metamorphic materials suitable for a variety of filtering applications.



(a) (b)

Fig. 2 *a) Extracted complex effective permittivity for the hole medium. b) Extracted complex effective permeability.*



(a) (b)

Fig. 3 *a) Power loss for a 10-monolayer hole medium slab. b) Dispersive refractive index for 3 metamorphic states.*

PROJECT OUTPUT IN 2009

Chapters in books

1. "Theory and Design of Metamorphic Materials", C. Kyriazidou, H. Contopanagos and N. Alexopoulos, Chapter 20 in Metamaterials Handbook, Vol. I Theory and Phenomena of Metamaterials, Part III, pp. 20.1-20.18, Filippo Capolino (Editor) CRC Press, Taylor & Francis, Boca Raton, FL. (Oct. 2009), 1736 pages.

Patents

1. "Unconditionally stable filter", U.S. Patent 7,555,278, H. Contopanagos, S. Kyriazidou, J. Rael and R. Rofougaran, 30 June 2009

ANNEXES

ANNEX I : PERSONNEL

Researchers

1. Tsoukalas D. 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. Nassiopoulou A.
13. Normand P.
14. Papanikolaou N.
15. Raptis I.
16. Tsamis C.
17. Tserepi A.

Research Engineers

1. Tsoi E.
2. Katsafouros S.

Other Scientific Staff

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

Technical and Administrative Personnel

1. Bolomiti E. (Contract)
2. Boukouras K. (Contract)
3. Georgiou Ch.
4. Kalpouzou M. (Contract)
5. Karmpadaki M. (Contract)
6. Kitsakis M. (Contract)
7. Kontakis K. (Contract)
8. Lagouvardou M.
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10. Makridi Z.
11. Makridis Z.
12. Mavropoulis I.
13. Mixelakaki E. (Contract)
14. Mpotsialas A. (Contract)
15. Sergis E.
16. Skoulikidou Ch. (Contract)
17. Tokpasidou E.
18. Zeniou A. (Contract)

Post doctoral Scientists

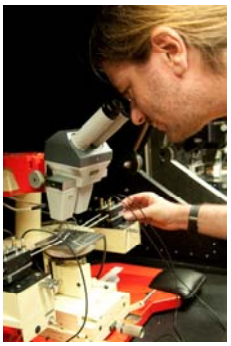
1. Gantzounis G. (Contract)
2. Gnanappa A.K. (Contract)
3. Goustouridis D. (Contract)
4. Hourdakis E.
5. Kokkoris G (Contract)
6. Kotsovos K. (Contract)
7. Makarona E
8. Palilis L.
9. Patsis G. (Contract)
10. Velessiotis D.

PhD Students

1. Almpanis E.
2. Asimakopoulos V.
3. Aksenov G.
4. Boulousis G. (Contract)
5. Broutas P.
6. Drygiannakis I. (Contract)
7. Georgiadou D.
8. Gianetta V. (Contract)
9. Goupidenis P.
10. Ioannou N. (Contract)
11. Kitsara M.
12. Kokorikos S.
13. Kontogiannopoulos I. (Contract)
14. Kontziampasis D. (Contract)
15. Kuppuaswamy V.K. (Contract)
16. Malenou A.
17. Manouras T.
18. Moschou D. (Contract)
19. Niarchos G.
20. Oikonomou P.
21. Papageorgiou D.
22. Pavli P. (Contract)
23. Triantafillopoulou R. (Contract)
24. Tsikrikas N. (Contract)
25. Tsougeni A. (Contract)
26. Tsouti V. (Contract)
27. Vlachopoulou M.
28. Zacharatos F. (Contract)

ANNEX II : INFRUSTRUCTURE AT IMEL

PROCESSING

Equipment	Techniques/competences
Silicon processing laboratory in a clean room area of 500 m^2, 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
DC Electrical measurements ▸ 3 probe stations for waferlevel measurements ▸ HP measuring systems (4142B, 4084B, 8110A, 4140B, 4284, 4192A, 34401, 16500A) ▸ Keithley measuring equipment (230, 220, 617, 195A, 6517A) ▸ Oxford cryostat for temperatures in the range LN-320K ▸ Janis low temperature wafer prober(4 probes) ▸ Cascade Microtech Summit 9101 Analytical Probe Station for 150mm wafers **RFI measurements** ▸ Anritsu 37269D Vector Network Analyzer 40MHz-40GHz	**Characterization of Dielectrics** ▸ Admittance/Impedance measurements (10Hz-1MHz, LN-400K) ▸ -V measurements (2 up to 4-terminal devices, LN-400K) ▸ Dielectric strength and charge-to-breakdown measurements (ISO/IEC 17025) ▸ Bias-Temperature-Stress measurements **Characterization of MIS Devices** ▸ Admittance/Impedance measurements (1Hz up to 1MHz, LN-400K) ▸ I-V measurements (2 up to 4-terminal devices, LN-400K) ▸ Hot-carrier stress measurements ▸ Bias-Temperature-Stress measurements

Optical

- Jobin Yvon spectrometer,wavelengths 300-1600nm
- 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

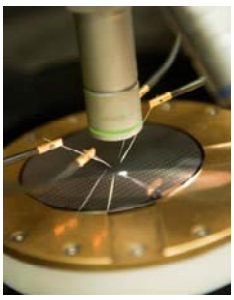
EEPROM device characterization and reliability measurements
Characterization of RF components

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

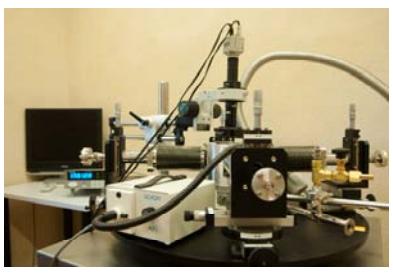


Modeling and simulation

- Process and device modeling
- RF modeling







ANNEX III : RESEARCH AND EDUCATION OUTPUT

Publications in refereed Journals

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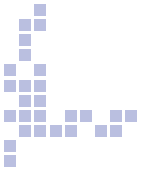

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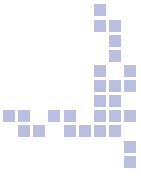

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3. “Comparison of electrical measurements with structural analysis of thin high-k Hf-based dielectric films on Si”, E. Hourdakis, M. Theodoropoulou, A. G. Nassiopoulou, A. Parisini, M. A. Reading, J. A. van den Berg, T. Conard, and S. Degendt, ECS Trans. 25 (3) 363-372 (2009)
4. “Disposable micro-fabricated electrochemical bismuth sensors for the determination of Tl(I) by stripping voltammetry”, Ch. Kokkinos, I. Raptis, A. Economou, Th. Speliotis Procedia Chemistry, vol. 1, issue 1, 1039-1042, 2009.
5. “Fabrication of Micro- and Nano-Electrodes by Selective Chemical Vapor Deposition of Cu on Si Substrates Patterned with AZ5214™ and PMMA”, G. Papadimitropoulos, S. Cibella, R. Leoni, A. Arapoyianni and D. Davazoglou, EUROCVD 17 ECS Transactions, 25 (8) 1285-1292 (2009)
6. “Growth of ZnO nanorods on patterned templates for energy harvesting applications”, Niarchos G., Makarona E. and Tsamis C., Proc. of SPIE Vol. 7362:73621L-1, (2009)
7. “High Performance Germanium n+/p and p+/n Diodes Using Low Temperature Metal Induced Dopant Activation and La2O3 Passivation”, A. Dimoulas, P.Tsipas, Th. Speliotis, V. Ioannou-Sougleridis, 216th Electro-Chemical conference, October 4 - 9, 2009 , Vienna, Austria.
8. “Initial Stages of Thermally and Hot-Wire Assisted CVD Copper on SiLK® and LTO Substrates Activated with Mercaptopropyl Triethoxysilane Self-Assembled Monolayers”, G. Papadimitropoulos, T. Speliotis, A. Arapoyianni and D. Davazoglou, EUROCVD 17, ECS Transactions. V25, No 8, p 893 (2009)
9. “Localized silicon nanocrystals fabricated by stencil masked low energy ion implantation: effect of the stencil aperture size on the implanted dose” R. Diaz, C. Dumas, J. Grisolia, T. Ondarçuhu, S. Schamm, A. Arbouet, V. Paillard, G. BenAssayag, P. Normand, J. Brugger, MRS Symp. Proc. 1160, pp. 61-66, 2009
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11. “Metal induced low temperature activation and La2O3 passivation of germanium n+/p and p+/n junctions”, V. Ioannou-Sougleridis, A. Dimoulas, P. Tsipas and Th. Speliotis, proceedings of the 39th European Solid-State Device Research Conference (ESSDERC) September 14-18 Athens, Greece pp 367-370.
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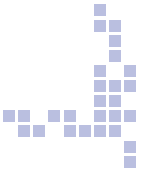
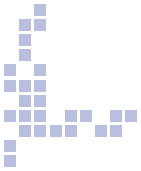
13. “Negative effective permeability of multilayers of ordered arrays of metal-dielectric nanosandwiches”, C. Tserkezis, N. Stefanou, G. Gantzounis, and N. Papanikolaou, Proc. SPIE 7353, 735305 (2009*)*
14. “Preparation and characterization of nanocrystals using ellipsometry and X-ray diffraction”, P. Petrik, S. Milita, G.Pucker, A. G. Nassiopoulou, J. A. van den Berg, M. A. Reading, M. Fried, T. Lohner, M. Theodoropoulou, S. Gardelis, M. Barozzi, M. Ghulinyan, A. Lui, L. Vanzetti, A. Picciotto, ECS Trans. 25 (3) 373-378 (2009)



15. "Short channel effects in SLS ELA polysilicon TFTs", *Proceedings of the 5th International* Kontogiannopoulos, G.P., D.C. Moschou, D.N. Kouvatsos, G.J. Papaioannou and A.T. Voutsas, Thin Film Transistors Conference (ITC '09) / 2009 Society for Information Display Europe Chapter Meeting, Paris, France, March 2009.
16. "The effect of small geometry on the degradation performance of SLS ELA polysilicon thin film transistors", Kontogiannopoulos, G.P., M.A. Exarchos, D.N. Kouvatsos, G.J. Papaioannou and A.T. Voutsas, Proceedings of the 29th International Display Research Conference IDRC '09) / Eurodisplay 2009, Rome, Italy, September 2009.
17. "Ultra-miniaturized monolithically integrated polymer coated Si optoelectronic cantilevers for gas sensing applications", Misiakos K, Raptis I, Goustouridis D, Gerardino A., Contopanagos H, Valamontes E, Kitsara M, IEEE Sensors 2009 (Christchurch, New Zealand, 10/2009)

Presentations in Conferences

1. "A multi-scale computational framework for plasma etching processes: Application to the investigation of surface kinetics on the reactor walls" (oral), G. Kokkoris, A. Goodyear, M. Cooke, E. Gogolides, PESM-Plasma Etch and Strip in Microelectronics 2nd International Workshop, 26-27 February 2009, Leuven, Belgium (2009)
2. "Characterization of MoOx nanostructured thin films for application in organic photonic devices", I.Kostis, M.Vasilopoulou, L.C.Palilis, D.G.Georgiadou, P.Argitis, N.A.Stathopoulos, A.Iliadis, N.Konofaos, D.Davazoglou, 1st International Commission for Optics Topical Meeting on Emerging Trends and Novel Materials in Photonics, Delphi, Greece, 2009.
3. "Conceptual Design of a Wireless Strain Monitoring System for Space Applications", P. Broutas, S. Kyriakis Bitzaros, D. Goustouridis, S. Katsafouros, D. Tsoukalas, S. Chatzandroulis, presented in Wireless Sensor Networks for Space Applications Workshop (WiSens4Space), 1 – 2 October 2009, Santorini, Greece
4. "Confined photons and phonons in nanopatterned silicon films" E. Almpanis, N. Stefanou, N. Papanikolaou, 2nd Mediteranean Conference on Nanophotonics, MEDINANO-2, Athens, October 26-27, 2009
5. "Coupled Plasmons and Resonant Effective Permeability of Metal-Dielectric-Metal Nanosandwich Assemblies", C. Tserkezis, N. Stefanou and N. Papanikolaou, 25th Panhellenic Conf. on Solid State Physics & Materials Science, Thesaloniki 2009
6. "Detailed Resist Film Modelling in Stochastic Lithography Simulation for Line-Edge Roughness Quantification" (oral), G. Patsis, D. Drygiannakis, E. Gogolides, I. Raptis, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)
7. "Direct laser printing of polymers for gas sensing applications", C. Boutopoulos, C. Pandis, P. Pissis, I. Zergioti, V. Tsouti, S. Chatzandroulis, COLA 2009 10th International Conference on Laser Ablation, Singapore 22-27 November 2009.
8. "Electromagnetic Simulation of Organic Photovoltaic Devices Using a Transmission Line Model" N.A.Stathopoulos, S.P.Savaidis, S.Yesayan, L.C.Palilis, M.Vasilopoulou and P.Argitis. 2nd International Symposium on Flexible Organic Electronics, 8-10 July 2009, Halkidiki, Greece,
9. "Emergence of periodic structures on treated films at nanoscale: Mechanism and modeling demonstration" (poster), V. Constantoudis, H. Christoyianni, E. Gogolides, Nanosciences & Nanotechnologies 2009, 13-15 July 2009, Thessaloniki, Greece
10. "Evaluation of biomolecular film thickness using white light reflectance spectroscopy"Kitsara M, Petrou P, Beltsios K, Raptis I, Kakabakos S, Instrumental Methods of Analysis (IMA 2009) (Athens, Greece, 10/2009)
11. "Fabrication of Micro- and Nano-Electrodes by Selective Chemical Vapor Deposition of Cu on Si Substrates Patterned with AZ5214™ and PMMA", G. Papadimitropoulos, S. Cibella, R. Leoni, A. Arapoyianni and D. Davazoglou, EUROCVD 17 ECS Transactions, 25 (8) 1285-1292 (2009)
12. "Growth of ZnO nanorods on patterned templates for energy harvesting applications", Niarchos G., Makarona E. and Tsamis C., Microtechnologies for the New Millennium 2009, 4-6 May 2009, Dresden, Germany (Poster)
13. "Initial Stages of Thermally and Hot-Wire Assisted CVD Copper on SiLK® and LTO Substrates Activated with Mercaptopropyl Triethoxysilane Self-Assembled Monolayers" G. Papadimitropoulos, T. Speliotis, A. Arapoyianni and D. Davazoglou, EUROCVD 17, ECS Transactions. V25, No 8, p 893 (2009)
14. "Inorganic metal oxides as cathode interfacial layers for polymer electronic devices", M. Vasilopoulou, L. C. Palilis, D. G. Georgiadou, P. Argitis, I. Kostis, G. Papadimitropoulos, N. A. Stathopoulos, A. Iliadis, N. Konofaos and D. Davazoglou, 2nd International Symposium on Flexible Organic Electronics, 8-10 July 2009, Halkidiki Greece
15. "In-situ monitoring of must fermentation by polymer coated interdigitated sensor arrays", P.Oikonomou, K.Manoli, D.Goustouridis, I.Raptis, M.Sanopoulou Instrumental Methods of Analysis (IMA 2009) (Athens, Greece, 10/2009)
16. "Integrated tool for the spreading, thermal treatment and in-situ process monitoring of thick photoresist films"D.Goustouridis, I.Raptis, E.Valamontes, M.Chatzichrisitidi Micro & Nano Engineering Conference (Gent, Belgium, 09/2009)



17. “Memory Structures Based on the Self-organization of Cu Nanoparticles Deposited by Hot-Wire CVD on Polythiophene Layers”, P. Dimitrakis, G. Papadimitropoulos, L. Palilis, M. Vasilopoulou, P. Normand, P. Argitis, D. Davazoglou, , EUROCVD-17 and CVD-XVII, 216th Meeting of the Electrochemical Society, 4-9 October 2009, Vienna, Austria.
18. “Metal induced low temperature activation and La2O3 passivation of germanium n+/p and p+/n junctions”, V. Ioannou-Sougleridis, A. Dimoulas, E. Golias, Th. Speliotis, 39th ESSDERC, September 14-18, Athens, Greece.
19. “Micro-fabricated TiO2-ZrO2 Affinity Chromatography Micro-Column on PMMA for Phosphopeptide Analysis”, Tsougeni K, Boulousis G,Roumeliotis T, Zorpas K, Speliotis T, Botsialas A, Raptis I, Tserepi A,Garbis SD, Gogolides E, IMA 2009, 4 - 8 October 2009, Athens, Greece (2009)
20. “Modeling and optimization of ZnO nanostructure arrays for improved energy conversion efficiency”, G. Niarchos, E. Makarona, C. Tsamis, Third International Conference on One-dimensional Nanomaterials (ICON), 7-9 December 2009, Atlanta, Georgia (Oral)
21. “Modeling of Line Edge Roughness Transfer during Plasma Etching” (oral), G. Kokkoris, V. Constantoudis, P. Xydi, G. P. Patsis, E.Gogolides, PESM-Plasma Etch and Strip in Microelectronics 2nd International Workshop, 26-27 February 2009, Leuven, Belgium (2009)
22. “Negative effective permeability of multilayers of ordered arrays of metal-dielectric nanosandwiches”, C. Tserkezis, N. Stefanou, G. Gantzounis, and N. Papanikolaou, SPIE Europe Photonics (2009)
23. “On the optical and structural properties of advanced SLS ELA polycrystalline silicon thin films”, Moschou, D.C. N. Vourdas, D. Davazoglou, D.N. Kouvatsos, V.E. Vamvakas and A.T. Voutsas, European Materials Research Society Spring 2009 Meeting, Strasbourg, France, May 2009.
24. “Optical Response of Plasmonic Nanoantenna Arrays”, E. Almpanis, N. Papanikolaou, C. Tserkezis and and N. Stefanou, 25th Panhellenic Conf. on Solid State Physics & Materials Science, Thesaloniki 2009
25. “Oxygen Plasma Nanotexturing of PS surfaces for Fabrication of DNA Arrays” (poster), K. Tsougeni, P. Petrou, A. Tserepi, S. Kakabakos, E. Gogolides, NanoBio Europe 2009, 16-18 June, Grenoble, France (2009)
26. “Photochemical Tuning of the Photo- and Electroluminescence Spectrum of a phosphorescent Pt complex inside PVK matrix” D. G. Georgiadou, L. Murphy, M. Vasilopoulou, L. C. Palilis, G. Pistolis, D. Dimotikali, J.A.G. Williams and P. Argitis, 2nd International Symposium on Flexible Organic Electronics, 8-10 July 2009, Halkidiki, Greece.
27. “Plasma etched nano-pillar arrays on polymer surfaces using colloidal lithography: Dual scale robust super hydrophobic and super hydrophilic wetting behaviour” (poster), K. Ellinas, A. Tserepi, E. Gogolides, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)
28. “Plasma Etching Technology for Fabrication and Surface Modification of Plastic Microfluidic Devices” (poster), M.-E. Vlachopoulou, K. Tsougeni, K. Kontakis, N.Vourdas, A. Tserepi, E. Gogolides, International Symposium on Plasma Chemistry - ISPC 19, 26-31 July 2009, Bochum, Germany (2009)
29. “Plasma-Directed Organized Nanodot Formation on Polymeric Surfaces” (poster), D. Kontziampasis, E. Gogolides, V. Constantoudis, N. Vourdas, M. Cooke, A. Goodyear, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)
30. “Plasma-Directed Organized Nanodot Formation on Polymeric Surface” (oral), D. Kontziampasis, N. Vourdas, V. Constantoudis, E. Gogolides, Nanosciences & Nanotechnologies 2009, 13-15 July 2009, Thessaloniki, Greece
31. “Plasma-Directed, Organized Nanodot Formation on Polymeric Surfaces” (oral), D. Kontziampasis, N. Vourdas, G. Boulousis, V. Constadoudis, A. Tserepi, E. Gogolides, NSTI Nanotech 2009, 3-7 May 2009, Houston, Texas (2009**)**
32. “Plasma-Induced Nanotexturing of Polymers for the Fabrication of Protein and DNA Arrays” (oral), K. Tsougeni, M.E. Vlachopoulou, P. Petrou, S. Kakabakos, A. Tserepi, E. Gogolides, International Symposium on Plasma Chemistry - ISPC 19, 26-31 July 2009, Bochum, Germany (2009)
33. “Porous Si technology for on-chip RF passives and other Si devices” A. G. Nassiopoulou, Symposium organized by the National Scientific Society “Micro&Nano” in the field of “New challenges in Microelectronics, Nanoelectronics, Optoelectronics and Sensors”, NCSR Demokritos, 6-7 November 2009
34. “Power Harvesting Scheme for Remotely Powered Sensor Tags”, P. Broutas, S. Kyriakis Bitzaros, I. Mourtsiadis, D. Goustouridis, S. Katsafouros, D. Tsoukalas, S. Chatzandroulis, ESSCIRC, 2009. ESSCIRC '09. Proceedings of, 14-18 September 2009, Athens, Greece
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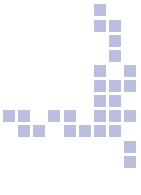
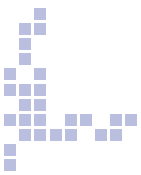
36. “Protein Arrays on SF6 Plasma Nanostructured PDMS Surfaces”, Vlachopoulou M-E, Tserepi A, Gogolides E, Petrou P, Kakabakos S, IMA 2009, 4 - 8 October 2009, Athens, Greece (2009)
37. “Protein patterning on plasma-modified PDMS and PMMA surfaces for bioanalytical applications” (poster), M-E. Vlachopoulou, K. Tsougeni, K. Tserepi, E. Gogolides, P. Petrou, S. Kakabakos, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)
38. “Protein Patterning Through Selective Plasma–Induced Modification of Glass Substrates” (oral), A. Malainou, A. Tserepi, P.S. Petrou, S.E. Kakabakos, E. Gogolides, IMA 2009, 4 - 8 October 2009, Athens, Greece (2009)



39. “Proton Transport in Polyoxometalate-Embedded Polymeric Films: Towards the Development of Novel Proton Memory Devices”, A. M. Douvas, E. Kapetanakis, P. Goupidenis, K. Beltsios, P. Normand, P. Argitis, International Polyoxometalate Symposium, 28 July-1 August, 2009, Bremen, Germany
40. “Raman studies (SERS) of rhodamine 6G on random and periodic arrays of silver nanoparticles”, A. Gabriileli, I. Theodorakos, T. Jun, I. Raptis, A. Gerardino, Th. Speliotis, N. Papanikolaou, I. Zergioti, D. Tsoukalas, Y. Raptis, Emerging Trends and Materials in Photonics ICO-PHOTONICS-DELPHI2009 October 7-9, 2009
41. “Simulation of Shot Noise effect on CD and LER of Electron Beam Lithography in 32nm Designs” (poster), G. Patsis, N. Tsikrikas, D. Drygiannakis, E. Gogolides, I. Raptis, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)
42. “Simulations of the electric field in hybrid organic photovoltaics using a transmission line model – Comparison with experimental results”, N.A.Stathopoulos, S.P.Savaidis, S.Yesayan, L.C.Palilis, M.Vasilopoulou, P.Argitis, 1st International Commission for Optics Topical Meeting on Emerging Trends and Novel Materials in Photonics, Delphi, Greece, 2009.
43. “Stable superhydrophobic surfaces induced by dual-scale topography on SU-8” (poster), M-E. Vlachopoulou, J.M. Velasco, A. Tserepi, E. Gogolides, MNE 2009, 28 September - 1 October 2009, Ghent, Belgium (2009)
44. “The role of gate width in transistor performance: Effects of gate sidewall roughness” (oral), V.Constantoudis, G.P. Patsis, E. Gogolides, XXV Panhellenic Conference: Solid State Physics and Materials Science, 20-23 September 2009, Thessaloniki, Greece
45. “The role of gate width in transistor performance: Effects of sidewall roughness” (poster), V.Constantoudis, G.P.Patsis, E.Gogolides, ESSDERC 2009, 14-18 September 2009, Athens, Greece
46. “Ultra-low-energy ion-beam-synthesis of Ge nanocrystals in thin ALD Al2O3 layers for memory applications”, P. Dimitrakis, A. Mouti, , C. Bonafos, S. Schamm G. Ben Assayag, V. Ioannou-Sougleridis, B. Schmidt, J. Becker, P.Normand, INFOS 2009, 29 June–1 July, Cambridge, UK.

Invited talks and Tutorial lectures

1. “Discrete charge storage memories”, P. Dimitrakis, Workshop on Nanoelectronics and Nanophotonics, Ankara, Turkey, January 26-28, 2009 (invited talk)
2. “Highly ordered porous alumina and porous Si films for electronic, photonic and sensor applications", A. G. Nassiopoulou (invited talk), REGMINA Workshop on MEMS and NEMS technologies, Belgrade, June 4-5 2009
3. “Improved performance hybrid-polymer optoelectronic devices using polyoxotungstates and tungsten oxides as cathode interfacial layers”, P.Argitis, M.Vasilopoulou, L.C.Palilis, G.Papadimitropoulos, D.G.Georgiadou, A.M.Douvas,N.A.Stathopoulos, K.Kotsovos, E.Ntantoumis, I.Kostis, A.Iliadis, N.Konofaos, D.Davazoglou, , 1st International Commission for Optics Topical Meeting on Emerging Trends and Novel Materials in Photonics, Delphi, Greece, 2009 (Invited)
4. “Nanoelectronics at the Center of Leading Edge Technologies", A. G. Nassiopoulou (invited talk), Workshop on Nanotechnology, organized by the Greek National Physics Society, 9 May 2009
5. “Nanoparticle Memories: CMOS, Organic and hybrid approaches”, P.Dimitrakis, Winter School on Nanoelectronics and Nanophotonics, Bilkent University, Ankara, Turkey, January 20-25, 2009 (tutorial lecture)
6. “Ordered arrays of SiO_2 nanodots with embedded Si nanocrystals: Fabrication and characterization", A. G. Nassiopoulou, (invited talk), 216th ECS Meeting – Vienna, Austria, E1 – Analytical Techniques for Semiconductor Materials and Process Characterization, 6.10.09
7. “Organic and Polymer Semiconductors – A New Class of Electronic Materials and Their Applications in Optoelectronic and Photonic Devices", L.C.Palilis, M.Vasilopoulou, D.G.Georgiadou, D.Davazoglou, P.Argitis, XXV Panhellenic Conference on Solid State Physics & Materials Science, Thessaloniki, Greece, 2009 (Invited)
8. “Polyoxometalate molecules in hybrid polymer-inorganic electronic and photonic devices”, P.Argitis, L.C.Palilis, M.Vasilopoulou, A.M.Douvas, E.Kapetanakis, E.Makarona, D.Velessiotis, G.Papadimitropoulos, P.Normand, N.Glezos, International Polyoxometalate Symposium, Bremen, Germany, 2009, (Invited)
9. “Porous Si as a local substrate technology platform for on-chip electronic and sensor applications", (invited talk) A. G. Nassiopoulou, TUAT/TEL International Workshop “Innovations of Silicon, by Silicon, for Silicon”, 18.9.2009, Tokyo
10. “Silicon nanostructuring through self-assempbed masking layers", A. G. Nassiopoulou (invited talk), EMRS 2009_Symposium M, Strasbourg, 9-13 June 2009
11. “The Physics of Advanced and Emerging Flash Memories”, P. Dimitrakis, Sympos. H, Tutorial Notes, MRS Spring Meeting, 13-18April, San Francisco 2009 (Tutorial lecture)
12. “Microfluidic devices and systems for biochemical analysis” (invited), E. Gogolides, Workshop Micro&Nano 2009, November 6-7, 2009
13. “Micro-nano fabrication meets chemical engineering: nanostructuring of polymers with plasmas” (invited), E. Gogolides, FORTH/ICE-HT Patras, Greece



14. "Micro and nano fabrication meets chemistry: Microfluidics and lab-on-chip systems for chemical analysis and physicochemical processes" (invited), E. Gogolides, Chemistry Department, UOA, December 2009

Patents

1. "International patent application (PCT/GR2009/000023, 14/04/2009), Memory devices using proton-conducting polymeric materials", Inventors: E. Kapetanakis, A.M. Douvas, D. Velessiotis, E. Makarona, P. Argitis, N. Glezos, P. Normand.
2. "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. Greek patent Application number:20080100404, 13.06.2008 PCT Application number: PCT/GR2009/000039, International Filing Date: 15.06.2009, Publication number: WO/2009/150479, Publication date: 17.12.2009
3. "A Capacitive Type Device for Chemical and Biological Sensing And A Method To Fabricate Same", NCSRD, P.Normand, S.Chatzandroulis, D.Goustouridis, V.Tsouti. Greek patent bureau (OBI), appl. no. GR20090100300 (2009),
4. "Unconditionally stable filter", U.S. Patent 7, 555,278, H. Contopanagos, S. Kyriazidou, J. Rael and R. Rofougaran, 30 June 2009
5. "Photoresists Prcessable Under Biocompatible Conditions" , P. Argitis, K. Misiakos, S. Kakabakos, A. Douvas, C.D. Diakoumakos, US Patent 7,608,389 B2, Oct 27, 2009
6. "Method for making a micro-array", A. Tserepi, E. Gogolides, P. Petrou, S. Kakambakos, P. Bayiati, E. Matrozos, PCT Application number: PCT/GR2008/000048, International Filing Date: 20.06.2008, Greek patent Application number: 20070100394, 20.06.2007, Publication number: WO/2008/155585, Publication date: 24.12.2008, US Patent & Trademark Office, App. No. 12/665817 Filing date: 21-12-2009

Organizition of Conferences, Symposia, Workshops

1. 39th European Solid-State Device Research Conference (ESSDERC), and 35th European Solid-State Circuits Research Conference (ESSCIRC), Athens, 14-18 September 2009
2. National Scientific Symposium on "Recent Developments in Microelectronics and MEMS", 6-7 November 2009
3. Workshop "Nanotechnology for electronic and photonic applications", Athens, 18 September, 2009

Editing of Conference Proceedings

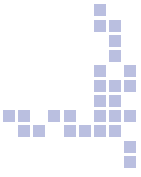
1. Proceedings of the 34th International Conference on Micro- and Nano-Engineering, MNE 2008, Athens, Greece, September 15-19, 2008, edited by I. Raptis, E. Gogolides, P. Normand and A. Tserepi, Microelectronic Engineering 86 (4-6), pp. 435-1518, April-June 2009.
2. Special issue on "Nanotechnology in Greece", published in the International Journal of Nanotechnology, vol. 6 (Nos 1/9) 2009, Edited by A. G. Nassiopoulou, C. Fotakis
3. Edition of the Proceedings of the 6th International Conference on Porous Semiconductor Science and Technology (PSST 2008). Special Issue of Physica Status Solidi. Edited by: A. G. Nassiopoulou, L. T. Canham, M. Sailor and P. Schmuki, Wiley-VCH (2009)

Organization of Schools

1. 5th Summer School "Methods in Micro-Nano Technology and Nanobiotechnology", an activity of NaBiA, 22-26 June 2009

PhD Theses

1. "Roughness formation during etching of Silicon and Polymers, and its use in microfabricated chromatography columns",G. Boulousis, National Technical Univ. of Athens.
2. "Development and characterization of thin films of Cu and copper oxides and application in electronic devices", G. Papadimitropoulos, University of Athens
3. "Development of thin film transistor fabrication technology optimized with respect to the polysilicon film structure resulting from the crystallization process". Despina Moschou, University of Athens
4. "Investigation of ageing degradation effects in polysilicon thin film transistors crystallized using advanced annealing techniques", Giannis Kontogiannopoulos, University of Athens
5. "Macroporous Si as a dielectric for local electrical isolation of Si and as a template for electrical interconnections through the wafer", F. Zacharatos National Technical Univ. of Athens
6. "Self - assembled porous anodic Al_2O_3 films on Si substrate and applications", V. Gianneta, University of Patras
7. "Hybrid sensor devices in the mesoscopic scale", PhD Thesis by A. Petropoulos, National Technical Univ. of Athens



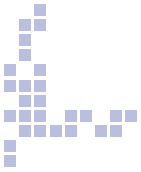
8. “Study of the influence of nitrogen on the electrical characteristics of devices fabricated on strained silicon substrates”, N. Kelaidis, Aristotle Univ. of Thessaloniki
9. “Diffusion and activation of p-type dopants in IV semiconductors for novel nanoelectronic devices”, N. Ioannou, Univ. of Patras
10. “Fabrication of Si nanocantilevers for efficient chemical detection”, V. Tsouti National Technical Univ. of Athens
11. “Fabrication and characterization of Metal Oxide Chemical Sensors”, R. Triantafyllopoulou, National Technical Univ. of Athens
12. “Silicon micromachined optical sensors for chemical/biological assays”, Maria Kitsara, University of Ioannina
13. “Study of physicochemical properties of thin polymer films and their effect in lithography”, Dimitrios Dygiannakis, National Technical University of Athens
14. “Simulation of electron beam lithography for structures with critical dimension <45nm”, Nikolaos Tsikrikas, National Technical University of Athens

Master Theses

1. “Fabrication of polymeric microfluidic channels with nanostructured walls: Characterization of the nanostructure and measurements of the pressure drop on water flow”,D. Papageorgiou, University of Athens
2. “Dual scale superhydrophilic, superhydrophobic, and oleophobic surfaces fabricated by colloidal lithography and plasma etching”, K. Ellinas, University of Athens
3. “Monte Carlo simulation of ion enhanced etching of polymers using a random walk representation of the polymer chains”, A. Anastasopoulos, University of Athens
4. “Selective chemical vapor deposition of vanadium oxides on Cu features made by colloidal lithography”, L. Zambelis, NTUA
5. “Micrographic concentration silicon photovoltaic cells”, G. L. Rokadakis, University of Athens
6. “Characterization and testing of a flow using porous Si thermal isolation”, P. Doukeris, University of Athens
7. "Growth and investigation of thermally oxidized thin porous silicon films embedded in MOS devices", A.K.Michelakis, University of Athens

Seminars, Schools and Courses

1. “Patterning and nanotexturing of substrates at the micro- and nano- scale for the fabrication of protein microarrays”, Workshop “Evaluation ofresults of Demoereyna 2005 Program”, A. Tserepi, December 1, 2009
2. During the advanced summer school “Methods in Micro-Nano Technology and Nanobiotechnology”, June 22-26, 2009 we tought the following labs: “Fabrication of microfluidic devices on plastic substrates by Soft lithography”, A. Tserepi, M.-E. Vlachopoulou and “Fabrication of plastic microfluidic devices by Lithography and deep polymer plasma etching techniques”, E. Gogolides, K. Tsougeni
3. “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
4. “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
5. "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
6. “Micro & Nano Fabrication”, S. Logothetidis, A. Nassiopoulou, E. Gogolides, Postgraduate Program on Nanosciences & Nanotechnologies of the Aristotle University of Thessaloniki
7. “Fabrication of integrated circuits: Laboratory courses”, E. Tsoi, D. Kouvatsos, A. Tserepi, Postgraduate Program on Microelectronics of the National and Kapodistrian University of Athens
8. “Computational methods”, P. Trohidou, G. Kokkoris, Postgraduate Program on Microelectronics of the National and Kapodistrian University of Athens
9. Lectures on the “CMOS devices and processes” by A. G. Nassiopoulou, for the MSc programme on Nanosciences and Nanotechnologies, Univ. of Thessaloniki, 2nd semester 2009
10. Lectures on “CMOS devices and processes” by A. G. Nassiopoulou for the MSc programmes on Microelectronics, University of Athens and Nanoelectronic devices and MEMs, National Technical Univ. of Athens, 1st Semester 2009-2010
11. “Optoelectronics and Applications”, S. Gardelis, Summer School, NCSR Demokritos, July 2009
12. “Microelectronic Materials and Device Technology”, S. Gardelis, 5th Nano2life International Summer School on Methods in Micro-Nanotechnology and Nanobiotechnology, 22-26 June 2009, Athens, Greece
13. Lectures on “Sensor technology” for the MSc program on Microelectronics, University of Athens



ANNEX IV : FUNDED PROJECTS in 2009

A. EU Projects

- **Micro2DNA (IST-FP6-STREP)** Contract No 027333
  "Integrated polymer-based micro fluidic micro system for DNA extraction, amplification, and silicon-based detection"
  Duration: 1/2/2006-31/5/2009
  Project leader: P. Normand

- **NEMOSLAB (IST-NoE- FP6)** Contract No 027804
  "NanoEngineered Monolithic Optoelectronic transducers for highly sensitive and Label-free Bionsensing"
  Duration: 1/1/2006-30/6/2009
  Project leader: K. Misiakos

- **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. Gogolides

- **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. Gogolides

- **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

- **ESA** - Sub-Contract FORTH-NCSRD- RFQ No 3-12083
  "Investigation of the use of III-Nitride quantum dot-resonant tunneling diodes structure as tuneable wavelength UV-VIS Detectors"
  Duration: 14/4/2008-14/4/2009
  Project leader: P. Normand

- **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. Gogolides

- **TAILPHOX (FP7)** Contract No 233883
  "TAILoring photon-phonon interaction in silicon PHOXonic crystals"
  Duration: 1/5/2009-30/4/2012
  Project leader: N. Papanikolaou

- **MiNaSys-CoE (Regpot-2009)** Contract No 245040
  "Micro and Nano Systems Center of Excellence"
  Duration: 1/12/2009-1/12/2012
  Project leader: D. Tsoukalas

B. National Projects

- **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-03ED202**
  "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

- **GSRT-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

- **MEMSENSE Corralia**
  "Development of Innovative sensor systems offering distributed intelligence"
  Duration: 1/5/2009-30/4/2012
  Project leader: S. Tsamis

- **Lab-on-chip Corralia**
  "Microelectronic components for Lab-on-Chip molecular analysis
  instruments for genetic and environmental applications"
  Duration: 1/11/2009-31/10/2012
  Project leader: S.Chatzandroulis