

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

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Projects Running:

- SPAM, Marie Curie-ITN, Contract No 215723
- "Lab-on-chip" Corralia-GSRT Contract No MIKPO2-ΣΕ-Γ/Ε-II

Objectives:

Our first objective is to use our rich plasma nanoscience and nanoassembly toolbox as an enabling technology for a variety of applications including Surface Science, Life Sciences and Energy, as well as for fundamental studies in these fields. More specifically, we use various top down and bottom up lithographic processes followed by plasma etching / processing not only for nano-relectronics and MEMs, but also for surface wetting control, surface engineering, microfluidics, microarrays and lab-on-a-chip fabrication:

- For nano-electronics, our work focused on simulation of Line Edge Roughness (LER) transfer during plasma etching, and on Contact Edge Roughness (CER) Characterization, where new software for CER detection and measurement from top down SEM images was developed. Molecular simulation and scaling theory was used to understand roughness formation on photoresist surfaces during development and its dependence on dissolution inhomogeneities. The predictions of that analysis were in agreement with experimental trends. (see section A). Finally we used for the first time in the international literature superhydrophobic surfaces for immersion lithography demonstrating extremely increased scanning speeds (see section C).
- For Life Science applications, Plasma Processing was used to fabricate microfluidics, lab on a chip, and microarrays. Our new technologies include Deep Plasma Etching of smooth PDMS microfluidics as an alternative to soft lithography, as well as colloidal lithography followed by plasma etching and selective deposition for nanoscale protein patterning. Furthermore, two analytical microfluidic devices were developed: a) An affinity chromatography chip for phosphopeptide enrichment with capacity superior to commercial off-line TiO₂ tips, b) A chip for DNA amplification using continuous flow PCR. (see section B).
- Plasma Nanoscience was used to create nanoscale pillars on polymers as well as Silicon or Silicon dioxide, and control their wetting properties and reflectivity. We have created superhydrophobic surfaces with minimal roughness and used them for very high scanning speeds in immersion lithography. We used colloidal lithography and plasma etching to create superamphiphobic (water and oil resistant) and superamphiphilic (water and oil

wetable) surfaces. We demonstrated cryogenic etching processes of Silicon leading to nanoscale Silicon pillars of high aspect ratio (>20:1). Finally we have continued the work of plasma directed organization and shown the effects of temperature and etcher wall material on the self-organization of these nanodots. (see section C)

- Work on plasma etching and plasma nanoscience was also complemented by plasma simulations (see section D).

Our second objective is to create the necessary infrastructure for plasma processing, and for lab on chip fabrication and characterization. Towards this end we installed a second helicon plasma reactor in the Institute and a laboratory for microfluidics and lab-on-chip assembly and characterization. (See section E)

RESEARCH RESULTS IN 2010

A. Micro and Nano Lithography: Simulation and Metrology

A1 Molecular simulation and scaling analysis of resist surface roughness during development

G. P. Patsis, V. Constantoudis, E. Gogolides

The sidewall roughness of resist lines (Line Edge Roughness (LER)) is considered one of the main obstacles to the successful implementation of future lithographies. Resist development is a standard lithographic step during which the contribution of material properties to LER formation is mostly manifested. However, during the development of a line and the formation of rough sidewalls, roughness is influenced by aerial image contrast, and post exposure bake in addition to material properties. This difficulty can be overcome by studying the evolution of surface roughness of open-surface resist films during development (depth-profiling method).

We have implemented the depth profiling method in a simulation framework by using a home-made stochastic simulator of the dissolution process which takes into account the molecular structure of resist films and employs the critical ionization model for the development (Fig. 1).

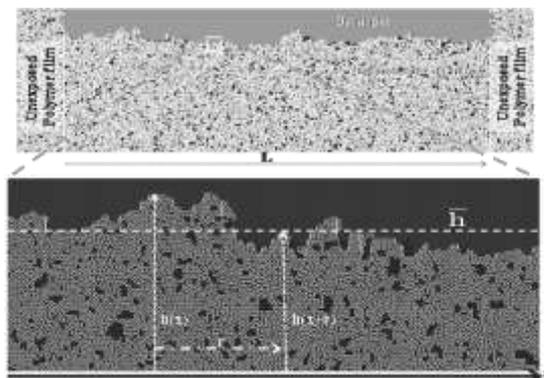


Fig. 1. A typical snapshot of 1D resist surface evolution (with a magnification of a small part of it) during development as given by the stochastic simulator used in the paper.

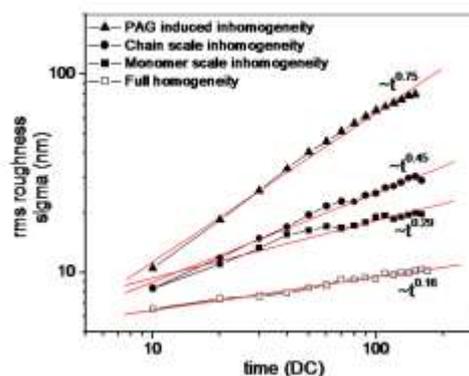


Fig. 2. Simulation results for the dependence of rms roughness on development time for a resist with increasing levels of inhomogeneities: on monomer scale (full squares), on chain scale (full circles) and on film scale PAG induced (full triangles). For the sake of comparison the behaviour of the roughness parameters of the fully homogeneous resist is also shown (open squares).

Since development of resist films is a dynamic phenomenon evolving in time, dynamic scaling theory is applied to give valuable information. Resists with both homogeneous and inhomogeneous local dissolution behaviour have been simulated. In homogenous polymers, slow rms roughness increase is reported and the scaling exponents are shown to obey the dynamical scaling hypothesis of Family-Viscek. Dissolution inhomogeneity is inserted on monomer scale (by using copolymers), on chain scale (by using mixture of copolymers) or on film scale by the activation of PhotoAcid Generator (PAG) molecules and the concomitant

acid diffusion. Our simulator predicts that any kind of inhomogeneity may cause much larger rms roughness than homogeneous solubility. Furthermore, PAG-induced inhomogeneity results in faster increase and larger values of roughness compared to chain-level-inhomogeneity and this in turn to larger values compared to polymers with monomer scale inhomogeneity (Fig. 2). Comparison with experimental results shows good agreement with the simulation predictions.

A2 Line Edge Roughness (LER) transfer during plasma etching

V. Constantoudis, G. Kokkoris, E. Gogolides

The question of the (an)isotropy of resist sidewalls after lithography is examined and the focus is on the impact that this (an)isotropy may have on line edge roughness (LER) transfer during plasma etching. The latter is critical in LER/LWR studies since it relates the resist LER to the variations in the gate length of a transistor along gate width which eventually affect device performance.

The (an)isotropy of resist sidewalls is investigated by analyzing measurements of 3D sidewall surfaces taken by CD-AFM or CD-SEM; the latter show that the sidewall morphology of commercial resist lines (3D Line Edge Roughness) after lithography and before etching exhibit anisotropy in the form of striations perpendicular to line direction (Fig. 3a). A measure for the anisotropy of the surfaces is introduced and the effect of anisotropy on LER transfer during trimming and pattern transfer is investigated by modeling and simulation. If the anisotropy is taken into account, the beneficial role of trimming in LER reduction during pattern transfer can be predicted (Figs. 3b and 3c) in agreement with experimental results. Furthermore, experimental and modeling studies (Fig. 3d) show that the CD-AFM measurements of the 3D Line Width Roughness may overestimate the correlation length; the measured correlation length depends on the AFM tip radius. Taking into account this finding we found that model predictions approach further the experimental results.

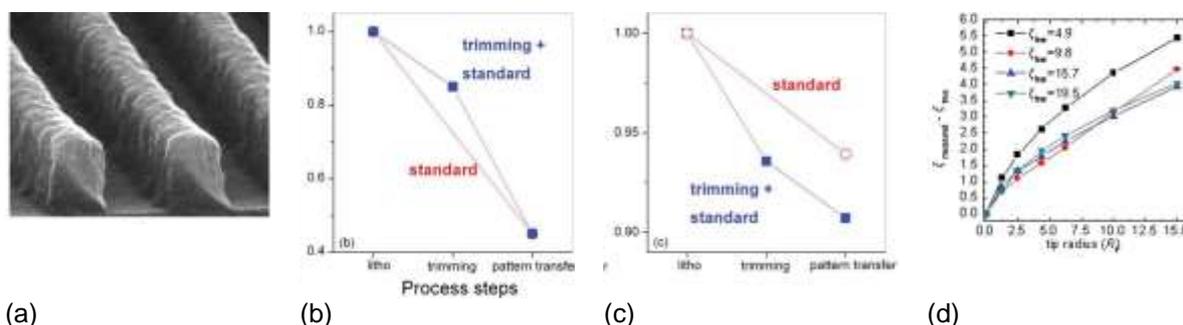


Fig. 3. (a) SEM image of resist sidewall where the anisotropy vertical to the line is shown. Normalized rms after lithography, trimming and pattern transfer resulted from simulation when (b) the anisotropy is not taken into account and when (c) anisotropy is taken into account. (d) The difference of measured with real correlation length versus the tip radius as predicted by the model of AFM measurement.

A3 Contact Edge Roughness (CER) metrology

V.-K. Murugesan Kuppaswamy, V. Constantoudis

With the continuous scaling down of the dimensions of lithographic structures, the roughness on their surfaces becomes an increasing fraction of their size and starts to affect their physicochemical properties. Up to now, the majority of related works have been focused on the sidewall roughness of lines (Line Edge Roughness (LER)) which has been a great concern in semiconductor industry. However, lithographic features are not only lines but also holes used for the opening of contacts and vias or shapes with more complicated geometry. We have focused on the metrology and evaluation of the roughness of contact holes (called Contact Hole or Edge Roughness, CHR/CER) which has recently attracted more attention due to its impact on circuit performance. In particular:

a) We developed software (CERDEMO) for the detection and characterization of CER from top down SEM images (Fig. 4) with emphasis on the frequency and spatial aspects of CER.

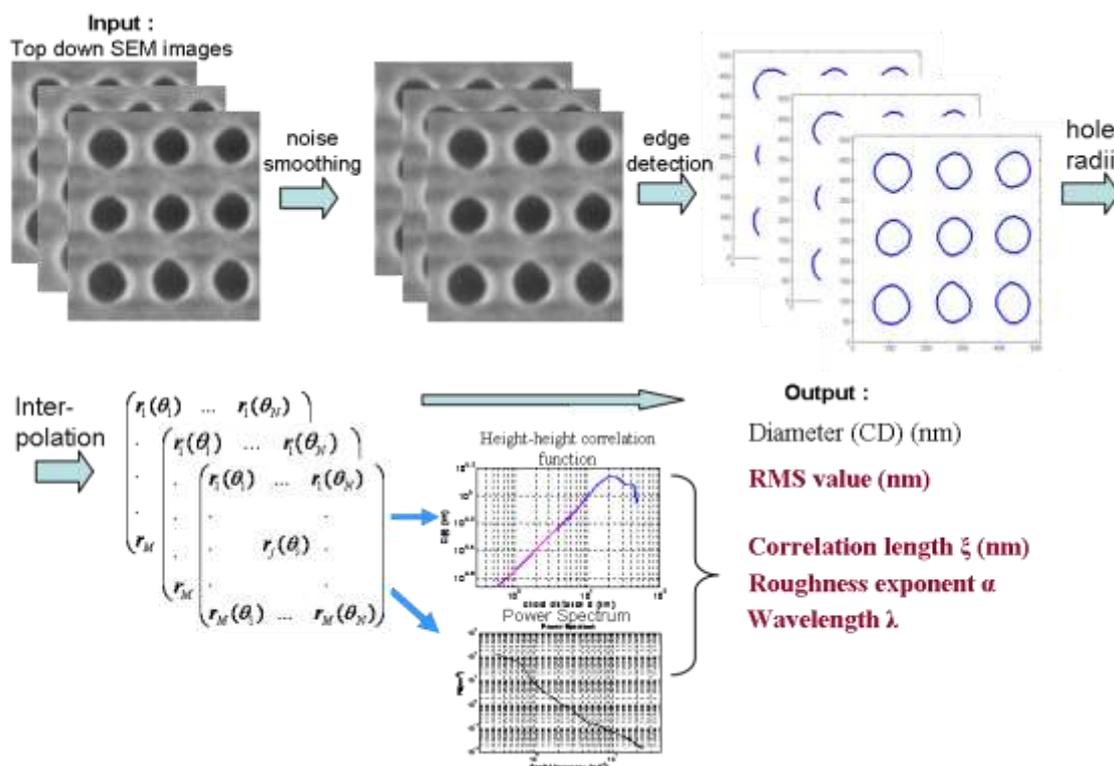


Fig. 4. Schematic flow diagram of CER evaluation methodology as implemented in software "CERDEMO" which has been developed by our group. It starts with top-down SEM images and outputs CER and dimensional parameters and functions taking into account the circular form of contact edges and its implications. (see <http://imel.demokritos.gr/software.shtml>)

b) We developed a code (CERMODEL) for the generation of model contact edges and images resembling the real SEM ones. We applied this model to show that the decrease of hole dimensions (CD) leads inevitably to decrease in rms value and increase of CD nonuniformity (rms – CD variation effect).

c) We applied CERDEMO software in the analysis of real EUV resist contact holes (nominal CD=50nm) and found that local process variations have stronger contribution to the uncertainty of CD and CER parameters than image magnification and noise smoothing with the latter having the smallest impact. Furthermore we estimated the impact of dose on CER and found that, contrary to LER, the reduction of dose leads to lower rms values. Given the change of CD caused by dose variations the role of the effect rms-CDvariation (see (b) above) has been investigated.

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

B1 Affinity chromatographic separations of phosphopeptides

K. Tsougeni, P. Zerefos, A. Tserepi, A. Vlahou, S. D. Garbis, E. Gogolides

We fabricated a $\text{TiO}_2\text{-ZrO}_2$ Affinity Chromatography micro-column on 2 mm PMMA plates, and demonstrated the enrichment and separation a) of a standard mono- and tetra-phosphopeptide, and b) of phosphopeptides contained in a tryptic digest of β -Casein. The chromatography column consisted of 32 parallel microchannels with common input and output ports and was fabricated by lithography directly on the polymeric substrate followed by plasma etching (i.e. standard MEMS processing) and sealed with lamination. The liquid deposited $\text{TiO}_2\text{-ZrO}_2$ stationary phase was characterized by X-Ray diffraction and was found to be mostly TiO_2 and ZrO_2 in crystalline phases. Off-chip UV detection and MALDI MS identification of the separated effluents were used. The chip connected to detection setup is shown in Fig. 5(a). The chip had a capacity of $> 1.4 \mu\text{g}$ (0.7 nmol) of a prototype mono-phosphopeptide and a recovery of $94 \pm 3 \%$, and can be used with small samples (less than $0.1 \mu\text{L}$ depending on the syringe pump used) (Fig. 5(b)).

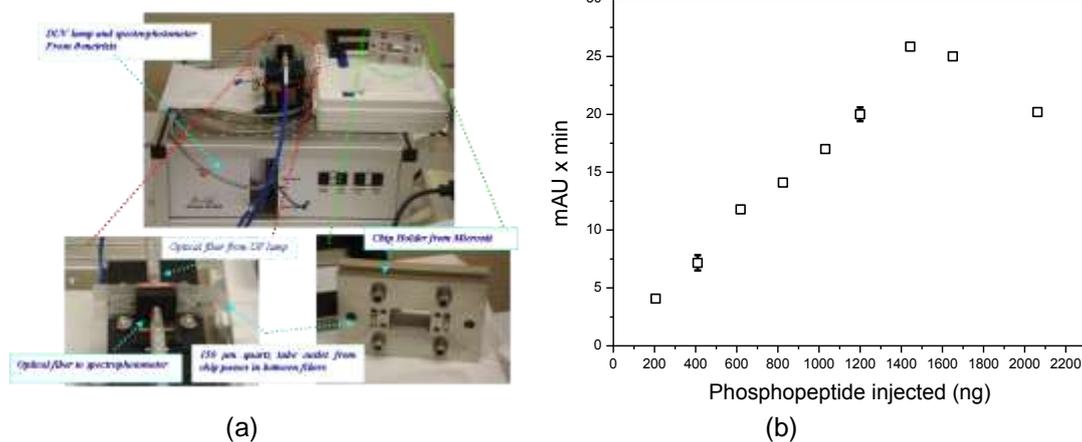


Fig. 5. (a) Experimental Setup for affinity chromatography experiments on chip using UV absorbance detection. (b) Study of microcolumn capacity (area of eluted peak) and recovery for prototype mono-phosphopeptide. Symbols represent peak-areas of the eluted peptide using the same column for 9 times.

B2 Nanoscale protein patterning on oxidized Si substrates using colloidal lithography and plasma processing

A. Malainou, K. Ellinas, P. Petrou, S. Kakambakos, E. Gogolides, A. Tserepi

Selective immobilization of proteins in well-defined patterns on substrate surfaces has recently attracted considerable attention as an enabling technology for applications ranging from basic research to biosensors and bioMEMS. Sub-micron protein patterning based on photolithography is reaching its limits, while dip-pen and e-beam lithography as serial processes lack scalability. We demonstrate a low-cost and high throughput process for nanoscale protein patterning on oxidized Si substrates based on colloidal lithography and plasma processing to define the spots (< 300 nm) where proteins are selectively adsorbed. A close-packed monolayer of PS microparticles is deposited on oxidized Si substrates and is used as etching mask to define SiO₂ spots (on Si), which after plasma-induced chemical modification are appropriate for selective protein immobilization. The immobilized proteins are detected by means of confocal and atomic force microscopy. Such nanoscale immobilized proteins can be successfully integrated into BioMEMS and microanalytical systems.

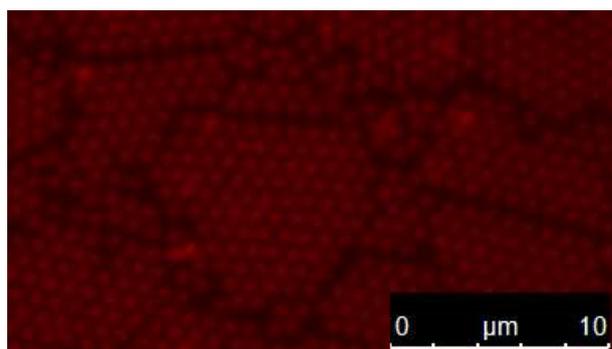


Fig. 6. Confocal Microscopy fluorescence image after selective protein immobilization on SiO₂ (red spots) and reaction with AF-546 labeled streptavidin.

B3 Miniaturized microfluidic device for DNA amplification with integrated microheaters on flexible polyimide substrate: fabrication and simulation

E. Mavraki, D. Moschou, G. Kokkoris, I. Kouris, S. Chatzandroulis, A. Tserepi

A low cost microfluidic device with *integrated microheaters* is fabricated on a thin flexible polymeric substrate, in order to perform DNA amplification on chip at faster

amplification rates, due to the reduced thermal capacity and large heat transfer rate between the sample and the temperature-controlled heating zones. We demonstrate a continuous-flow PCR microfluidic device, fabricated on double-sided Cu-clad polyimide (Pyradox[®]), using PCB-based technology and plasma etching. Each microheater defines one of the three temperature zones through which the DNA sample is cycled for 25 times as it flows continuously through the microchannel. The fabricated device is fully characterized structurally, electrically and thermally. Electrical measurements confirm the functionality of the microheaters both as temperature sensors and thermal elements. Heat transfer and fluid dynamics computations are also performed to ascertain the device behavior.



Fig. 7. Part of the microfluidic on top side of the flexible PI substrate.

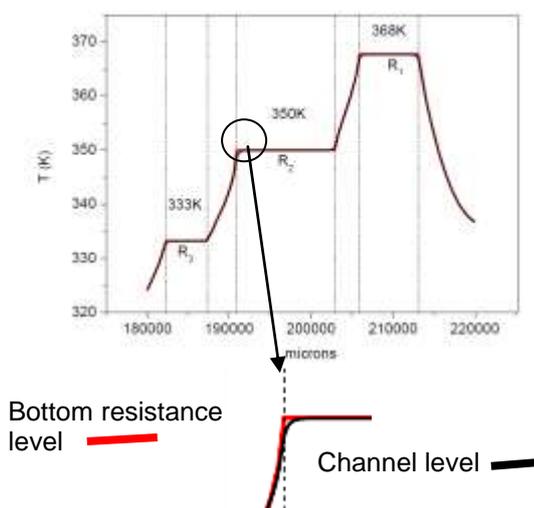


Fig. 8. Temperature profile (obtained from simulation) on the microheater plane (bottom side of substrate) compared to that on middle microchannel plane.

B4 Fabrication of PDMS microchannels by plasma etching: elimination of roughness on etched surfaces

M.-E. Vlachopoulou, E. Gogolides, A. Tserepi

In previous years, SF₆ plasma etching of PDMS in a high-density plasma reactor with alumina walls has been explored as a route, alternative to soft lithography, for the fabrication of microfluidic devices made of PDMS. Simultaneously, control of etched surface properties (chemistry and topography) has been achieved, through proper tuning of plasma processing conditions or using wet etching. This year, PDMS etching experiments were performed in a reactor with a quartz dome (recently installed at IMEL), resulting in a significantly reduced surface roughness, due to elimination of alumina from the reactor dome. Exploring also the effect of the mask material on plasma-induced roughness, the SU-8 resist was used as etching mask layer deposited either on top of an aluminum mask or directly on PDMS. In the latter case, thorough elimination of bottom nanoroughness was achieved as shown in Fig. 9. This can be implemented in the case that smooth PDMS microchannels are desired.

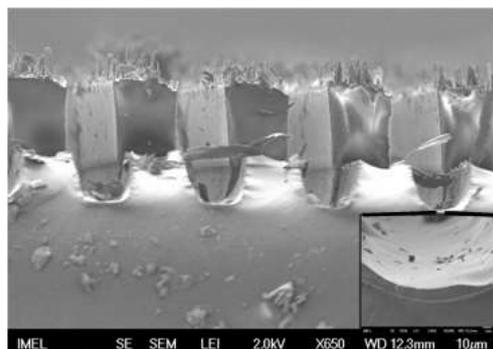


Fig. 9. SEM image of a cross-section of PDMS microchannels etched for 45 min in a quartz dome reactor. As etching mask, SU-8 was used directly on PDMS. The inset shows negligible bottom roughness.

C. Plasma Nanoscience and Applications in wetting control

C1 Controlling roughness: From etching to nanotexturing and plasma directed organization on organic and inorganic materials

E. Gogolides, D. Kontziampasis, A. Tserepi and others

We unveiled how plasma-wall interactions in etching plasmas lead to either random roughening / nanotexturing of polymeric and Silicon surfaces, or formation of organized nanostructures on such surfaces. We conducted carefully designed experiments of plasma-wall interactions to understand the causes of both phenomena, and presented Monte-Carlo simulation results confirming the experiments. We discussed emerging applications in wetting and optical property control, protein adsorption, microfluidics and lab-on-a-chip fabrication and modification, and cost-effective silicon mold fabrication. We proposed new plasma reactor designs for the future to take advantage of the observed phenomena for new micro and nanomanufacturing processes

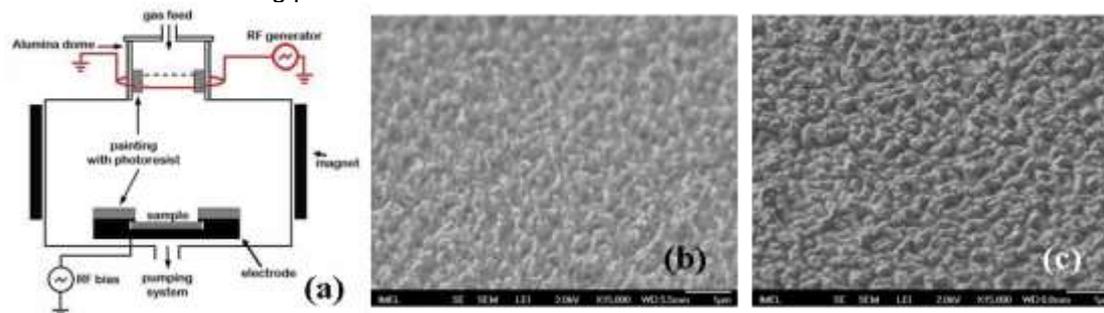


Fig. 10. Plasma nanotexturing of PMMA in O_2 and the role of reactor walls. (a) Schematic of the MET Helicon reactor showing the positions of painting with photoresist polymer the walls in order to reduce wall material sputtering. (b) PMMA film etched for 2min in a reactor with an Alumina dielectric cylinder. The SEM image shows the morphology of a polymer film and the roughness formed. (c) PMMA film etched for 2min in a quartz dielectric cylinder.

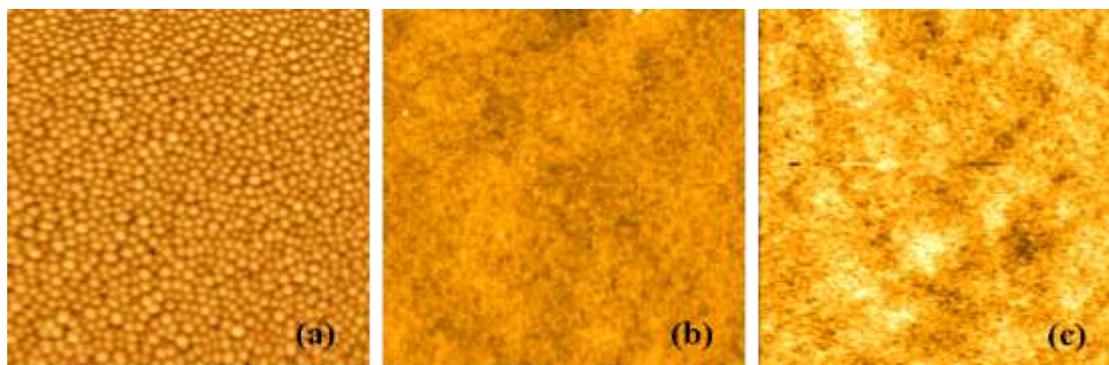


Fig. 11. Plasma directed organization on PMMA film in O_2 plasma and the role of reactor walls. AFM images ($2 \times 2 \mu\text{m}$) are shown. Typical etch rates are 600 nm/min , while nanodot formation is observed only at certain wall conditions. (a) Wall condition 1 (Alumina, Anodized Al, Helicon) ($rms=6.5 \text{ nm}$, etch time 40s). Nanodot formation is evident. (b) Wall condition 2 (Polymer, Polymer, Helicon) ($rms=0.3 \text{ nm}$, etch time 40s). No nanodots are observed. (c) Wall condition 3 (Polymer, Anodized Al, Helicon) ($rms=0.4 \text{ nm}$, etch time 40s). No nanodots are observed.

C2 Superhydrophobic surfaces for Immersion Lithography

E. Gogolides, A. K. Gnanappa, M. Riepen, F. Evangelista

The dynamic contact line behavior of water on nanotextured rough hydrophobic and superhydrophobic surfaces was studied and contrasted to smooth hydrophobic surfaces for application in immersion lithography. Liquid loss occurs at the receding meniscus when the smooth substrate is accelerated beyond a critical velocity of approximately 1 m/s . Nanotexturing the surface with average roughness values even below 10 nm results in critical velocity larger than 2.5 m/s , the upper limit of our apparatus. This unexpected increase in critical velocity is observed for both sticky hydrophobic and slippery superhydrophobic surfaces. We attribute this large increase in critical velocity both in increased receding contact angle and in increased slip length for such nanotextured surfaces.

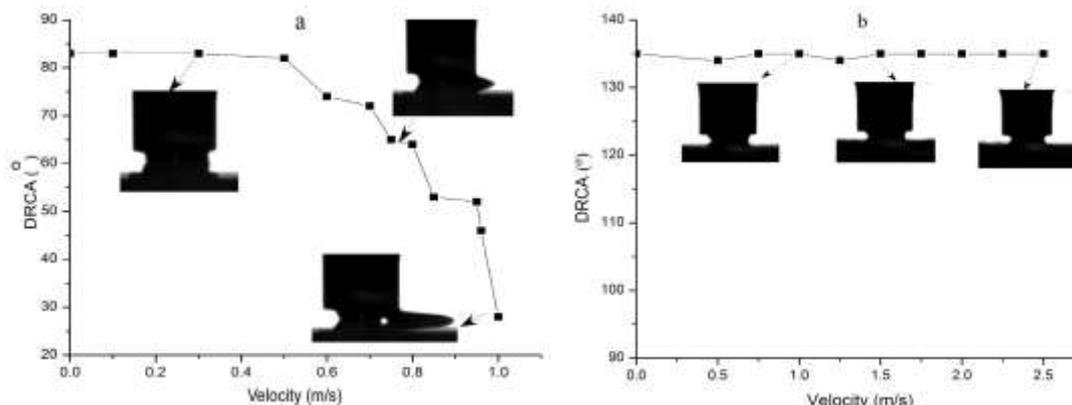


Fig. 12. Dynamic receding contact angle as a function of wafer velocity for a) smooth hydrophobic surface b) superhydrophobic surface

C3 Superamphiphobic surfaces using colloidal lithography and plasma etching

K. Ellinas, E. Gogolides, A. Tserepi

Ordered, hierarchical (triple-scale), superhydrophobic, oleophobic, superoleophobic, and amphiphilic surfaces on Poly(methyl methacrylate) PMMA polymer substrates were fabricated using Polystyrene (PS) microparticle colloidal lithography, followed by Oxygen plasma etching-nanotexturing (for amphiphilic surfaces) and optional subsequent fluorocarbon plasma deposition (for amphiphobic surfaces). The PS colloidal microparticles were assembled by spin-coating. After etching / nanotexturing, the PMMA plates are amphiphilic and exhibited hierarchical (triple-scale) roughness with microscale ordered columns, and dual-scale (hundred nano/ ten nano meter) nanoscale texture on the particles (top of the column) and on the etched PMMA surface. The spacing, diameter, height, and reentrant profile of the microcolumns were controlled with the etching process. Following the design requirements for superamphiphobic surfaces, we demonstrated enhancement of both hydrophobicity and oleophobicity as a result of hierarchical (triple-scale) and re-entrant topography. After fluorocarbon film deposition we demonstrated superhydrophobic surfaces (contact angle for water 168° , compared to 110° for a flat surface), as well as superoleophobic surfaces (153° for diiodomethane, compared to 80° for a flat surface).



Fig. 13. Superamphiphobic and superamphiphilic surfaces produced on PMMA. Water drops roll on the first and spread on the second. Inserts are SEM images top view (left) and cross section (right) of the topography.

C4 Nanoscale silicon etching

A. Smyrnakis, E. Gogolides, A. Tserepi

The fabrication of a wide range of micro- and nano-scale devices requires patterning of silicon and demands the formation of ever-smaller features and higher aspect ratios. We developed a cryogenic high-density plasma etching process for silicon that uses processing temperatures below -100°C and a gas mixture of SF_6/O_2 , and excels in its high selectivity over resist and polymeric mask and its very high aspect ratio capability. This anisotropic process was optimized in the micro- and nanoscale leading to the formation of high aspect ratio ($>18:1$) silicon pillars with smooth controllable profiles. For the patterning, “mesh-

assisted" colloidal lithography was employed, as a self-assembly cost-effective process alternative to optical lithography. Before the pattern transfer to silicon, an isotropic oxygen plasma etching step is used to reduce the polystyrene colloidal particle diameter offering full control of the pillar diameter. These silicon nanopillars can find possible application for silicon solar cells or as molds for nanoimprint lithography.

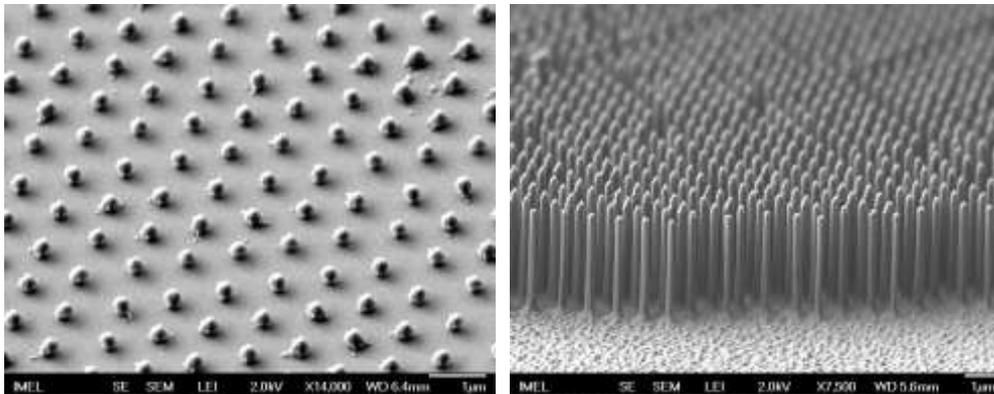


Fig. 14. (a) Polystyrene colloidal particles after the isotropic shrinking; (b) Si pillars (diameter 200nm) fabricated by the cryogenic etching process, following pattern transfer from colloidal lithography mask.

D. Plasma etching, plasma assisted, and chemical vapour deposition simulation

D1 Simulation of plasma roughening

G. Kokkoris, V. Constantoudis, E. Gogolides

The potential of plasma etching to produce periodicity on surfaces is investigated with a stochastic modeling framework for morphology evolution. The framework handles gas transport in the rarified regime with Monte Carlo method and uses a cellular representation of the etched surface. Generally, three types of particles, i.e. ions, reactive neutral species causing etching, and depositing particles (etch-inhibitors), are considered to abstractly approximate the complex plasma environment; their interaction with the substrate defines the surface roughness. The periodicity on the surfaces is identified by the peak in the power spectral density (PSD) of the surface height. It is found that the mechanisms of a) ion reflection, which leads to formation of holes (Fig. 15), and b) simultaneous to ion-driven etching deposition, which results to formation of dots (Fig. 16), can induce periodicity on the etched surface.

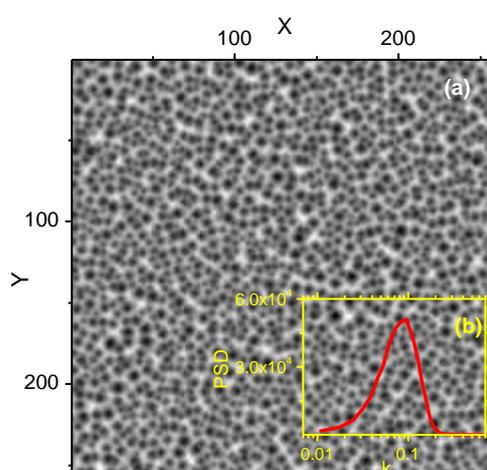


Fig. 15. (a) Periodic holes on the surface under the mechanism of ion reflection. (b) PSD indicating the periodicity.

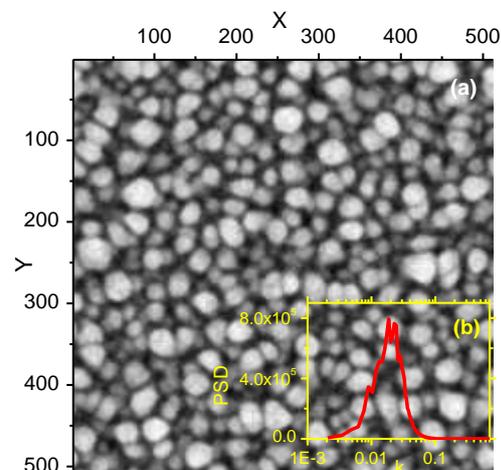


Fig. 16. (a) Periodic dots on the surface under the simultaneous to ion-driven etching deposition. (b) PSD indicating the periodicity.

D2 Multiscale modeling of chemical vapour deposition processes

G. Kokkoris

The size of the devices shrinks to lower scales and the specifications of the deposited films (thickness, conformality, surface morphology) refer to properties in micro- or nano-scale. More advanced, compared to conventional single scale, multiscale modeling methods are needed for studying the phenomena in the co-existing (multiple length) scales during the filling of a micro- or submicro-trench in a chemical vapor deposition (CVD) reactor. A multiscale modeling framework is used to link the operating parameters of the CVD reactor with the film profile evolution inside trenches on a wafer with predefined topography (an array of micro-trenches). The framework couples a reactor scale model (RSM), used for the description of the macro-scale in the reactor bulk, with a feature scale model (FSM), used for the description of the film profile evolution of the micro-scale features (e.g. trenches or holes) on the wafer (Fig. 17a). The coupling is performed through the local (along the wafer) correction of the surface reactions kinetics taking into account the micro-topography on the wafer without including it in the computational domain of the RSM. The consumption of species on the wafer depends on the deposition instant (Fig. 17b) as the micro-topography on the wafer changes versus time due to the film deposition; the available for deposition area changes as the trenches are filling. The density (number) of trenches on the wafer affects the film deposition (Fig. 17c) due to loading effects, i.e. the depletion of reactants due to their increased consumption in the micro-topography on the wafer surface.

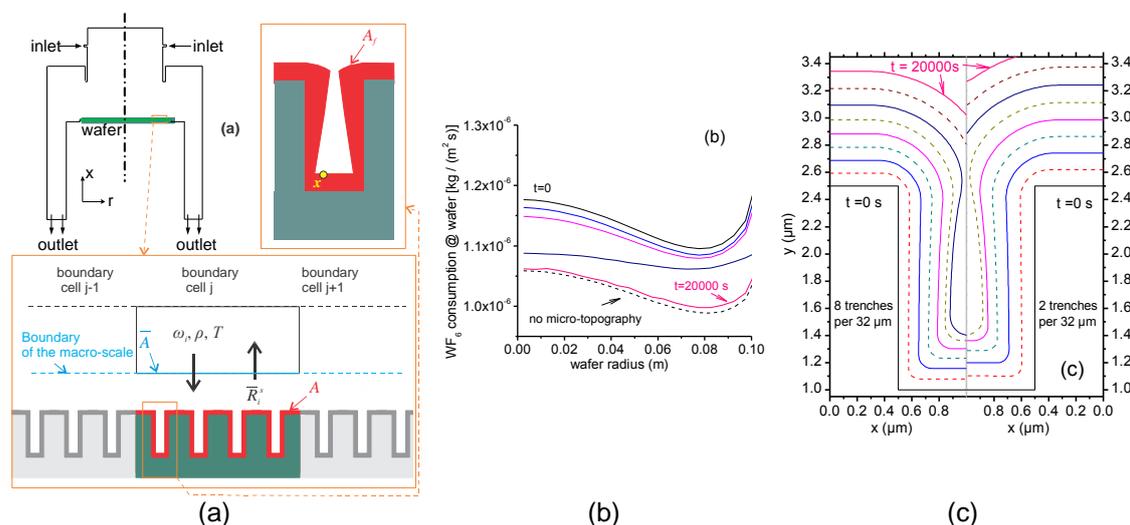


Fig. 17. (a) The schematic of the coupling methodology. (b) Tungsten (W) deposition from Tungsten hexafluoride (WF_6) and Hydrogen is the case studied. The consumption of WF_6 along the wafer for different time instances. (c) W film profile evolution at the same position on the wafer under different trenches-surface-density (8 and 2 trenches per 32 μm).

E. Acquisition and Installation of new Equipment and Infrastructure for plasma processing and Lab on Chip assembly and characterization

During the past year, a second Helicon Plasma etching system was acquired as a loan from Centre Interuniversitaire de MicroElectronique et Nanotechnologies (CIME Nanotech) in France with the kind intervention of Dr Pascal Normand. The new system was installed in the plasma laboratory of IMEL. There are now two identical systems for plasma processing, one dedicated to Silicon MEMS etching using the Bosch process and in fluorocarbon polymer deposition, and another dedicated to Oxygen and Sulfure Hexafluoride chemistries for polymer processing for polymeric MEMS, microfluidics, and Lab on Chip fabrication. Both systems are capable of cryogenic etching as well as heating up to 60 C, and are equipped with in-situ spectroscopic ellipsometry.

In addition, this past year, characterization equipment for microfluidics and Lab on Chip was bought. The equipment consists of miniaturized pumps and valves for pumping tiny liquid amounts (labsmith company), and a UV-spectrophotometer with optical fibers and CCD detection (θ -metrisis company) for optical absorption or fluorescence characterization of

chromatographic effluents from microchannels. This device has been used for affinity chromatography of phosphopeptides.



Fig. 18. (a) Photograph of the plasma laboratory with the two MET helicon plasma etchers from Adixen.

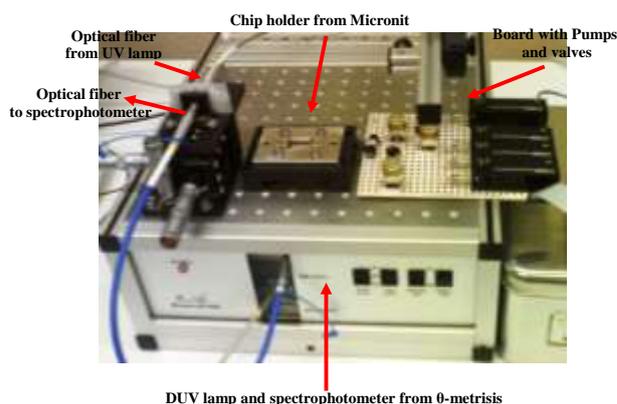


Fig. 18. (b) Photograph of the microfluidics / lab-on-chip characterization equipment (micropumps from labsmith and UV spectrophotometer from θ -metrisis)

Due to the installation of the MET system, the facility for Lab on Chip assembly had to be moved in a new laboratory which was also inaugurated this year. The lab includes a hot press for thermal bonding or embossing, equipment for hole drilling, sawing, as well as a small chemical hood for cleaning.



Fig. 19. Photographs from the Lab on Chip assembly laboratory

PROJECT OUTPUT IN 2010

Publications in International Journals and Reviews

Microfluidics – Microarrays – Lab-on-a-Chip for Life Sciences

1. ““Smart” polymeric microfluidics fabricated by plasma processing: Controlled wetting, capillary filling and hydrophobic valving”, Tsougeni, K., Papageorgiou, D., Tserepi, A., Gogolides, E., (2010) Lab on a Chip - Miniaturisation for Chemistry and Biology, 10 (4), pp. 462-469.
2. “Plasma nanotextured PMMA surfaces for protein arrays: Increased protein binding and enhanced detection sensitivity”, Tsougeni, K., Tserepi, A., Constantoudis, V., Gogolides, E., Petrou, P.S., Kakabakos, S.E., (2010) Langmuir, 26 (17), pp. 13883-13891.
3. “Protein arrays on high-surface-area plasma-nanotextured poly(dimethylsiloxane)-coated glass slides”, M-E. Vlachopoulou, A. Tserepi, P.S. Petrou, E. Gogolides, S.E. Kakabakos, (2010) Colloids and Surfaces B: Biointerfaces, DOI:10.1016/j.colsurfb.2010.11.031
4. “Study of flow and pressure field in microchannels with various cross-section areas”, Petropoulos, A., Kaltsas, G., Randjelovic, D., Gogolides, E., (2010) Microelectronic Engineering, 87 (5-8), pp. 827-829.

Plasma Nanoscience for wetting control and Plasma Simulation

5. “Stable superhydrophobic surfaces induced by dual-scale topography on SU-8”, Marquez-Velasco, J., Vlachopoulou, M.-E., Tserepi, A., Gogolides, E., (2010) Microelectronic Engineering, 87 (5-8), pp. 782-785.

6. "Micro and nano structuring and texturing of polymers using plasma processes: Potential manufacturing applications", Gogolides, E., Vlachopoulou, M., Tsougeni, K., Vourdas, N., Tserepi, A., (2010) *International Journal of Nanomanufacturing*, 6 (1-4), pp. 152-163.
7. "Plasma directed assembly and organization: Bottom-up nanopatterning using top-down technology", Vourdas, N., Kontziampasis, D., Kokkoris, G., Constantoudis, V., Goodyear, A., Tserepi, A., Cooke, M., Gogolides, E., (2010) *Nanotechnology*, 21 (8), art. no. 085302.

Lithography and Line Edge Roughness

8. "Optimized surface silylation of chemically amplified epoxidized photoresists for micromachining applications", Kontziampasis, D., Beltsios, K., Tegou, E., Argitis, P., Gogolides, E., (2010) *Journal of Applied Polymer Science*, 117 (4), pp. 2189-2195.
9. "Stochastic modeling and simulation of photoresist surface and line-edge roughness evolution", Patsis, G.P., Drygiannakis, D., Constantoudis, V., Raptis, I., Gogolides, E., (2010) *European Polymer Journal*, 46 (10), pp. 1988-1999.
10. "Effects of resist sidewall morphology on line-edge roughness reduction and transfer during etching: is the resist sidewall after development isotropic or anisotropic?", Constantoudis, V., Kokkoris, G., Gogolides, E., Pargon, E., Martin, M., (2010) *J. Micro/Nanolith. MEMS MOEMS* Vol. 9, 041209
11. "Evolution of resist roughness during development: Stochastic simulation and dynamic scaling analysis", Constantoudis, V., Patsis, G.P., Gogolides, E., (2010) *J. Micro/Nanolith. MEMS MOEMS* Vol. 9, 041207
12. "Detailed resist film modeling in stochastic lithography simulation for line-edge roughness quantification", Patsis, G.P., Drygiannakis, D., Raptis, I., (2010) *Microelectronic Engineering* 87 (5-8), pp. 989-992.
13. "Simulation of shot noise effect on CD and LER of electron-beam lithography in 32 nm designs", Patsis, G.P., Tsikrikas, N., Drygiannakis, D., Raptis, I., (2010) *Microelectronic Engineering* 87 (5-8), pp. 1575-1578.

CVD Process modelling

14. "Multiscale modeling in chemical vapor deposition processes: Coupling reactor scale with feature scale computations", Cheimarios, N., Kokkoris, G., Boudouvis, A.G., (2010) *Chemical Engineering Science*, 65 (17), pp. 5018-5028

Other Collaborative Work

15. "Entropy analysis of natural language written texts", Papadimitriou, C., Karamanos, K., Diakonou, F.K., Constantoudis, V., Papageorgiou, H., (2010) *Physica A: Statistical Mechanics and its Applications*, 389 (16), pp. 3260-3266.

International Conference Proceedings

Lithography and Line Edge Roughness

1. "Is the resist sidewall after development isotropic or anisotropic? Effects of resist sidewall morphology on LER reduction and transfer during etching (oral)", Vassilios Constantoudis, George Kokkoris, Evangelos Gogolides, Erwine Pargon, Mickael Martin, *Proceedings of SPIE -Advanced Lithography*, San Jose, California, USA, 21-25 February 2010, 7639-34, art. no. 76392T, (2010)
2. "Evolution of resist roughness during development: stochastic simulation and dynamic scaling analysis (poster)", Vassilios Constantoudis, George P. Patsis, Evangelos Gogolides, *Proceedings of SPIE -Advanced Lithography*, San Jose, California, USA, 21-25 February 2010, 7639-105, art. no. 76392H, (2010)
3. "Line-edge roughness effects on transistor performance: the role of the gate-width design (poster)", Vassilios Constantoudis, George P. Patsis, Evangelos Gogolides, *Proceedings of SPIE -Advanced Lithography*, San Jose, California, USA, 21-25 February 2010, 7641-41, art. no., (2010)
4. "Line Width Roughness effects on device performance: The role of the gate width design", Constantoudis, V., Gogolides, E., Patsis, G.P., (2010) *Proceedings of SPIE - The International Society for Optical Engineering*, 7641, art. no. 764116.
5. "Line Width Roughness effects on device performance: The role of the gate width design", Constantoudis, V., Gogolides, E., Patsis, G.P., (2010) *2010 27th International Conference on Microelectronics, MIEL 2010 - Proceedings*, art. no. 5490486, pp. 265-268.
6. "Evolution of resist roughness during development: Stochastic simulation and dynamic scaling analysis", Constantoudis, V., Patsis, G.P., Gogolides, E., (2010) *27th International Conference on Microelectronics, MIEL 2010 - Proceedings*, art. no. 5490483, pp. 269-272.

CVD Process modelling

7. "A Computational Framework for Multiscale Modeling in Chemical Vapor Deposition Processes (oral)", N. Cheimarios, G. Kokkoris, A. G. Boudouvis, *Proceedings of 5th European Conference on Computational Fluid Dynamics, ECCOMAS CFD 2010*, Lisbon, Portugal, June 14-17, 2010.
8. "An efficient parallel fixed point iteration method for multiscale analysis of chemical vapor deposition processes (oral)", N. Cheimarios, G. Kokkoris, A. G. Boudouvis, *Proceedings of Conference in Numerical Analysis (NumAn 2010)*, Chania, Greece, September 15-18, 2010.

International Conference Presentations

Microfluidics – Microarrays – Lab-on-a-Chip for Life Sciences

1. “Micro-fabricated TiO₂-ZrO₂ Affinity Chromatography Micro-Columns on Polymeric or Silicon Substrates for Phosphopeptide Analysis (oral)”, K. Tsougeni, G. Boulousis, T. Roumeliotis, K. Zorpas, T. Speliotis, A. Botsialas, I. Raptis, A. Tserepi, S.D. Garbis, E. Gogolides, Lab-on-a-Chip European Congress, 25-26 May 2010, Dublin, Ireland
2. “Protein Patterning Through Selective Plasma-induced Modification of Silicon Oxide and Glass Substrates (oral)”, A. Tserepi, A. Malainou, E. Gogolides, P. S. Petrou, S. E. Kakabakos, Advances in Microarray Technology, 25-26 May 2010, Dublin, Ireland
3. “Multifunctional, “Smart”, Polymeric Microfluidics Fabricated by Plasma Processing: Applications in Capillary Filling and Passive Superhydrophobic Valving (poster)”, K. Tsougeni, D. Papageorgiou, A. Tserepi, E. Gogolides, Lab-on-a-Chip European Congress, Dublin, Ireland, May 24-25 2010
4. “Protein and DNA Patterning on Plasma-modified Polymeric Surfaces for Bioanalytical Applications (poster)”, K. Tsougeni, M.-E. Vlachopoulou, P. Petrou, S. Kakabakos, A. Tserepi, E. Gogolides, “Advances in Microarray Technologies”, Dublin, Ireland, May 24-25 2010
5. “Micro-fabricated TiO₂-ZrO₂ Affinity Chromatography Micro Columns on Poly(methyl methacrylate) (PMMA) substrates for Phosphopeptide Analysis (oral)”, K. Tsougeni, E. Gogolides, 36th International Conference on Micro & Nano Engineering, GENOA (Italy), 19-22 September 2010
6. “High-density patterning of proteins on substrates for applications in lab-on -a chip devices and microarrays (poster)”, A. Malainou, A. Tserepi, P. Petrou, S. Kakabakos, E. Gogolides, 36th International Conference on Micro & Nano Engineering, GENOA (Italy), 19-22 September 2010
7. “Submicrometer protein patterning using colloidal lithography and plasma processing (poster)”, A. Malainou, K. Ellinas, P.S. Petrou, S.E. Kakabakos, E. Gogolides, S. Pagakis, A. Tserepi, 4th International Conference on Micro-Nanoelectronics, Nanotechnologies & MEMs, NCSR Demokritos, Athens, 12 – 15 December 2010
8. “Continuous-flow polymeric microfluidic device with integrated microheaters for on-chip DNA amplification (poster)”, E. Mavraki, D. Moschou, S. Chatzandroulis, A. Tserepi, 4th International Conference on Micro-Nanoelectronics, Nanotechnologies & MEMs, NCSR Demokritos, Athens, 12 – 15 December 2010
9. “Designing a continuous flow microfluidic device for polymerase chain reaction (PCR) (poster)”, I. Kouris, G. Kokkoris, A. Tserepi, 4th International Conference on Micro-Nanoelectronics, Nanotechnologies & MEMs, NCSR Demokritos, Athens, 12 – 15 December 2010

Plasma Nanoscience for wetting control and Plasma Simulation

10. “Mechanisms inducing periodic holes or dots on plasma etched surfaces (oral)”, G. Kokkoris, V. Constantoudis, E. Gogolides, 3rd workshop on Plasma Etch and Strip in Microelectronics (PESM 2010), 4-5 March 2010, Grenoble, France
11. “Plasma Directed Assembly and Organization: Bottom-up Nanopatterning Using a Top-down Technology”, D. Kontziampasis, N. Vourdas, G. Kokkoris, V. Constantoudis, A. Goodyear, A. Tserepi, M. Cooke, E. Gogolides, 3rd workshop on Plasma Etch and Strip in Microelectronics (PESM 2010), 4-5 March 2010, Grenoble, France
12. “Plasma Directed Assembly and Organization: Effect of Plasma Processing Conditions on Order and Nanodot Dimensions (poster)”, D. Kontziampasis, G. Kokkoris, V. Constantoudis, A. Smyrnakis, A. Zeniou, E. Gogolides, The 54th International Conference on Electron, Ion and Photon Beam technology and Nanofabrication (EIPBN), Anchorage, Alaska, June 1-4, 2010
13. ““Mesh-assisted” colloidal lithography and plasma etching: A route to large-area, uniform, ordered nano-pillar production on versatile substrates (poster)”, K. Ellinas, A. Malainou, A. Zeniou, A. Tserepi, E. Gogolides, 36th International Conference on Micro & Nano Engineering, GENOA (Italy), 19-22 September 2010
14. “Amphiphobic, Plasma Nanotextured Polymer Surfaces (poster)”, A. K. Gnanappa, K. Ellinas, A. Tserepi, E. Gogolides, 36th International Conference on Micro & Nano Engineering, GENOA (Italy), 19-22 September 2010
15. “Superhydrophobic Surfaces for Water Immersion Lithography (poster)”, A. K. Gnanappa, E. Gogolides, F. Evangelista, M. Riepen, 36th International Conference on Micro & Nano Engineering, GENOA (Italy), 19-22 September 2010
16. “Plasma Directed Assembly and Organization: Formation of polymeric nanodots and silicon nanopillars (oral)”, A. Smyrnakis, D. Kontziampasis, A. Zeniou, A. Tserepi, E. Gogolides, 63rd Gaseous Electronics Conference & 7th International Conference on Reactive Plasmas, October 4-8, 2010, Paris, France
17. “Controlling roughness - from etching to nanotexturing and plasma directed organization on organic and inorganic material (oral - invited)”, E. Gogolides, iPlasmaNano-II Conference, Second International Symposium on Plasma Nanoscience, 12 – 15 December 2010, Murrumarang Resort, South Coast, New South Wales, Australia (INVITED)
18. “Contact Line Dynamics of a Superhydrophobic Surface: Application for Immersion Lithography (oral)”, A.K. Gnanappa, E. Gogolides, F. Evangelista, M. Riepen, 2nd European Conference on Microfluidics (MicroFlu'10), December 08-10, 2010, Toulouse, France

19. "Fabrication of Micro and Nano Textured Superamphiphobic Surfaces (oral)", K. Ellinas, A. Kumar Gnanappa, A. Tserepi, E. Gogolides, 4th International Conference on Micro-Nanoelectronics, Nanotechnologies & MEMs, NCSR Demokritos, Athens, 12 – 15 December 2010
20. "Bridging micro- with macro-scale in chemical vapor deposition processes (poster)", N. Cheimarios, S. Garnelis, G. Kokkoris, A. G. Boudouvis, 4th International Conference on Micro-Nanoelectronics, Nanotechnologies & MEMs, NCSR Demokritos, Athens, 12 – 15 December 2010
21. "Plasma Directed Assembly and Organization: Materials effect and pattern transfer (poster)", D. Kontziampasis, A. Smyrnakis, G. Kokkoris, V. Constantoudis, A. Zeniou, E. Gogolides, 7th International Conference on Nanosciences & Nanotechnologies (NN10) 11-14 July 2010, Ouranopolis Halkidiki, Greece
22. "Mechanical Characteristics of Plasma-induced Nano-Roughness and Nano-Texture on PMMA and other Polymers (poster)", A. Kumar, D. Kontziampasis, A. Tserepi, E. Gogolides, A. Skarmoutsou, C.A. Charitidis, 7th International Conference on Nanosciences & Nanotechnologies (NN10) 11-14 July 2010, Ouranopolis Halkidiki, Greece

Lithography and Line Edge Roughness

23. "The Line Edge roughness (LER) problem: From Lithography-to Plasma Etching-to Device Operation (oral invited)", E. Gogolides, V. Constantoudis, G. Kokkoris, 3rd workshop on Plasma Etch and Strip in Microelectronics (PESM 2010), 4-5 March 2010, Grenoble, France
24. "Line Width Roughness Effects on Device Performance: The Role of the Gate Width Design (oral)", V. Constantoudis, E. Gogolides, G. Patsis, (2010) IEEE 27th International Conference on Microelectronics - MIEL 2010, 16-19 May 2010, Nis, Serbia
25. "Evolution of Resist Roughness During Development: Stochastic Simulation and Dynamic Scaling Analysis (oral)", V. Constantoudis, G. Patsis, E. Gogolides, (2010) IEEE 27th International Conference on Microelectronics - MIEL 2010, 16-19 May 2010, Nis, Serbia
26. "Contact Edge Roughness: Characterization and Modeling (poster)", Vijaya-Kumar M.K., V. Constantoudis, E. Gogolides, 36th International Conference on Micro & Nano Engineering, GENOA (Italy), 19-22 September 2010
27. "Fractal geometry in nanofabricated structures: The key role of roughness (oral)", V. Constantoudis, G. P. Patsis, E. Gogolides, 4th International Conference on Micro-Nanoelectronics, Nanotechnologies & MEMs, NCSR Demokritos, Athens, 12 – 15 December 2010
28. "Measurement and Characterization of Contact Hole Roughness: Frequency and Spatial Analysis (poster)", Vijaya Kumar Murugesan Kuppuswamy, V. Constantoudis, E. Gogolides, 4th International Conference on Micro-Nanoelectronics, Nanotechnologies & MEMs, NCSR Demokritos, Athens, 12 – 15 December 2010

CVD Process modelling

29. "Multiscale modeling of deposition processes (oral-invited)", A. G. Boudouvis, N. Cheimarios, G. Kokkoris, 6th Chemical Engineering Conference for Collaborative Research in Eastern Mediterranean Countries, EMCC-6, Belek, Antalya, Turkey, March 7-12, 2010.
30. "A Computational Framework for Multiscale Modeling in Chemical Vapor Deposition Processes (oral)", N. Cheimarios, G. Kokkoris, A. G. Boudouvis, 5th European Conference on Computational Fluid Dynamics, ECCOMAS CFD 2010, Lisbon, Portugal, June 14-17, 2010.
31. "An efficient parallel fixed point iteration method for multiscale analysis of chemical vapor deposition processes (oral)", N. Cheimarios, G. Kokkoris, A. G. Boudouvis, Conference in Numerical Analysis (NumAn 2010) , Chania, Greece, September 15-18, 2010.

Greek Conference Presentation

1. "Micro-fabricated TiO₂-ZrO₂ affinity chromatography chip on poly(methyl methacrylate) (PMMA) substrates for phosphopeptide analysis", K. Tsougeni, P. Zerefos, A. Tserepi, A. Vlahou, S. Garbis, E. Gogolides, 7th Aegean Analytical Chemistry Days (AACD2010), Mytilene, Lesvos, 29 September - 03 October 2010
2. "Plasma nanotextured amphiphobic polymer surfaces (poster)", A. K. Gnanappa, K. Ellinas, A. Tserepi, E. Gogolides, 80 Hellenic Polymer Society Symposium (H-POL8), 24-29 October 2010, Hersonissos, Crete, Greece

Conference Participation

- MNE 2010 - 36th International Conference on Micro & Nano Engineering
- SPIE 2010
- MIEL 2010 - 27th International Conference on Microelectronics
- PESM - Plasma Etch and Strip in Microelectronics 3rd International Workshop 2010
- Lab-on-a-Chip European Congress 2010
- Advances in Microarray Technology 2010
- EIPBN 2010 - 54th International Conference on Electron, Ion and Photon Beam technology and Nanofabrication

- 63rd Gaseous Electronics Conference 2010 & 7th International Conference on Reactive Plasmas 2010
- iPlasmaNano-II Conference, Second International Symposium on Plasma Nanoscience 2010
- MicroFlu 2010 - 2nd European Conference on Microfluidics
- 4th International Conference on Micro-Nanoelectronics, Nanotechnologies & MEMS
- AACD 2010 - 7th Aegean Analytical Chemistry Days
- H-POL8 2010 – 8th Hellenic Polymer Society Symposium
- NumAn 2010 - Conference in Numerical Analysis
- ECCOMAS CFD 2010 - 5th European Conference on Computational Fluid Dynamics
- EMCC-6 - Conference for Collaborative Research in Eastern Mediterranean Countries

Ph. D. Thesis

“Micro- and nano- texturing of polymers for the fabrication of microanalytic devices”

Katerina Tsougeni, Chemist, MSc, PhD,

National and Kapodistrian University of Athens, Chemistry Department

Thesis advisor-supervisor: Evangelos Gogolides.

Thesis supervisor at the University of Athens: Prof. E. Iatrou

M. Sc. Thesis

“Cryogenic Etching Process for Silicon Micro and Nanostructures”

Athanasios Smyrnakis, School of Applied Mathematical and Physical Sciences (NTUA), MSc

Masters Programme in Microsystems & Nanodevices, National Technical University of Athens

Thesis Advisor-Supervisor: Evangelos Gogolides

Seminars – invited talks

- “Controlling roughness - from etching to nanotexturing and plasma directed organization on organic and inorganic material (oral - invited)”, E. Gogolides, iPlasmaNano-II Conference, Second International Symposium on Plasma Nanoscience, 12 – 15 December 2010, Murrumarang Resort, South Coast, New South Wales, Australia
- “Multiscale modeling of deposition processes (oral-invited)”, A. G. Boudouvis, N. Cheimarios, G. Kokkoris, 6th Chemical Engineering Conference for Collaborative Research in Eastern Mediterranean Countries, EMCC-6, Belek, Antalya, Turkey, March 7-12, 2010

Courses

- During the advanced summer school “Methods in Micro-Nano Technology and Nanobiotechnology”, September 13-17, 2010 we taught the following lectures and lab: “Principles of nanotechnology and nanobiotechnology” (E. Gogolides), “Microfabrication technologies for plastic analytical microfluidics” (A. Tserepi), “Conventional patterning schemes for hard substrates for bioanalytic microdevices” (E. Gogolides), “Fabrication of microfluidic devices on plastic substrates by Soft lithography and deep polymer plasma etching” (A. Tserepi, M.-E. Vlachopoulou, K. Tsougeni, A. Zeniou). See video on Nano2Life Site: <http://n2lvip.tau.ac.il/> Demokritos Summer School
- “Microelectronics and Microsystems fabrication processes”, (E. Gogolides, D. Davazoglou, A. Nassiopoulou), Postgraduate Programs on Microsystems and Nanodevices of the National Technical University of Athens and Micro and Nano Electronics of the National and Kapodistrian University of Athens
- “Plasma Processing for Micro and Nano Fabrication”, (E. Gogolides, G. Kokkoris, V. Constantoudis, A. Tserepi), Postgraduate Program on Microelectronics of the National and Kapodistrian University of Athens
- “Microfluidic systems”, (D. Mathioulakis, I. Anagnostopoulos, A. Tserepi), Postgraduate Program on Microsystems and Nanodevices of the National Technical University of Athens
- “Simulation of Micro and Nano-Patterning”, (E. Gogolides, G. Kokkoris, V. Constantoudis, A. Tserepi), Postgraduate Program on Mathematical Modelling in Modern Technologies and Financial Engineering of the National Technical University of Athens
- “Fractal geometry and its applications in microelectronics”, (V. Constantoudis), Demokritos Summer School, 05-16 July 2010
- “Process and device simulation” (G. Kokkoris), Postgraduate Program on Microelectronics of the National and Kapodistrian University of Athens

Organization of Schools

- 6th Summer School “Methods in Micro-Nano Technology and Nanobiotechnology”, co-sponsored by the PEOPLE-ITN-237962 project CYCLON (<http://www.itn-cyclon.eu>).
<http://imel.demokritos.gr/SummerSchool2010/index.htm>