Master Thesis/Internship

Topic Guide 2011-2012

imec

Information

Students from universities and engineering schools can apply for a master thesis and/or internship project at imec. Imec offers topics in engineering and (industrial) sciences in different fields of research.

The topics are arranged according to the imec business programs. You can find more detailed information on each research program under the heading 'Research' on www.imec.be.

How to apply?

Send an e-mail with your motivation letter and detailed resume to the supervising scientist(s) mentioned at the bottom of the topic description of your preference. The scientist(s) will screen your application and let you know whether or not you are selected for a project at imec.

It is not recommended to apply for more than three topics.

For more information, go to the Internship and Master Thesis pages under the Education heading on our website.

I. CMOS Scaling R&D

Deposition, characterization and application of dielectric films

New dielectric films are being developed for many applications in integrated circuits. Dielectric films are, in general, used to form an electrical insulator between active devices-transistors and/or electrically conducting metal lines. Their main characteristics are:

- good uniformity over the wafer
- good conformality over possible topography
- high resistivity
- controlled stress
- hardness and Young's modulus

The deposition process also needs to be :

- reproducible and compatible with other process steps in the manufacturing of the integrated circuit
- the adhesion of the film to films below and above has to be assured
- the reliability of the IC is strongly depending on the quality of the dielectric films

The characterization of thin dielectric films consists of several phases. First you start with the determination of thickness, refractive index, chemical composition through FTIR, stress, Young's modulus, hardness, porosity, hydrophilicity, dielectric constant, and leakage of the films. If this characterization looks promising, a second series of tests which simulate other (former and later) process steps, are performed; this also includes tests to determine the adhesion to other films, mainly by 4 point bending analysis. Also, a more detailed chemical analysis, e.g. through XPS and TOFSIMS, will be performed. If all test are positive, finally, the material is used in an integration process, resulting in a real test chip and the final electrical characterizations (including reliability characterizations) are made.

The student will be very strongly involved in the detailed characterization of the basic film properties. Hereby (s)he will use state of the art analysis equipment, such as ellipsometers, a Fourier Transform Infrared spectrometer, a high precision mass measurement system, and others. Furthermore (s)he will also be involved in the next phase of the characterization cycle, as setting up the processes for the simulation of integration aspects and the electrical characterization on test chips.

Academic and industrial results will be reported in meetings where both imec staff and industrial affiliates participate.

Type of project: thesis or internship for a period of minimum 3 months

Degree: Master in Sciences or Master in Engineering majoring in material science, physics, electronics

Responsible scientist(s):
For further information or for application please contact Patrick Verdonck (patrick.verdonck@imec.be) and Els Van Besien (els.vanbesien@imec.be).

Using a variational principle to solve Poisson's and Schroedinger's equations self-consistently within a single loop: how far can we go?

Transport calculations for modern semiconductor devices heavily rely on the local charge distribution and the related electrostatic potential established inside the device structures. As such, one is bound to solve the Schroedinger equation self-consistently with Poisson's equation and a number of constitutive equations relating the electron and hole concentrations to the wave functions of the quantum states and their occupancies. Designing appropriate numerical code to deal with this task, one is immediately faced with a significant computational burden due to the highly non-linear dependence of the charge density on the potential. Moreover, the necessity of feeding back the charge density into the code that solves Poisson's equation is reflected in the double loop that conventionally handles the self-consistent solution.

Recently, an efficient but non-linear variational principle has been developed that provides a simultaneous solution of all equations that can be carried out within a single loop that minimizes a proper action functional. So far however, the necessary condition that the charge density be a local functional of the potential, has restricted the application of the principle to those cases where the charge density can be treated either classically or quantum mechanically, yet within the adiabatic approximation.

The purpose of this thesis is to work out the non-linear variational principle for a number of simple test structures (e.g. pn-diodes, planar and double-gate MOSFETs) and to make a first attempt towards embedding the variational calculus in a more rigorous quantum mechanical treatment.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in theoretical physics, computational physics, nano-science

Responsible scientist(s):
For further information or for application please contact Wim Magnus (wim.magnus@imec.be) and Bart Soree (bart.soree@imec.be).

A semi-analytical model for leakage currents in MOS capacitors

Recently, a new model has been devised to predict the leakage current in a planar MOS capacitor. The model incorporates the competition between the local generation and recombination of electrons and holes in the inversion layer, and the tunneling of electrons penetrating through the oxide layer. Moreover, the new model is found to solve also the "current" paradox dealing with the absence of net electric currents carried by quasi-bound states. Presently, the model is implemented in a computer program that traces the time evolution of decaying charge packets, but there is also room for analytical exploration.

The purpose of this thesis is to calculate semi-analytically the tunneling decay rate of the electrons residing in the inversion layer as a function of the oxide thickness and other relevant material parameters. In particular, the student will examine to which extent the time dependent decay can be considered exponential.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in theoretical physics, computational physics, nano-science

Responsible scientist(s):
For further information or for application please contact Wim Magnus (wim.magnus@imec.be) and Bart Soree (bart.soree@imec.be).

Ab initio study of the surface chemistry of Atomic Layer Deposition (ALD)

Atomic Layer Deposition (ALD) is an advanced technique to deposit thin films on a substrate from gas phase precursors. The film is deposited layer by layer through a cyclic process of self-limiting surface reactions. The use of self-limiting surface reactions results in a number of unique features, such as growth control at the atomic level and conformal deposition of extremely complex nanostructures.

Thanks to the process control at the atomic level, ALD has applications in nanotechnology. For example, the performance of computer chips and memory cells can be improved by introducing novel materials deposited by ALD, for example high-k dielectric oxides. A new potential application is energy storage in supercapacitors with nanostructured materials. ALD can also be used to increase the efficiency of solar cells, e.g. by introducing a passivation layer.

Despite its application in industry, there are still uncertainties about the surface chemistry and reaction mechanisms of many ALD processes. Therefore, this project aims at a better understanding of the chemisorption reactions in ALD by theoretical calculations. The reactivity of different ALD precursors with respect to surface sites can be computed by using molecular cluster models or by periodic structure calculations. The calculations are based on Density Functional Theory (DFT) or on more advanced ab initio methods if required. The obtained theoretical results will be combined with relevant experimental information. The combination of experiment and theory can result in new insights that allow further optimization of ALD processes.

Type of project: thesis for a period of minimum 6 months

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in chemistry, physics, material science

Responsible scientist(s):
For further information or for application please contact Annelies Delabie (Annelies.Delabie@imec.be) and Geoffrey Pourtois (Geoffrey.Pourtois@imec.be).

Investigation and optimization of the electrical switching properties of Resistance RAM memory cells (RRAM)

The Resistance RAM is a new class of memories emerging as serious candidate for future memory replacement, in particular for high-density memory application. Resistance RAM cells typically consist of insulating oxide layers sandwiched between two metal electrodes, and exhibiting resistive-switching properties, that is to say the application of an electrical current/voltage to the cell induces reversible changes of the cell resistance, which allows thus programming different memory states.

For numerous resistive-switching metal/oxide/metal stacks, the switching to the low resistance state (LRS) is due to the formation of a conductive filament through the oxide while the return to the high resistance state (HRS) is due to partial rupture of this filament, the two operations being electrically induced. Depending on the materials used in the stack, the conductive filament is formed due to a sort of oxide breakdown leading to oxygen depletion along the breakdown path (Fig1a) or the conductive filament may be formed due to injection of the electrode metallic element into the oxide (Fig1b).

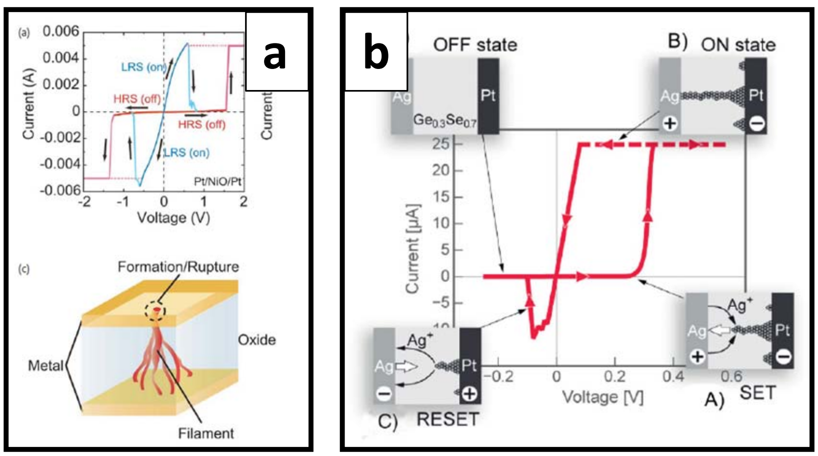


Fig1. (a) Current-Voltage characteristics showing switching to different resistance states, and conductive filament formed by local oxygen depletion in the oxide (from "A. Sawa, Materials Today, 11, 2008"); (b) Current-voltage switching traces and schematic of filament formation due to electrochemical dissolution and growth of the electrode metal element (from "R. Waser et al., Adv. Mater., 21, 2009")

The purpose of the thesis is to study the resistive-switching properties of different types of Resistance RAM stacks, in order to (1) better understand the switching mechanism, and (2) identify optimum material stack characteristics improving the memory parameters of the cell.

To this aim the study will mainly consist in electrical measurements using conventional Current-Voltage measurements, as well as pulse-programming testing for scaled devices. Specific measurements like temperature-dependent I-V or impedance measurements may also be required.

The effects of different stack parameters will be addressed by varying the nature of electrodes and oxides, the thicknesses, the microstructures, applying special treatments or anneals...

Type of project: thesis or internship for a period of minimum 4 months

Degree: Master in Science or Master in Engineering majoring in material science, physics, electronics

Responsible scientist(s):
For further information or for application please contact Ludovic Goux (ludovic.goux@imec.be).

Study of loading effects during thermal etch processes in an MOCVD reactor

Classical manufacturing techniques of integrated circuits consist of material deposition by layer growth processes such as metal-organic chemical vapor deposition (MOCVD) and the subsequent selective removal of material in lithographically defined areas. Whereas routinely wet chemical and dry etching techniques are used, recently in-situ etch processes have been explored. In-situ etching of device layer structures in an MOCVD reactor has several advantages compared to ex-situ: it leaves the etched surface free of contaminants and native oxides, and as such provides the best conditions for further epitaxial growth; it contributes to saving processing time and reducing handling risks, hence considerably helps saving on fabrication costs.

Nevertheless, when applying this technique on patterned wafers some intrinsic processing problems arise: the etching rate strongly depends on the size of the active areas on a micrometric scale (effect known as local loading effect) and on their ratio to the total wafer surface on a macroscopic scale (global loading effect). Loading effects (or area dependent reaction rates) are mainly due to local variations in gas phase concentration and surface temperature.

The project will focus on the study of micro and macro loading effects when applying in situ HCl recessing of InP buffer layers grown inside shallow trench isolation (STI) trenches in a state of the art MOCVD reactor located in the 300 mm cleanroom. This work frames in the development of high mobility channels made up of compound semiconductor (III-V) materials for end-of-the-roadmap CMOS technologies.

The candidate is expected to set up and run the experiments and analyze the results (electron and optical microscopy, High Resolution Profilometry). Based on the experimental results, a model will be set up which allows deeper insight in the various parameters that determine these loading effects (temperature, gas flows and concentrations, pressure, pattern dependency…) and that will help fine-tuning the etch process and to improve the project performance.

Type of project: thesis or internship

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in materials science

Responsible scientist(s):
For further information or for application please contact Tommaso Orzali (tommaso.orzali@imec.be).

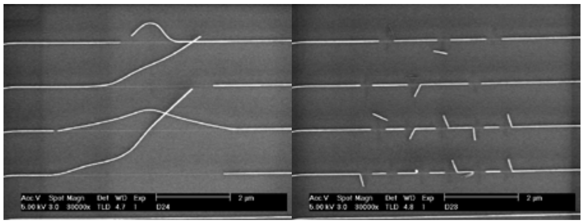
A detailed analysis of damage due to advanced cleaning

Fabrication of electronic integrated circuits requires very high performance cleaning that is very selective with respect to the substrates and the fine features present on the silicon surface. We are currently investigating the use of advanced cleaning methods like:

- megasonic cleaning: use of acoustic energy of an applied sound field to clean Si-wafers
- aerosol cleaning: use of impact energy of liquid/solid droplets to clean Si-wafers

In order to qualify those techniques optical inspection techniques are used to detect unwanted cleaning induced damage on the Si-wafers (like broken lines, see figure). High-tech inspection tools can detect these microscopic defects. In order to get a better insight into the cleaning mechanisms, the obtained data (defects) has to be analyzed carefully: defect count, defect classification, defect distribution and frequency are some of the parameters that help us to understand the cleaning phenomena.

Together with a multidisciplinary group of people you will participate in cleaning experiments. The aim of the experiments is to develop advanced cleaning methods without inducing damage. A important part of the work will be to inspect the wafers, classify the defects and analyze the results. You will identify trends in cleaning/damage performance of prototype tools. Depending on capabilities, progress and interest, also experimental work in the cleanroom may be required.



Type of project: thesis or internship or thesis with internship

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in material science, physics, electronics, chemistry

Responsible scientist(s):
For further information or for application please contact Antoine Pacco (antoine.pacco@imec.be).

Electroless deposition of copper seed layers for microelectronics applications

Context

Copper is used widely as metal interconnection in ultralarge scale integrated (ULSI) and 3D Interconnects owing to its low resistivity and high reliability against electromigration. The present damascene and 3D copper interconnections are fabricated by electroplating on a physical vapour deposited Cu seed layer. Bottom-up fill of Cu using additives in acid electroplating solutions has been studied extensively. Although the electrodeposition process achieved the filling of deep and narrow trenches and high aspect-ratio vias with copper, a few critical issues remain to be addressed, which include the need for a uniform and continuous sputtered copper seed layer, and the problem of non-uniform current distribution on the wafer.

The purpose of this work is to develop and characterize an electroless plating chemistry that is less dependent on the incoming resistivity of the substrate and dependency on the position within the wafer.

The effects of chemistry and experimental conditions on the deposition mechanism of the electroless Cu bath will investigated by electron microscopic and focus ion beam observation of the cross sections of the trenches in patterned substrates and by deposition rate measurements on unpatterned substrates.

Description of the work

The primary objective of the project is to investigate, develop and control an eletroless plating process directly on the thin barrier layers.

The student will test different commercial chemistries and benchmark with model chemistries. Different barrier and seed layers, such as Plasma Enhanced Atomic Layer Deposited (PEALD) Ru, Ta, TaN, Ti, TiN, Co, W are suitable candidates together with alternative advanced organic materials, such as Self-Assembled Monolayers. The type of work proposed is fully experimental and intensive deposition tests are expected together with the preparation of the chemical solutions in the lab. Among other techniques, Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), X-photon Spectroscopy (XPS), X-ray diffraction spectroscopy (XRD), four point probe Sheet Resistance (Rs) measurement, four point bending adhesion measurement, are suitable candidates to be used for the characterization of the liner material and of the directly deposited copper layer. These analyses will be supported by the Imec characterization team. Given the international character of imec, good knowledge of English is necessary.

Type of project**:** thesis or internship or thesis with internship for a period of minimum 6 months

Degree: Master in Industrial Sciences of Master in Science majoring in chemistry, chemical engineering, materials science (electrochemistry background is highly appreciated).

Responsible scientist(s):
For further information or for application please contact Silvia Armini (armini@imec.be).

Evaluation of ferroelectric properties of strontium titanate deposited by atomic layer deposition

$SrTiO_3$ is an oxide material with cubic perovskite structure that shows very stable dielectric properties as a function of temperature and frequency and, hence, can be used for a wide range of electronic applications. It is an incipient ferroelectric with high dielectric constant and low dielectric loss, but remains in a paraelectric phase down to near 0 K[1]. Strontium titanate films are deposited by atomic layer deposition (ALD) at IMEC within the Thin Films department using $Sr(^tBu_3Cp)_2$ and $Ti(OCH_3)_4$ as metal source and H_2O as oxidant[2]. Dielectric constant of the thin films can be tuned by changing the Sr/Ti ratio[3]. It is known that strain effect in thin films of $SrTiO_3$ can lead to a substantial increase of the spontaneous polarization and Curie temperature, and can even drive it into the ferroelectric phase[4]. This possibility brings new applications of $SrTiO_3$ thin films in the field of composite ferroelectric/ferromagnetic materials, where electrically induced deformation of the ferroelectric can lead to a control over the magnetization of the ferromagnet[5]. In this respect the interest will go in studying the magnetic properties right at the FM/FE interface. This research field is currently investigated at the K.U.Leuven within the group of K. Temst and A. Vantomme.

1. K. A. Muller and H. Burkard, Physical Review B, 1979, 19, 3593-3602.
2. M. Popovici, S. Van Elshocht, N. Menou, J. Swerts, D. Pierreux, A. Delabie, B. Brijs, T. Conard, K. Opsomer, J. W. Maes, D. J. Wouters and J. A. Kittl, Journal of the Electrochemical Society, 2010, 157, G1-G6.
3. N. Menou, M. Popovici, S. Clima, K. Opsomer, W. Polspoel, B. Kaczer, G. Rampelberg, K. Tomida, M. A. Pawlak, C. Detavernier, D. Pierreux, J. Swerts, J. W. Maes, D. Manger, M. Badylevich, V. V. Afanas'ev, T. Conard, P. Favia, H. Bender, B. Brijs, W. Vandervorst, S. Van Elshocht, G. Pourtois, D. J. Wouters, S. Biesemans and J. A. Kittl, Journal of Applied Physics, 2009, 106, 094101.
4. J. H. Haeni, P. Irvin, W. Chang, R. Uecker, P. Reiche, Y. L. Li, S. Choudhury, W. Tian, M. E. Hawley, B. Craigo, A. K. Tagantsev, X. Q. Pan, S. K. Streiffer, L. Q. Chen, S. W. Kirchoefer, J. Levy and D. G. Schlom, Nature, 2004, 430, 758-761.
5. H. Zheng, J. Wang, S.E. Lofland, Z. Ma, L. Mohaddes-Ardabili, T. Zhao, L. Salamanca-Riba, S.R. Shinde, S.B. Ogale, F. Bai, D. Viehland, Y. Jia, D.G. Schlom, M. Wuttig, A. Roytburd, R.Ramesh, Science, (2004), 303, 661-663

Type of project: internship for a period of up to 6 months

Degree: Master in Science majoring in material science, physics, electronics

Responsible scientist(s):
For further information or for application please contact Mihaela Popovici (popovici@imec.be).

Study of the influence of cleaning agents to improve Cu-Cu and Cu-CuSn thermo-compression bonding for 3D IC integration

By using 3D chip stacking, it is possible to extend the number of functions per 3D chip well beyond the near-term capabilities of traditional scaling technologies. The reliability of the stacking is anyway influenced by the selected materials and processes.
Oxidation of Cu, Sn or other materials used for the inter-metallic connection can definitely affect the quality of the overall integration process, therefore it is necessary to fundamentally understand the effect of metals oxidation and identify the benefits that an appropriate cleaning process would introduce.

For this specific topic the student would be required to identify an optimal procedure to quantify the effects of the oxidation. He will be also asked to identify possible cleaning agents and evaluate the effects on stacking yield by defining and executing appropriate DoEs. During the execution phase he will be supported by imec experts and allowed to use imec advanced facility.

Type of project: thesis with internship

Degree: Master in Science or Master in Engineering majoring in material science, physics, electronics

Responsible scientist(s):
For further information or for application please contact Antonio La Manna (antonio.lamanna@imec.be).

Micro-bumping metallurgy for 3D integration and reliability improvement

The electronics industry is increasingly looking into 3D integration in order to address the ever continuing product needs of miniaturization and performance increase for future generation of ICs. This result in high speed interconnects with reduced noise and crosstalk as compared to wire bonded assemblies. 3D integration requires a physical stacking such as die to die (D2D) or die to wafer (D2W) while forming a permanent electrical and mechanical connection between the input/output pins of the devices. Fine pitch micro-bump connection is considered as a promising approach for making die to die interconnections due to its lower bonding temperature.

A micro-bump consists of a solder bump and an Under-Bump-Metallisation (UBM) on the die. This UBM must meet several requirements. First it must provide a strong, stable, low resistance electrical connection to the underlying metal such as aluminum and Cu. Then it must adhere well both to the underlying metal and to the surrounding IC passivation layert. The UBM must also provide a strong barrier to prevent the diffusion of other bump metals into the IC. Finally the UBM must be readily wettable by the bump metals, for soldering.
Meeting all these requirements generally requires multiple layers of different metals, such as an adhesion layer, a diffusion barrier layer, and a solderable layer. The multi-layer UBM must be compatible metals which in combination have low internal mechanical stresses. Moreover, the composite UBM should result from processes that are relatively simple, inexpensive, and easily reproducible in volume production. Finally, the UBM must provide high reliability for chip stacking which incorporates different materials with a large CTE mismatch.

For this specific topic the applicant would be required to investigate an UBM alternative of the current Cu or Ni. He will be also asked to assess the properties of this new micro-bump and the kinetics of UBM/ Sn reaction. Moreover, he is asked to integrate this new UBM in 3D chip stacking and evaluate the electrical performance such as electro-migration, thermal cycling and high temperature storage. He should be able to execute appropriate DoEs under the guide of his mentor. During the execution phase he will be supported by imec experts and allowed to use imec advanced facility.

Type of project: thesis with internship

Degree: Master in Science or Master in Engineering majoring in material science, physics, electronics

Responsible scientist(s):
For further information or for application please contact Antonio La Manna (antonio.lamanna@imec.be) and Wenqi Zhang (wenqi.zhang@imec.be).

Characterizing the effects of processing and design options on the electrical properties, performance, and reliability of 3D circuits

By stacking chips in the 3D dimension, it is possible to extend the number of functions per microchip well beyond the near-term capabilities of traditional scaling technologies. The performance, yield, and reliability of 3D stacks depend on the successful integration of multiple processing steps often executed in different facilities.
Characterizing the effects of alternative processing options on the electrical characteristics of 3D circuits would allow the development of efficient, robust, and cost effective 3D integration flows. Furthermore, studying and evaluating pioneering 3D test structures will help to explore design solutions and provide answers to issues arising by the vertical stacking of integrated circuits.

The candidate for this position will perform electrical tests on 3D chips and materials. He/she will characterize and analyze the electrical properties of the test structures to determine the effects of different processing options. In addition, 3D demonstrator circuits will be characterized to specify the performance and reliability of different 3D design styles. The candidate will execute different measurement procedures and will also develop and enhance test procedures to investigate additional principles and characteristics of 3D circuits. During the execution phase he/she will be supported by imec experts and will use the advanced electronic testing infrastructure available at imec.

Type of project: thesis with internship

Degree: Master in Science or Master in Engineering majoring in electrical/electronic engineering, physics, material science

Responsible scientist(s):
For further information or for application please contact Dimitrios Velenis (dimitrios.velenis@imec.be).

Mitigation of mask blank defectivity in extreme ultra-violet lithography

Extreme ultraviolet lithography (EUVL) is the only lithography technique presently considered capable for the fabrication of electronic devices of the 16nm half-pitch technology generation. In lithography a mask is used to multiply the intended pattern onto silicon by imaging (= "printing"). Defectivity of an EUVL mask is considered a very critical issue that needs to be solved before high-volume manufacturing via EUVL will be feasible. Especially the EUVL-specific mask defects, i.e., the so-called multi-layer (ML) defects, are considered critical. The ML-mirror is the quarter-wave stack that realizes reflection of EUV light (~13.5nm). Just a very local, few nanometer high or deep distortion of the EUV mirror on the mask can be enough to make this mask defect a yield killer. Such a defect is considered non-reparable in the literal sense of the word.

Presently inspection of the starting material, the so-called blank already coated with the ML mirror, is not capable and sensitive enough to assure that all its defects expected to print on wafer can be detected already in that stage. This causes the problem that the dedicated manufacturers of such blanks do not have enough sensitivity to be fully aware of the problem to be solved. Another technique, which consists of making sure that these defects are only in non-critical parts of the mask pattern, suffers from the same flaw that not all blank defects are detected early enough.

Another technique attempts to make these defects non-printable by compensating the intended mask pattern for their presence. The topic of this study is to define the input for such compensation repair. A difficulty is that the printing behavior of such ML defects requires the knowledge of their 3D-nature, whereas present defect characterization techniques are constrained to their surface morphology only. New techniques may be possible but must be non-destructive for the mask. Understanding the printing behavior of such defect is considered a valuable candidate to help defining the input for the compensation.

The major part of this work will use simulation (using an existing package) to define the best possible input for such compensation repair, based on analysis results. Involvement in experimental work is also intended.
Will *you* help to solve this problem?

Type of project: thesis for a period of 8 to 10 months

Degree: Master in Science or Master in Engineering majoring in material science or physics

Responsible scientist(s):
For further information or for application please contact Rik Jonckheere (rik.jonckheere@imec.be).

Electroless deposition of copper on self-assembled monolayers (SAMs) for damascene and 3D interconnects

Context

Cu is the interconnect material of choice in the metallization step for advanced semiconductor device manufacturing. A typical interconnect structure is composed of $Cu/Ta/TaN/SiO_2$ where the Ta/TaN layer is required as a barrier to prevent interdiffusion between Cu and the underlying dielectric resulting in electrical shorting. Due to its poor electrical conductivity, relative to Cu, the barrier layer thickness must be minimized while maintaining high performance diffusion barrier properties and good adhesion strength with neighboring layers. Nevertheless, barrier layer formation has become increasingly difficult as the technology node is reduced. An alternative to the conventional barrier process is an organic "self-assembling" system, so-called self-assembled monolayer (SAM). This inherently bottom-up process involves the anchoring of bi-functionalized organic molecules on the inter-layer dielectric surface.

The current approaches to Cu metallization include chemical vapor deposition, physical vapor deposition (PVD), selective electroless deposition (ELD) and electroplating. As device sizes decrease, accommodated by scaling and materials changes, electrochemical deposition is considered the most promising method due to its many advantages such as good uniformity and gap filling ability, selectivity and low processing temperatures. Due to the need for applied power and non-uniform current distribution of Cu electroplating, Cu ELD is especially emphasized for future interconnect technologies. In addition, ELD Cu is a promising alternative to PVD Cu for high aspect ratios through silicon vias (HAR TSVs) where the limitations of the PVD technique are also reached.

In the ELD method deposition occurs via the chemically-promoted reduction of metal ions without an externally applied potential. It is therefore a soft deposition technique expected having the potential to eliminate or greatly reduce the metal penetration through the SAMs observed for medium-to-low-reactivity metals, such as copper.

The purpose of this work is to develop and characterize an ELD process on the thin SAM organic film. The effects of the SAMs chemistry (functional groups, vapor vs. liquid phase deposition, deposition solvents etc...) and ELD experimental conditions (pH, temperature, time, concentrations, post-deposition thermal treatment) on the deposition mechanism and efficiency of the electroless Cu bath (e.g. in terms of Cu thickness and roughness control, adhesion at the interfaces dielectric/SAMs/Cu, ...) will be investigated.

Description of the work

The primary objective of the project is to investigate, develop and control a Cu ELD process directly on the thin SAM organic film. The student will test different commercial chemistries and benchmark with model chemistries. The type of work proposed is fully experimental and intensive deposition tests are expected together with the preparation of the chemical solutions in the lab. Among other techniques, Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), X-photon Spectroscopy (XPS), X-ray diffraction spectroscopy (XRD), four point probe Sheet Resistance (Rs) measurement, four point bending adhesion measurement, are suitable candidates for the characterization of the liner material and of the directly deposited copper layer. These analyses will be supported by the Imec characterization team. Given the international character of IMEC, good knowledge of English is necessary.

Type of project: thesis or internship or thesis with internship for a period of minimum 6 months

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in chemistry, chemical engineering, materials science

Responsible scientist(s):
For further information or for application please contact Silvia Armini (armini@imec.be).

Superlattices: defining the boundaries of the ultimate CMOS scaling

Graphite-like 2D nanolattices of dielectrics and semiconductors with enhanced anisotropic electronic properties are good candidates to pave the way to the ultimate scaling and performances of future nanoelectronic devices. Graphene, the most studied representative of the 2D graphitic materials, has overshadowed research on other potential quasi-2D nanolattices with totally unexplored physical properties. For instance, 3D materials, in which a strong anisotropy is introduced in the band structure could potentially lead to enhanced mobilities and display quasi-2D properties. Such structures could be induced in regular ultrathin Si and Ge, in which, the periodicity along the vertical growth direction is artificially broken by the insertion of monolayer-thick non-semiconducting layers. In such a case, the band structure and the density of states could be strongly modified reducing in-plane effective mass while inhibiting the transport perpendicular to the layers. This could reduce gate leakage and carrier scattering, thus maintaining high mobility at low equivalent oxide thickness.

Unfortunately, little is known on the fundamental physical properties of these materials. To properly engineer them, one needs to obtain a deep insights into the very fundamental properties of matter (electronic gap, effective mass, scattering processes,...). In that respects, modeling techniques based on the combination of simplified one-dimensional quantum mechanical model for the charge carriers (effective mass approximation) with density functional theory, are tools of choice that can be used to predict their electronic and transport properties and hence provide the guidance needed to boost the mobility of the charge carriers in the material.

The project consists in modeling the properties of such superlattices by using advanced solid state physics techniques. The simulations will provide both guidelines and fundamental understanding into the electronic and transport properties of the structures.

Imec will provide training to both UNIX/Linux and to the material modeling techniques. To be eligible, applicants must have a Master degree in either physics, chemistry or in electrical/material engineering. A strong motivation, a good knowledge of solid-state physics and UNIX/LINUX are a plus. Excellent writing and oral communication skills are desired.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in theoretical physics, computational physics, nano-science, chemistry

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Geoffrey Pourtois (geoffrey.pourtois@imec.be) and Wim Magnus (wim.magnus@imec.be).

3D finite element analysis (FEA) based on a multilevel sub-modeling approach to examine stress strain distribution in sub micron Cu interconnects due to chip package assembly

In digital circuits, insulating dielectrics separate the conducting parts (wire interconnects and transistors) from one another. As the Cu interconnect wires in Interconnects Circuits (ICs) become more closely spaced, the dielectrics used to insulate them must have a lower dielectric value (k-value) in order to reduce capacitance. One way to reduce the k-value of dielectric is introducing porosity however it makes the material softer due to the reduction in Young's modulus. The softness of dielectric materials became a problem for semiconductor manufacturers. In package bonding, reflow temperature profile starts from near room temperature to the peak temperature, which is above the solder melting point, and then back to the room temperature. During the cool-down period, the silicon chip and the organic package shrink by different extents, due to different coefficients of thermal expansion (CTE). The mismatch in thermal expansion/shrinkage between chip and package can lead to significant deformation and stress, both locally and globally. This deformation and stress can lead to delamination in Cu/low-k structure.
To investigate this problem, a 3D finite element analysis (FEA) based on a multilevel sub-modeling approach need to be employed to bridge the gap in feature sizes between the package and interconnect structure. It will enable us to examine in detail the stress-strain distribution in these structures.

In this topic the student will use FEM to model the package in a global scale and the interconnect structure in the local scale and use global/local modeling to bridge the gap in feature size.

A good knowledge of finite element Modeling (FEM) is a plus.

Type of project: internship or thesis for a period of minimum 6 months

Degree: Master in Engineering or Master in Science majoring in mechanical engineering, physics

Responsible scientist(s):
For further information or for application please contact Melina Lofrano (melina.lofrano@imec.be) and Bart Vandevelde (bart.vandevelde@imec.be).

Effect of confinement and position of dopants on the ionized impurity scattering limited mobility in a few-dopant double gate FET or all-around gate cylindrical nanowire FET

As nanowire dimensions are scaled down the number of dopants in the nanowire becomes small. Even for a relatively large doping density of 1019 cm-3 a cylindrical nanowire with radius 5 nm and channel length 10 nm will only contain about 7 dopants. As a result, the usual method of impurity averaging does not work and the discrete nature of dopants needs to be taken into consideration. In this thesis the student is expected to calculate the electrostatic potential of a single Coulomb charge in a nanowire surrounded by a dielectric and metal gate. The Coulomb field of a charge residing in a semiconducting nanowire or double gate structure is determined by the boundary conditions imposed on the electrostatic potential of this charge. In a semiconducting nanowire FET with surrounding dielectric and gate or a double gate FET structure with dielectric and metal gate, the electrostatic potential is determined by solving Poisson's equation for a single charge with appropriate boundary conditions. For a double gate FET the presence of the planar dielectric and metal gates will also determine the electrostatic potential of the Coulomb charge. The obtained electrostatic potential is used to calculate the scattering rate for ionized impurity scattering using the Boltzmann equation in the relaxation time approximation together with Fermi's golden rule. The student is expected to investigate the effect of confinement (wire radius, gate voltage) and of dopant position in the wire on the low-field mobility.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Anton Pham (anton.pham@imec.be) and Wim Magnus (wim.magnus@imec.be).

Characterization and modeling of the junctionless pinch-off III-V nanowire for novel device applications

A junctionless pinch-off nanowire FET is a novel device invented in imec which is uniformly doped throughout source, channel and drain. It has been shown that the junctionless transistor offers the promise of superior scaling to sub-22 nm dimensions compared to regular transistors. Originally, the junctionless nanowire transistor was designed to avoid detrimental surface interactions which have a negative impact on the transport properties of charge carriers inside the channel of the device such as surface roughness or remote phonon scattering. The uniform doping throughout source, channel and drain greatly simplifies the fabrication process due to the absence of doping junctions. The current-voltage characteristics of this novel device are very similar to a conventional inversion mode (MOSFET) device. The current in this device is carried by the majority carriers delivered by the dopants. In order to switch off the current, an all around gate must deplete the doped channel by applying a gate voltage (field effect).

Moreover, the junctionless nanowire transistor can also be used in the low-temperature regime to possibly create a superinsulator which is a material with infinite resistance. Such material should (in analogy to a superconductor) show a phase transition with respect to temperature and/or applied voltage [1]

The student is expected to measure the electrical properties of single III-V nanowire devices by means of conventional probe stations, with and without cryogenic capability, for which he will be adequately trained. The data collected (current vs. voltage characteristics) will be organized and plotted to extract the quantities of relevance and interest.

The student is also expected to interpret the characterization results by modeling the junctionless pinch-off transistor. Here, the student can make use of the expertise available in the physics, modeling and simulation group. Analytical modeling can be performed by using an existing model in which the material parameters are adjusted to handle III-V materials, and if feasible and/or desirable quantum mechanical modeling of the transport properties of charge carriers in the III-V nanowire can also be performed by the student.

[1] "Superinsulator and quantum synchronization", V. M. Vinokur, T. I. Baturina, M. V. Fistul, A. Y. Mironov, M. R. Baklanov and C. Strunk, Nature 452, 613616 (2008).

Type of project: thesis

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Mirco Cantoro (mirco.cantoro@imec.be), Bart Soree (bart.soree@imec.be) and Wim Magnus (wim.magnus@imec.be).

Electronic structure and electrostatics of a square cross section gate all-around junctionless pinch-off nanowire FET

A junctionless pinch-off nanowire FET is a novel device invented in imec which is uniformly doped throughout source, channel and drain. It has been shown that the junctionless transistor offers the promise of superior scaling to sub-22 nm dimensions compared to regular transistors. Originally, the junctionless nanowire transistor was designed to avoid detrimental surface interactions which have a negative impact on the transport properties of charge carriers inside the channel of the device such as surface roughness or remote phonon scattering. The uniform doping throughout source, channel and drain greatly simplifies the fabrication process due to the absence of doping junctions. The current-voltage characteristics of this novel device are very similar to a conventional inversion mode (MOSFET) device. The current in this device is carried by the majority carriers delivered by the dopants. In order to switch off the current, an all around gate must deplete the doped channel by applying a gate voltage (field effect).

The student is expected to investigate a square cross sectional nanowire of macroscopic dimensions and obtain the pinch-off voltage as a function of the dimensions of the cross section and the doping density. For ultrathin nanowires where quantization due to confinement kicks in, a self-consistent Poisson-Schrodinger solver needs to be written to obtain the electronic structure (energy spectrum and electron density). Also in this case, one can obtain the pinch-off voltage as a function of wire dimensions and doping density.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Anton Pham (anton.pham@imec.be) and Wim Magnus (wim.magnus@imec.be).

Remote Coulomb, surface roughness and ionized impurity scattering in novel nanowire all-around gate FET devices

In nanowire MOS field-effect transistors (FETs) degradation of the low-field mobility due to interactions occuring at or near the interface between the substrate and the insulator are important in the strong inversion regime. In this strong inversion regime, the electrons are mainly residing near the interface which results in a stronger coupling of the electrons with interactions which are localized near or at the substrate-insulator interface.
The working principle of the novel junctionless pinch-off transistor does not require a strong inversion regime, but is based on current carried by majority carriers flowing throughout the entire volume of the channel. As a result one expects a lower impact of the detrimental surface interactions.
On the other hand, the junctionless pinch-off nanowire transistor requires doping, which in turn will depress the low-field mobility due to ionized impurity scattering. In order to calculate the low-field mobility one needs the scattering rates obtained from the Boltzmann transport equation in the relaxation time approximation in combination with Fermi's golden rule together with the energy spectrum and group velocities obtained from a self-consistent Poisson-Schrodinger solver.

The student is expected to derive the scattering rates for the scattering mechanisms mentioned above and tu numerically implement these into an existing Poisson-Schroedinger solver for a all-around gate nanowire FET. The student will compare the obtained results for such a device when operating in inversion mode (MOSFET) and operating as a junctionless transistor.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Anton Pham (anton.pham@imec.be) and Wim Magnus (wim.magnus@imec.be).

Effect of screening on scattering and low-field mobility in semiconducting cylindrical nanowire FETs

Transport of charge carriers in nanowire FETs is hampered by scattering events that determine the low-field mobility. For a semiconducting nanowire the main scattering agents are the electron-phonon scattering, ionized impurity scattering and surface roughness scattering. The most significant impact of the electron-electron interaction on these scattering rates is usually taken into account by screening of the interactions. In order to calculate the screening factor for the interactions one needs to calculate the dielectric function in the RPA approximation. For bulk this is a well-known procedure, but in a confined system with cylindrical geometry the eigenfunctions are not pure plane waves, and the calculation becomes more involved. It is expected that the student becomes acquainted with the theory of electronic screening and performes a theoretical derivation of the dielectric screening function and calculates the impact on one or more relevant interactions (electron-phonon, ionized impurity scattering) for a cylindrical nanowire.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Anton Pham (anton.pham@imec.be) and Wim Magnus (wim.magnus@imec.be).

Energy spectrum of a cylindrical nanowire with periodic width fluctuations

In this thesis the energy spectrum for a cylindrical nanowire with periodic width fluctuations will be calculated. In first instance, the student must get acquainted with the well known solutions for the free standing cylindrical nanowire in the effective mass approximation (Bessel functions). Next, the case of a single localized, but rotational invariant width fluctuation (bulge) will be considered. Depending on whether it is an radial inward or outward bulge one can obtain bound states or scattering states respectively. Finally, the case of an infinite array of periodically spaced width fluctuations will be considered.

The student will perform the aforementioned calculations by making acceptable approximations which will render the problem tractable. If necessary the student can also rely on available software to numerically solve the problem. The student will make an analysis of the energy spectrum and draw preliminary conclusions with respect to the transport properties of the charge carriers in the nanowire.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Anton Pham (anton.pham@imec.be), Wim Magnus (wim.magnus@imec.be) and Bart Partoens (bart.partoens@ua.ac.be).

Phonon confinement and the electron-phonon interaction in the continuum approximation in double gate or cylindrical nanowire FETs

Usually, the electronic structure of ultrathin double gate FETs is obtained from a Poisson-Schrodinger solver which accounts for quantization due to confinement. The obtained electronic structure (energy spectrum, electron density profile) is then used to calculate the low-field mobility. An interaction which is always present at room temperature is the electron-phonon interaction. In literature this quantity is usually calculated by making use of bulk phonons. For electrostatic induced confinement in bulk this is an acceptable approach. When geometrical confinement is present because of material barriers rather than electrostatically induced confinement, phonons cannot be considered to behave in a bulk-like manner anymore. In this case phonons will also feel the confinement and this will change the phonon spectrum. The student is expected to calculate the phonon spectrum and the impact on the electron-phonon limited low-field mobility.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Anton Pham (anton.pham@imec.be) and Wim Magnus (wim.magnus@imec.be).

Raman spectroscopy in III-V nanowires : role of confinement on the phonon dispersion and Raman lineshapes

In strongly confined systems, such as 1-D semiconducting nanowires, the phonon dispersion is altered with respect to corresponding bulk material. As a result, the characteristics peaks visible in the Raman spectra (which contain the fingerprints of the vibrational properties of the material under analysis) will feature changes in their lineshape.
The student is first expected to model the Raman intensity using a simple model derived from literature. After this implementation, the student will investigate the possibility to improve the model by taking into account phonon confinement in a more rigorous manner. In particular, in the case of acoustic modes, it is possible to use an existing continuum approximation whereby the confinement can be taken into account by applying the proper boundary conditions at the nanowire surface. In the case of optical modes, the student will perform a literature study on how to tackle phonon confinement. The student can then calculate the Raman intensity and compare his results with the models available in literature.

The student will also perform Raman spectroscopy measurements on a sample 1-D system, that is InAs nanowires (and the corresponding bulk), to test the field of validity of the calculations performed. The spectra acquired by measuring the samples in different laser excitation conditions (e.g. geometry, wavelength, and power) will be analyzed and fitted to extract the quantities of interest, to be compared with the results of the modeling activity described above.

Type of project: thesis

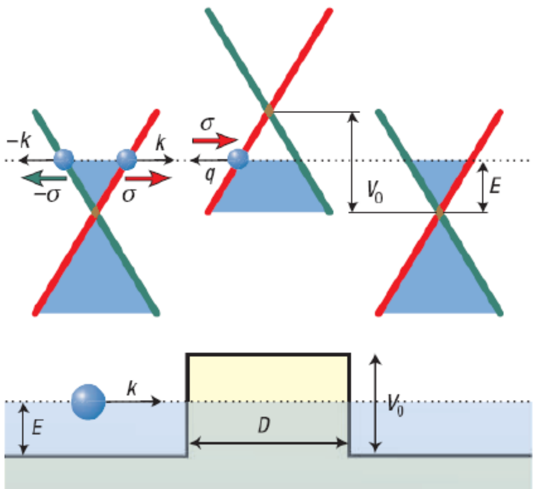
Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Mirco Cantoro (mirco.cantoro@imec.be) and Wim Magnus (wim.magnus@imec.be).

Graphene: condensed matter physics with relativistic electrons

Graphene is a single atomic layer of graphite which is a honeycomb lattice of carbon atoms. Graphene was presumed not to exist in the free state, being described as an 'academic' material and believed to be unstable. Indeed more than 70 years ago, Landau and Peierls argued that 2D crystals were thermodynamically unstable and could not exist. It came as a big surprise to the scientific community that 7 years ago in 2004 the group of Geim (Manchester University) was able to produce free-standing graphene layers with very remarkable properties, e.g. it is the strongest material on earth and the electrons have a linear energy spectrum, i.e. they are massless Dirac particles.

In this project, you will study the tunneling through potential barriers in trilayer graphene. You will investigate whether or not Klein tunnelling occurs in such a system of three layers of graphene which exhibits an energy spectrum with properties of both massless Dirac particles and massive particles with a parabolic spectrum.



Tunnelling through a potential barrier in graphene. a Schematic diagrams of the spectrum of quasiparticles in single-layer graphene. The spectrum is linear at low Fermi energies (<1 eV). The red and green curves emphasize the origin of the linear spectrum, which is the crossing between the energy bands associated with crystal sublattices A and B.

b Potential barrier of height *V0* and width *D*. The three diagrams in **a** schematically show the positions of the Fermi energy *E* across such a barrier. The Fermi level (dotted lines) lies in the conduction band outside the barrier and the valence band inside it. The blue filled areas indicate occupied states. The pseudospin denoted by vector *σ* is parallel (antiparallel) to the direction of motion of electrons (holes), which also means that *σ* keeps a fixed direction along the red and green branches of the electronic spectrum.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis or internship or thesis with internship

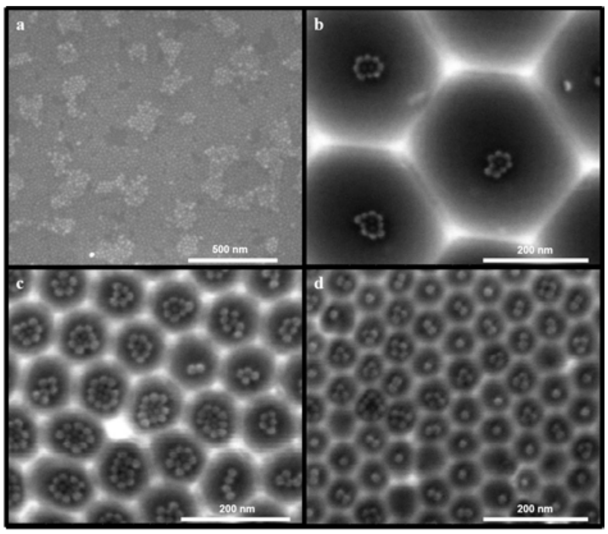
Degree: Master in Science or Master in Engineering majoring in physics, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Bart Partoens (bart.partoens@ua.ac.be), Wim Magnus (wim.magnus@imec.be) and Francois Peeters (francois.peeters@ua.ac.be).

Self-assembly of magnetic particles

Magnetic nanoparticles (NPs) are promising systems for several technological applications, e.g. in magnetic data storage media and spintronic devices or in plasmonic, photonic or nanomedical systems. Large experimental efforts are being devoted in order to investigate and control their chemical and physical properties. The magnetic properties of such NP assemblies depend on their degree of packing and ordering, which can lead to different inter-particle interactions with different short range and long range behaviour. Various synthesis methods have become available in order to control the formation, packing and self-assembly of NPs at the nanoscale. These methods range from inorganic materials (as e.g. metallic or metal-oxide NPs), macromolecules, and biomolecules on 1D and 2D surfaces, and on 3D patterned substrates.

Within this project the different possible configurations of magnetic nanoparticles have to be calculated using Monte Carlo and Molecular Dynamics simulation techniques. Those nanoparticles will interact with a patterned substrate which can have circular, hexagonal or channel patterns.



SEM image of clusters of nanoparticles on different patterned Al substrates.

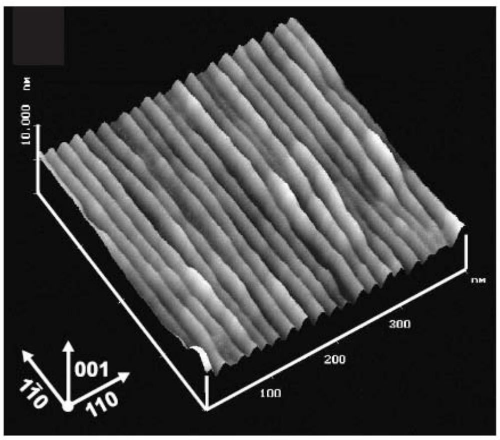
Type of project: thesis or internship or thesis with internship

Degree: Master in Science or Master in Engineering majoring in physics, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Wim Magnus (wim.magnus@imec.be), Francois Peeters (francois.peeters@ua.ac.be) and Vyacheslav.Mislo (vyacheslav.misko@ua.ac.be).

Holes in semiconductor nanostructures

To understand the optical properties of semiconductors, we have to know the electronic band structure. Knowing the initial and final states of the electrons, we calculate the optical absorption using Fermi's golden rule. Many phenomena in semiconductors involve low energy carriers only. The lowest excitations correspond to promoting electrons from the top of the valence band to the bottom of the conduction band, creating two types of charge carriers, electrons in the conduction band and holes in the valence band. For such phenomena it is sufficient to know the band structure at the band extrema. The first goal of this project is to introduce the k.p method which is a model to describe the band structure of semiconductors near the band edges. As a next step, we want to investigate how the electronic properties (especially the holes) are modified in a nanostructure. Therefore we will apply the effective mass approximation within the k.p model. The final goal of this project is to realize a computer code that calculates the hole energy states in a quantum well and a quantum wire.



Typical atomic force microscopy (AFM) image of uncapped InAs/InP quantum wires grown by MBE on an InP(001) substrate (from L. Gonzalez et al., APL 76, 1104 (2000).

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis or internship or thesis with internship

Degree: Master in Science or Master in Engineering majoring in physics, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Wim Magnus (wim.magnus@imec.be), Francois Peeters (francois.peeters@ua.ac.be) and Bart Partoens (bart.partoens@ua.ac.be).

Graphene plasmonics

Plasmonics is a fast growing field in nano-electronics/optics/photonics because it allows efficient coupling of light with nanostructures. The possibility of capturing light with a wave length larger than the dimensions of the nanostructure through plasmonic excitations opens new avenues towards interesting new applications. Traditionally, noble metals such as silver or gold are used in plasmonic nanostructures. Recently, however, intriguing plasmonic behavior has been observed in graphene, a single atom thick graphite sheet, which has not been explored before in this field. In this thesis the student is expected to perform a literature study of this new and fast growing field with a focus on graphene plasmonics. The student is also expected to perform a few theoretical calculations relevant for graphene plasmonics.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Pol Vandorpe (pol.vandorpe@imec.be) and Wim Magnus (wim.magnus@imec.be).

Sub band decomposition method for modeling nanodevices

The modeling of ballistic quantum transport in nanodevices usually involves a self-consistent solution between the Schrödinger and the Poisson equations. This usually requires huge computer resources to obtain the current voltage characteristics. The sub band decomposition approach relies on the decomposition of the wave function on sub band eigen functions, which account for the confinement of the electrons in the whole structure. The method can be applied to study large 2D and 3D real systems with a drastic reduction of the numerical cost, since the dimension of the transport problem for the Schrödinger equation is now reduced in real space.

The student is expected to get acquainted with the formalism and write code to numerically implement the formalism for either a nanowire, double gate or a graphene device.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Wim Magnus (wim.magnus@imec.be) and Anton Pham (anton.pham@imec.be).

Multi subband simulations of transport in short channel junctionless nanowire pinch-off FETs using the relaxation time approximation

A junctionless pinch-off nanowire FET is a novel device invented in imec which is uniformly doped throughout source, channel and drain. It has been shown that the junctionless transistor offers the promise of superior scaling to sub-22 nm dimensions compared to regular transistors. Originally, the junctionless nanowire transistor was designed to avoid detrimental surface interactions which have a negative impact on the transport properties of charge carriers inside the channel of the device such as surface roughness or remote phonon scattering. The uniform doping throughout source, channel and drain greatly simplifies the fabrication process due to the absence of doping junctions. The current-voltage characteristics of this novel device are very similar to a conventional inversion mode (MOSFET) device. The current in this device is carried by the majority carriers delivered by the dopants. In order to switch off the current, an all around gate must deplete the doped channel by applying a gate voltage (field effect).

For a short channel nanowire MOSFET the transport simulation using the semiclassical model based on the PE-SE-multi subband BTE has been shown to be accurate enough. Compared to the quantum transport model, the semiclassical model is more efficient in terms of computational time. In this thesis the student will implement similar transport approach for the short channel junctionless nanowire pinch-off FETs.

The candidate should have a strong background/interest in quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Wim Magnus (wim.magnus@imec.be) and Anton Pham (anton.pham@imec.be).

Tunneling in two dimensions

Tunneling is a quantum mechanical phenomenon where a particle travels through a region where classical mechanics prohibit its presence. The phenomenon has fascinated many since the first discoveries of quantum mechanics until today. Sometimes the products of tunneling are unwanted, for example: radiation from nuclear decay or leakage current in MOSFETs. But in other cases tunneling can be used to our advantage: the human scent relies on a tunneling process to distinguish smells. Zener and Esaki diodes rely on tunneling for their operation. Recently a tunnel transistor has been proposed with the promise of greatly improved performance compared to the existing MOSFETs. Although the basic tunneling principle is well established, almost all investigations have been done with respect to tunneling in a straight line that is, tunneling in one dimension. In a transistor with three terminals, the potential can have rapid changes in two- or three dimensions. For this reason the investigation of tunneling beyond the one-dimension is necessary.

The student will investigate the tunneling process in two dimensions, try to gain understanding in the process and observe the deviations from the use of existing one-dimensional models.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Wim Magnus (wim.magnus@imec.be) and William Vandenberghe (william.vandenberghe@imec.be).

Tunneling in semiconductor heterostructures

At very small operating voltages, the MOSFET can no longer be switched off and this could put an end to the progress that has been made in semiconductor device scaling. Fortunately, a new kind of tunnel transistor (TFET) has been proposed with the promise of being able to operate at much smaller operating voltages than the MOSFET.

A drawback of these new tunnel transistors is their low on-current when they are fabricated from silicon which has a large bandgap. When smaller bandgap materials such as germanium or III-V semiconductors are used, the on-current greatly improves but silicon is the material of choice in the semiconductor industry. A natural solution is the use of a heterostructure: germanium/III-V and silicon in the same device.

Starting from the Schrödinger equation, the student will investigate the tunneling in a one-dimensional heterostructure.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Wim Magnus (wim.magnus@imec.be) and William Vandenberghe (william.vandenberghe@imec.be).

Studying quantum transport in nano-MOSFETs using spectral functions

With continued device scaling, modern day transistors (MOSFETs) have dimensions in the order of a few nanometers making quantum effects play an important role. Studying these quantum effects encompasses the formidable task of finding all solutions to the Schrödinger equation on the entire device. The result is a set of wavefunctions with quantum numbers labeling each different wavefunction. From the wavefunctions and the energy spectrum, the quantum effects and the electronic transport in the device can be studied.

Rather than directly using the wavefunctions with its quantum numbers. The student will study quantum effects in a MOSFET using so-called spectral functions. Using spectral functions has some advantages: it eliminates the need of keeping track of all the quantum numbers and facilitates the calculation of tunneling phenomena for example. The student will investigate methods to calculate the spectral functions and use them to obtain the current in a MOSFET.

The candidate should have a strong background/interest in solid-state physics, quantum mechanics and computational physics.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, nanoscience, nanotechnology

Responsible scientist(s):
For further information or for application please contact Bart Soree (bart.soree@imec.be), Wim Magnus (wim.magnus@imec.be) and William Vandenberghe (william.vandenberghe@imec.be).

Process simulations to improve the link between electrical data of processed tunnel field-effect transistors and simulated predictions

Straightforward downscaling of the basic components of the electronics industry according to Moore's law will reach its end within the next 10 years. To continue towards the nanoscale, complex technological barriers will have to be overcome, and eventually further downscaling will be prevented due to physical limitations associated with the small dimensions.

This prospect stimulates research towards alternatives for the current CMOS nano-electronic devices. Promising candidates for integration in post-CMOS nano-electronic devices are semiconducting nanowires. Nanowires allow the fabrication of heterostructures, without the typical high defect concentration at the interface between two materials with different lattice constant, which is a consequence of the capability of nanowires to tolerate material stress. The fabrication of heterostructures, which also includes the integration of III-V materials on silicon, offers many new perspectives for nano-electronic devices.

In this master thesis, the student will investigate a nanowire-based tunnel field-effect transistor. Based on the input from the processing experts, the student will set up a process simulation mimicking as closely as possible the actual fabrication process. The resulting device configuration, in particular the resulting two-dimensional doping profile, will be inserted in the device simulator. The student will interpret the predicted characteristics of the device simulator and compare the results to the experimental data. The extracted information will be communicated back to the processing experts and a feedback loop to optimize the process flow will be established.

For this master thesis, a good knowledge of semiconductor physics is required. Process and device simulations can be done with existing software packages. If needed, additonal measurements can be performed in imec's electrical characterization labs. During this master thesis, the student will also learn about the tunnel field-effect transistor fabrication process as well as the additional electrical, optical and profilometric characterization techniques.

Type of project: thesis for a period of 6 months

Degree: Master in Science or Master in Engineering majoring in electrical engineering, physics, nanotechnology, material science

Responsible scientist(s):
For further information or for application please contact Anne Verhulst (anne.verhulst@imec.be).

The creation of nanoforces by microbubbles

Background of the project

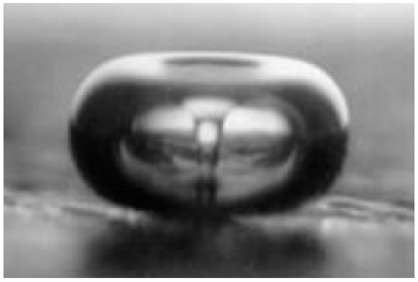


Figure 1 Implosion of a bubble

Bubbles can be created in fluids and are used for a broad range of applications. Under the influence of pressure variations, bubbles can implode which is shown in figure 1. The last few years, the research in microbubbles has been ramped up, because imploding microbubbles can be used in biomedical applications. An example is the implosion of microbubbles near a cancer cell, which result in the perforation of the cell membrane. Once the cell membrane is open, the injection of medicine is facilitated. The ruptured membrane of living cells usually heals within a time span of a few minutes. An example of a ruptured cell is shown in figure 2. In the semiconductor industry, oscillating bubbles are used to remove contaminants or nanoparticles from fragile structures. By using ultrasound or, in other words, the same sound field for visualizing fetuses, small bubbles can be created. These microbubbles oscillate with the same rhythm as the sound field. If the sound pressure is high enough, the bubbles will oscillate very strong and they can even collapse. Such a collapsing bubble will remove nanoparticles from a surface. Currently the implosion is not very well controlled and also results in damaged fragile structures. More in depth research is necessary to control the nanoforces created by the imploding microbubbles.

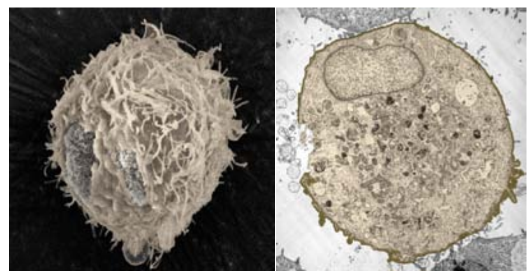


Figure 2 Cell ruptured by an imploding bubble

Discription of the work

The fist goal of the project is to see if the addition of surface active agents or surfactents to the liquid can improve the control of nanobubbles and the resulting nanoforces. We will look to surfactants that will reduce the surface tension of the liquid. As a result, bubble creation and oscillation will be altered and several techniques, e.g. sonoluminescence, cavitation noise measurement... , will be employed to measure the intensity of bubble oscillations. Some of the experiments will be very close related with the application. Nanoparticles will be deposited on a surface in a controlled way, which will be measured with light scattering techniques. Next, these particles will have to be removed with the microbubbles that are created during the application of ultrasound.

Type of project: thesis for a period of minimum 4 months (full time) and maximum 1 year

Degree: Master in Science or Master in Engineering majoring in physics, chemistry, material science

Responsible scientist(s):
For further information or for application please contact Steven Brems (steven.brems@imec.be).

Surface etching and passivation of III-V materials

Context

Today all transistors in integrated circuits are fabricated on Si substrates, in some cases alloyed with limited amounts of Ge. In order to meet the future requirements imposed by the scaling roadmap, the next generation of transistors will be built on III-V compound semiconductor substrates.

The manufacturing of transistors consists of different processing steps involving multiple exposures to wet chemical solutions to obtain controlled etching or highly selective removal of undesired layers and contaminants. A clean and stoichiometric surface is hereby critical since an interface with high defect density will lead to device deterioration. In general, III-V materials are poorly passivated compared to Si and form complex and chemically inhomogeneous and unstable oxides. Besides these native oxides, also unwanted contamination from previous processing steps should be removed. Therefore a controlled clean with limited substrate loss and no roughness generated is required. Although III-V materials have been used extensively the past decades, their etching properties are mostly described on a µm-scale and also very little attention has been given to the cleanliness of the substrates.

In order to design wet chemical solutions that lead to an appropriate surface pre-conditioning to allow very sensistive processing of these III-V substrates, a thorough understanding of the interactions between the substrate and the chemical solutions is needed and the basic etching mechanism needs to be investigated on a sub-nanometer scale.

Description

The goal of this work is the controlled surface preparation and characterization of III-V substrates after wet chemical treatment. Focus will be on InGaAs but GaAs and InAs will be included as well in this work as easier model systems. The purpose of this work is to find optimal conditions for removal of all surface oxides and, on the other hand, a controlled etching of few monolayers of the substrate to remove surface defects in the crystal lattice. This sub-nanometer etching should be non-preferential to maintain the surface stoichiometry. In addition, the re-oxidation of the substrate needs to be avoided.
For the evaluation of the surface properties and cleanliness of the III-V substrates, different analytical techniques are employed such as:

- Spectroscopic ellipsometry and/or weight measurements for a rough determination of substrate loss and etch kinetics
- ICP-MS for the determination of dissolved III-V material in the cleaning liquid in order to determine the dissolution rate of sub-monolayers of material
- Contact angle measurements to assess surface hydrophobicity or hydrophilicity
- XPS for determination of chemical bondings and composition
- Atomic Force Microscopy for measurement of the surface roughness on an atomic scale.

Type of project: internship for a period of minimum 2 months

Degree: Master in Science majoring in chemistry (interest for analytical chemistry), material science

Responsible scientist(s):
For further information or for application please contact Daniel Cuypers (daniels.cuypers@imec.be) and Rita Vos (rita.vos@imec.be).

Electrical characterization of band-to band tunneling devices for understanding the impact of process and geometrical parameters on the device performance and correlation with existing models

Continuous downscaling of CMOS technology according to Moore's law is reaching its end and post-CMOS research in nanoelectronics is increasingly needed to overcome some of the CMOS limitations. The main limitation to current CMOS is the rapidly increasing power consumption of electronic circuits.

Research towards alternatives to the current CMOS nano-electronic devices is growing. Promising candidates for integration in post-CMOS nano-electronic devices are tunneling devices. These devices hold the promises of further reduction of the supply voltage of electronics thanks to their improved subthreshold slope. However, these devices also face many challenges. The drive current needs to be improved by bringing into the device architecture and its processing, materials with lower bandgap than silicon, heterostructures and even stress. The tunneling junction parameters can have a large impact on the tunneling rate and need further investigation. New architectures for improving the tunneling efficiency are also of interest.

In this master thesis, the student will investigate tunnel field-effect transistors, in different configurations. The goal is that the student comes to a better understanding of the impact of process and geometrical parameters on the band-to-band tunneling device performance. The topic of this master thesis will complement the simulation work on-going in the team to better correlate electrical data with existing models. The results of the thesis will allow a better understanding of the critical parameters in the device and the student will propose improvement to the Tunnel-FET architecture.

For this master thesis, a good knowledge of semiconductor physics is required. Simulations can be done with existing software packages, measurements can be performed in imec's electrical characterization labs. During this master thesis, the student will also learn about different advanced electrical characterization techniques.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in nanoscience, nanotechnology, electrical engineering, physics, material science

Responsible scientist(s):
For further information or for application please contact Anne Vandooren (anne.vandooren@imec.be).

Surface modification of Ge and III/V materials for gate stack passivation

Germanium and compound semiconductors (III/V) are replacing Si as the MOS transistor channel material in chip fabrication. Passivation of the oxide-semiconductor interface is one of the major issues to be tackled in order to build devices that outperform the Si channel. Passivation of the Ge and III/V interface with the high-k dielectric can be done by modifying the semiconductor surface in situ before high-k deposition. A chemical way of surface modification is a treatment by means of H2S after removal of the native oxide. This will result in a S-terminated Ge or IIIV surface. In the subsequent deposition of the high-k dielectric by ALD (Atomic Layer Deposition), the S-terminated surface needs to react with the ALD precursors and this will again change the chemical and electrical properties of the interface. This project will focus on the chemical reaction mechanisms and kinetics of the surface modification and subsequent ALD reactions. Several chemical and structural analysis techniques will be used to unravel these surface reactions (XPS, SIMS, TXRF ...).

Type of project: thesis or internship or thesis with internship for a period of minimum 3 months

Degree: Master in Industrial Sciences or Master in Science majoring in chemistry, physics, materials science

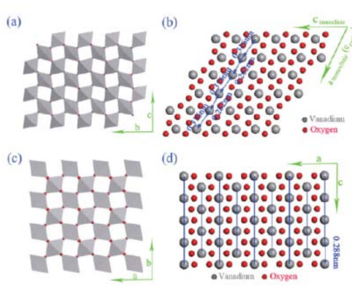
Responsible scientist(s):
For further information or for application please contact Sonja Sioncke (sonja.sioncke@imec.be).

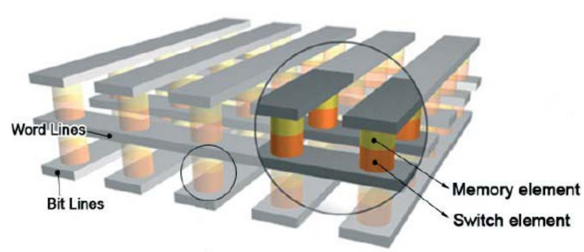
Tailored functional oxides for nanoelectronics

The tremendous decrease of scale of microelectronic components to the nano-regime has led and leads to the continued development of new products and markets: PCs, laptops, mobile phones, mobile internet, ubiquitous computing, sensor arrays… The enabler of this scaling, the MOSFET, is unfit to continue the downscaling trend beyond 5-10nm gate length. For flash memory it is expected that the downscaling cannot be extended because the charge used to store one bit should scale down to less than 100 electrons. At such low numbers, the information retention becomes problematic. Therefore new solutions are explored.

Electronic devices based on transition metal oxides are promising candidates for memory applications. Using functional oxides with tailored properties creates opportunities for new device concepts that allow continuing the scaling roadmap. Some of these oxides can undergo a Metal to Insulator Transition (MIT) which could be used as a switching phenomenon for memory applications such as in RRAM (Resistive RAM). The MIT phenomenon occurs in materials with strong Coulomb repulsion between electrons and can be induced by a change in temperature, pressure or chemical composition or when an electric field or optical pulse is applied. The challenge is to harness these phenomena in a nano-scale memory.

The work's objective is to study VO2, a prototype functional oxide showing a metal-to-insulator transition at 68C. This encompasses electrical characterization and modeling of different devices in which the VO2 is incorporated. You will investigate the underlying physics of the MIT transition in these devices and the feasibility of using these functional oxides for memory applications. Possibilities exist to look into the material properties of VO2 thin films and device fabrication. Depending on your interests, one or several aspects of this research can be incorporated in the work.





MIT in VO2 : (a)(b) low temperature M1 phase

(c)(d) high temperature rutile phase

RRAM memory array

Type of project: thesis or internship

Degree: Master in Science or Master in Engineering

Responsible scientist(s):
For further information or for application please contact Koen Martens (koen.martens@imec;be) and Iuliana Radu (iuliana.radu@imec.be).

Analysis of corrosion issues during CMP

Chemical Mechanical Polishing (CMP) is a technique used to planarize a variety of circuit structures built on silicon wafers. A combination of mechanical polishing and chemical reactions at the surface gradually removes layers of deposited metals, oxides, nitrides etc. from the substrate. During this process, it is crucial to achieve a perfectly flat substrate in order to allow the fabrication of well-defined circuit components in subsequent process steps. CMP processes use a conditioned polishing pad and slurries to polish the surface, the precise characteristics depending on the particular substrate that needs to be planarized. The slurries usually contain both nanoparticles (as abrasives) and chemicals like oxidizers and inhibiting agents that assist in achieving an even polishing across the wafer without causing defects on the surface.

Since CMP is both a chemical and mechanical process, a variety of mechanisms occur at the polished surface during the CMP process, including various (galvanic and other) corrosion reactions. Corrosion at the boundaries of the device structures on the wafer may cause electrical problems down the line and with new technologies moving to even smaller device structures, it becomes increasingly important to control these corrosion issues. The goal of this project is to analyze the electrochemical processes that occur during CMP polishing and to find ways to minimize corrosion damage.

This project will use both ex situ and in situ electrochemical techniques that monitor the chemical reactions occurring at the surface in static mode and while it is being polished, respectively. The experiments will involve preparation of solutions in the chemical lab and the use of a potentiostat setup in order to gather electrochemical data. The in situ experiments will be performed on our experimental polisher in imec's 200mm cleanroom. Other analysis techniques (e.g. sheet resistance, weight, etch rate measurements etc) will enhance the gathered electrochemical data to ensure a full and complete analysis.

The student should have a basic knowledge of chemistry and lab work, experience with performing electrochemical measurements is a major advantage. He/she is expected to run the experiments, analyse the results and to adjust further experiments accordingly. Given the international character of imec, good knowledge of English is required.

Type of project: thesis or internship or thesis with internship for a period of minimum 6 months

Degree: Master in Industrial Sciences or Master in Science of Master in Engineering majoring in chemsitry, chemical engineering, materials science

Responsible scientist(s):
For further information or for application please contact Lieve Teugels (lieve.teugels@imec.be).

Chemical & structural characterization of plasma damage and polymers deposited on low-k sidewalls: the small-gap technique

Anisotropic dielectric etching is usually performed with fluorocarbon-based plasma, where a preferential polymerization occurs along the feature sidewalls, protecting its surface from the etch species. With the introduction of metal-hardmask-based patterning for low-k dielectric etch, wet removal of those sidewall polymers turns out to be a real technological challenge. Due to the extremely small sizes of the investigated structures (trenches ranging from 20 to 50nm), the evaluation of sidewall polymers and plasma damage is a challenge that remains to be tackled.

This project aims at using a new method for polymer sidewall evaluation, bringing those microscopic features into macroscopic sizes[1]. This allows, on one hand to generate samples to be used for wet clean tests, and on a second-hand to be studied by characterization techniques like FTIR or XPS. The method consists in shielding ion bombardment by building a roof structure on the wafer (also called 'small-gap'). Underneath the roof, only neutrals can penetrate, therefore the exposed surface show similarities with a feature sidewall.

In this work, we will evaluate what is the effect of gap parameters on the transport of different species, what type of plasma damage can be observed under the roof and how far this compares with measurements in real patterned structures. This work-package requires a lot of practical work in cleanroom environment, mastering state-of-the art 300mm plasma etch tool, as well as thin film characterization methods such as spectroscopic ellipsometry, Fourier-transformed infra-red spectroscopy methods (FTIR), water contact angle measurements. Optical emission spectrometry (plasma characterization) and XSEM (surface characterization) may be used.

Type of project: thesis or internship for a period of minimum 3 months

Degree: Master in Science of Master in Engineering majoring in material science, physics, chemistry

Responsible scientist(s):

For further information or for application please contact Laurent Souriau (laurent.souriau@imec.be) and J.-F. de Marneffe (marneffe@imec.be).

[1] http://scitation.aip.org/journals/doc/JVTAD6-ft/vol_23/iss_4/634_1.html and http://scitation.aip.org/journals/doc/JVTBD9-ft/vol_26/iss_1/11_1.html

Evaluation of photoresist outgassing for extreme ultraviolet lithography

Extreme Ultraviolet (EUV) light is currently of increased interest in semiconductor processing. EUV Lithography (EUVL) is the leading candidate for 22nm half-pitch device manufacturing and beyond. One of the concerns of this process technology is related to outgassing of materials in the vacuum environment – e.g. from photoresists –, which, enhanced by the EUV irradiation, can result in a reflectivity decrease of the optical elements and in other decrease of exposure tool performance.

In this field the student would work at imec on an experimental outgassing set-up (Fig. 1) to evaluate the EUV related outgassing and contamination and is involved in outgassing analysis of various photoresist materials. This will contribute significantly to the understanding how materials and process conditions can impact contamination in the EUV scanners, and lead to procedures to qualify resist materials before they are used on the EUV scanners.

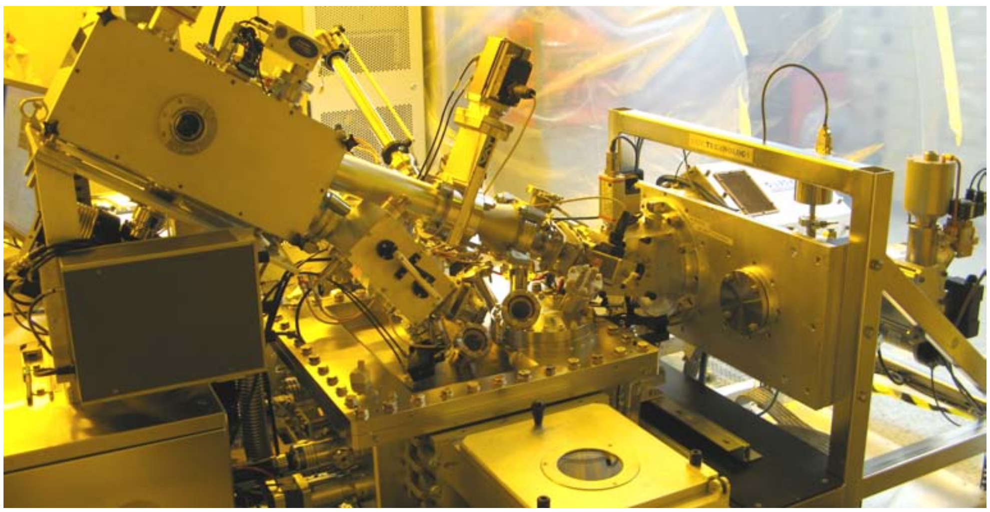


Fig. 1 : Experimental EUV outgassing set-up at IMEC for investigation of outgassing of lithography materials.

Type of project: internship for a period of minimum 6 months

Degree: Master in Science of Master in Engineering majoring in material science, physics, chemistry

Responsible scientist(s):
For further information or for application please contact Ivan Pollentier (ivan.pollentier@imec.be).

Study of bulk and surface reactions in liquid plasma generated by RF and Ultrasounds

Plasma technology, due to the presence of electrons, radicals and ions, is known to provide a very reactive environment allowing for reactions that are not possible between the non dissociated molecular equivalents. The project aims at the development of plasma-in-liquid technology where a plasma phase is generated inside gas bubbles in liquids. This particular plasma is achieved by coupling together acoustic cavitation through an Ultrasonic (US) field in liquid (for bubble generation) with a Microwave (μW) or Radio Frequency (RF) oscillation excitation to sustain the plasma. Cavitation bubbles in the liquid medium provide the confined gaseous environment where a plasma can be ignited. Conventional gaseous plasmas present some disadvantages such as low material densities, need for volatile by-products, poor heat dissipation and the need for expensive vacuum technology. The use of a liquid precursor for plasma reactions could reduce most of these disadvantages by providing much higher reactivity and yield, together with a wider range of chemical reactions. It is expected that the newly developed technology will find applications such as film/nanoparticles deposition, etching/cleaning processes, and waste water treatment.

In this work, the effect of RF and US parameters on plasma ignition in different liquids will be evaluated. The role of pressure and gas flow will also be investigated. Experiments will target two complementary areas:

- Liquid bulk characterization after plasma reaction, addressing clear dependencies on reaction parameters.
- Feasibility of direct deposition on substrate with and without functionalized areas will be explored. Proof-of –concept of film/particle deposition and their grade of uniformity (<100 nm) will be tested.

This work-package requires a lot of practical work in clean room environment, a full training on the dedicated apparatus for plasma production, as well as on several characterization techniques such as XSEM imaging with Energy Dispersion X-Ray Spectroscopy (EDX), Raman spectroscopy, and Fourier-transformed infra-red spectroscopy methods (FTIR). In order to characterize the plasma and correlate the observations with plasma emission properties, optical emission spectroscopy (OES) will be used.

Type of project: thesis or internship for a period of minimum 3 months

Degree: Master in Science of Master in Engineering majoring in material science, physics, chemistry

Responsible scientist(s):
For further information or for application please contact Elisabeth Camerotto (elisabath.camerotto@imec.be).

Void detection in advanced interconnect lines by energy dispersive X-ray spectroscopy (EDS) and backscattered electron (BSE) imaging

A main challenge that Cu interconnects are facing for further downscaling, especially below 20 nm, is the formation of tiny voids in interconnect lines during the fabrication process. This leads to an increase of the resistance of the interconnect lines and reduces their reliability. Energy dispersive x-ray spectroscopy (EDS) has recently shown promising results for the detection of voids in copper lines down to a line width of 15 nm. EDS is a characterization technique for elemental analysis of a sample used in combination with scanning electron microscopy (SEM). When the electron beam of the SEM system hits the sample surface, X-rays are emitted which are detected by the EDS detector. Another method which has shown promising results for void detection in copper interconnect lines is backscattered electron (BSE) imaging. Backscattered electrons are electrons of the beam hitting the sample that are reflected from the sample by elastic scattering.

In this topic, the student will investigate the detection of small voids in sub-50 nm advanced interconnect structures. EDS and BSE will be applied on the same structures and will be compared with each other with respect to their sensitivity, resolution and applicability. Besides Cu lines also experimental line structures in cobalt and/or tungsten will be evaluated.

The student will be trained in the use of a SEM and EDS system. He/She will learn the basics of state-of-the-art analysis techniques and will get familiar with interconnect technology. The student will closely interact with other members of the materials and components analysis (MCA) department.

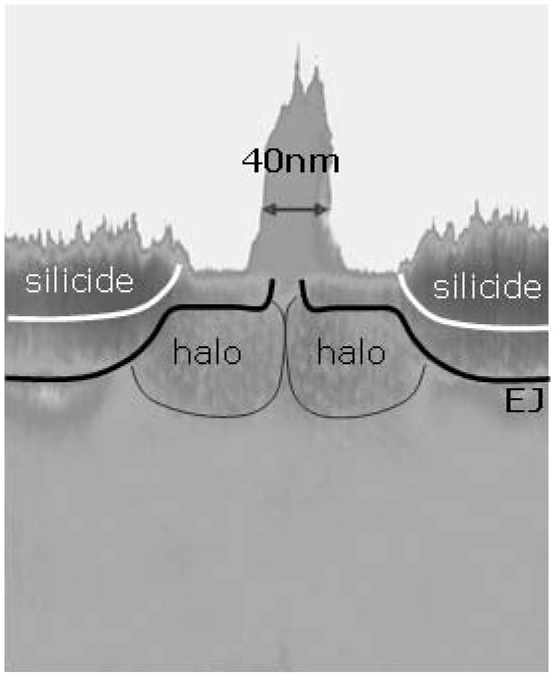
Type of project: thesis or internship

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, material science, chemistry

Responsible scientist(s):
For further information or for application please contact Thomas Hantschel (thomas.hantschel@imec.be).

Analysis of surface preparation for HV and UHV-SSRM

The SSRM technique is an AFM-based technique used to obtain 2D carrier maps of electronic devices (MOS, bipolar transistors, FinFets, nanowires,…) with (sub)-nm resolution. Samples therefore need to be cross-sectioned (polishing or cleaving). The latter may lead to artifacts such as Fermi-level pinning, surface states, native oxide,…



High Vacuum-SSRM, and recently Ultra High Vacuum-SSRM, versions have been introduced with improved performances relative to the ambient version, due to water layer removal, as well as reduced native oxide growth, contamination and anodic oxidation during the measurements.

In order to fully benefit from the vacuum, a more detailed understanding of the impact of the measurement environment is required as well as the role of eventual passivation procedures and cleaning/heating treatments after cross section preparation.

Task of the student(s) will be to study these effects and to correlate the electrical (HV-SSRM and UHV-SSRM) performance with existing models for the high pressure SSRM-contact. The latter will involve studies on spatial resolution, ohmic contact formation (through studies of I-V curves), tip and sample erosion, and life time (re-growth, oxidation,..) of the sectioned surface.

Type of project: thesis or internship

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, material science, chemistry

Responsible scientist(s):
For further information or for application please contact Pierre Eyben (pierre.eyben@imec.be).

Development of a professional data analysis package for the micro-four point probe (M4PP)

The micro-four point probe (M4PP) is an electrical technique that allows for the very accurate measurement of the (sheet) resistance of a very thin (sub-100 nm) highly conductive semiconductor layer on top of a substrate of opposite impurity type (n- or p-type) (by pushing a current through the outer two probes and measuring the resulting voltage difference between the inner two probes). In 2009 such a M4PP tool has been installed at Imec. The tool came with commercial software (from Denmark) for the sheet resistance raw data collection, but not for the data manipulation of the many different data files or consequent data interpretation.

When applying this technique to a bevelled surface (slanted), one can generate a sheet resistance versus depth profile, from which the underlying carrier depth profile can be extracted. The latter is of crucial importance for the development of future state-of-the art transistors. In 2010 an initial version of a brand new M4PP data treatment software package named "Tivoli" has been implemented for silicon material.

The goal of the second working year of this project is, to continue the development of the Tivoli package for both surface sheet resistance and carrier depth profiling analysis. The programming environment is Microsoft Visual C++, with the Trolltech/Nokia Qt4 class libraries and Qwt graphics libraries. Issues involved in this work will be: (i) Expanding the data browser, i.e. a user-friendly interface for loading all files (can be more than 100) from a single M4PP measurement folder , (ii) For surface analysis (mapping module), making different types of result plots (resistance/voltage versus position, two-dimensional 200- and 300 mm resistance contour maps, etc.), (iii) For carrier depth profiling, implementing probe pitch correction algorithms and expanding data extraction towards new materials (germanium, etc.), (iv) Adding further support for making overlays with profiles from other measurement techniques, (v) Eventually semi-automatically generation of analysis results reports (in MS Word or PDF format).

It is not the aim of this work to develop new data treatment "algorithms'. This subject is, however, a challenge for those who wish to specialise themselves in all aspects and capabilities of object-oriented Windows programming within the Visual C++ environment with a multi document-view architecture (MDI) environment, focussing on a user-friendly graphical user interface (GUI).

Type of project: thesis (for a period of minimum 6 months) with internship (for a period of minimum 1 month)

Degree: Master in Industrial Sciences majoring in electrical/electronic engineering, option information and communication techniques (ICT)

Responsible scientist(s):
For further information or for application please contact Trudo Clarysse (trudo.clarysse@imec.be).

Carrier depth profiling with the micro-four point probe (M4PP) on advanced ultra-shallow CMOS semiconductor structures

As CMOS devices get smaller with each technology node, the processes needed to fabricate and characterize these also become more and more complex. New fabrication processes for source-drain extensions typically involve low-energy cocktail or cluster implants (to obtain ultra-shallow junctions (USJ's)), with or without Ge pre-amorphization, combined with flash rapid thermal or laser-based millisecond annealing cycles (to maximize activation while minimizing out-diffusion). Crucial technological parameters which directly relate to the performance of the final devices are the sheet resistance of the involved USJ's and the shape of their carrier depth profile.

Historically conventional four-point probes (with mm separation and 100 g load) have been used (and still are) for the determination of the sheet resistance. The Spreading Resistance Probe has been used for carrier depth profiling of USJ's on Silicon and Germanium and Electrochemical Capacitance Voltage on III-V materials. As new high mobility materials are, however, introduced and USJ become shallower (sub-50 nm), these conventional tools become basically useless (too high probe penetration, too large contacts, large correction factors, insufficient depth control, etc.).

A new promising tool to solve these problems is the micro-four point probe (M4PP). It has already been shown in the recent past that this tool can measure the surface sheet resistance very accurately with virtual zero penetration and is able to perform well on many types of new materials (SiGe, Ge, InGaAs, GaAs, etc.). Hence, the main goal of this work is to develop a reliable procedure for the extraction of accurate sub-50 nm carrier depth profiles from sheet resistance depth profile measured along a beveled (slanted) surface on these new materials.

The major steps in this work will be: (i) Familiarizing oneself with all the tools involved in this work (M4PP, profilometers, different polishing tools, software for carrier profiling, etc.), (ii) Optimizing sample preparation (polishing) for the different materials, (iii) Optimizing oxide deposition procedures for optimal starting point definition, (iv) Investigate the impact of different sensitivities (different probe pitches) and bevel angles (different measurement settings) on the accuracy of the extracted profiles, (v) correcting the carrier profiles for eventual artifacts (non-flatness bevel, insulating boundary effects), (vi) comparing results with other techniques such as Scanning Spreading Resistance Microscopy (SSRM) or Nanoprober data.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical/electronic engineering, material science

Responsible scientist(s):
For further information or for application please contact Trudo Clarysse (trudo.clarysse@imec.be).

Characterization of advanced nanostructures using a nanoprober tool

Imec's nanoprober combines a scanning electron microscopy (SEM) system, four nanomanipulation units and a parameter analyzer in one tool. Additional other components have recently been added to the nanoprober such as an energy dispersive X-ray spectroscopy (EDS) unit, an electron beam induced current (EBIC) module and a micro-gripper which are extending the application range and allow for various manipulation, measurement and characterization tasks. It is used for example for electrically probing nanostructures such as nanowires and carbon nanotubes, for characterizing localized thin-film stacks, and for manipulating nanostructures using a pick-and-place approach.

The goal of this project is the further development of procedures for carrying out electrical measurements in an automated sequence. A basic software application based on the Labview programming language has been developed in the first phase and this software module will now be further developed and optimized in this project. The student will further improve the existing software program, implement additional features and will carry out electrical measurements on calibration and device structures. The student will work in a characterization lab environment and will be trained in SEM and nanoprobing.

Type of project: thesis or internship

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, material science, chemistry

Responsible scientist(s):
For further information or for application please contact Thomas Hantschel (thomas.hantschel@imec.be) and Kai Arstila (kai.arstila@imec.be).

Study of Photo Modulated Optical Reflection (PMOR) on advanced materials

Photo modulated optical reflection (PMOR) is a technique in which two separate lasers, a pump and a probe, are used. The modulated pump laser generates a high injection level (> 1e18/cm3) of excess carriers in the investigated semicondutor structure and also causes a temperature change, both of which lead to variations of the underlying refractive index within the structure. The variations in reflected signal of the second probe laser, due to these changes, are then recorded and contain information about, for example, junction depth, peak carrier concentration, slope of the dopant depth profile, etc. At Imec a PMOR based tool, named Thermaprobe (using a modulation frequency of 1 MHz) is available. This tool can measure so called offset curves over a relative wide range (where the probe and pump laser beam spots are separated from each other).

Up to recently, all PMOR work at Imec has focussed on silicon material. However, for the development of future technology nodes, there is a large interest in structures developed in germanium and/or InGaAs (III-V) materials. The last year an exploratory PMOR study on Ge/SiGe was made. The goal of this work is to continue and extend this work further and to be able to present the final results at an international conference.

This work will consist out of the following main parts: (i) familiarize oneself with the existing silicon and germanium related PMOR data and theory, (ii) Run additional experiments to complete the PMOR datasets for SiGe and pure Ge structures, eventually with measurements done outside of Imec (KLA-Tencor in the US, or Semilab in Hungary) (using different offset ranges or wave lengths), (iii) Perform initial measurements on doped InGaAs layers., (iv) Develop a theoretical insight into the signals measured on these new materials, and how the signals can be used for junction depth determination, profile shape reconstruction, etc., (v) Extend the current Si-based simulation environment (using a device simulator named FSEM), to compare simulations based on the new theoretical insights with experimental data.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, electrical/electronic engineering, material science

Responsible scientist(s):
For further information or for application please contact Trudo Clarysse (trudo.clarysse@imec.be) and Janusz Bogdanowicz (janusz.bogdanowicz@imec.be).

Advanced materials characterization using ion beam scattering

This topic is an opportunity to familiarize with one of the fundamental materials characterization techniques in a state-of-the-art nanoelectronics research center. You will be exposed to challenges in current and future CMOS technology.

Novel materials processing techniques and characterization approaches have boosted the nanoelectronics industry dramatically. Innovation in these fields is a key to the success of imec as an internationally renowned microelectronics research center.

Various novel materials have been introduced in nanoelectronics technology recently such as high-k materials (e.g. HfO_2) replacing the SiO_2 insulator in advanced transistors, and metals (e.g. TiN) replacing poly-Si as a gate material. Yet, the introduction of novel materials is expected to be even more essential in the future. Research is ongoing to replace Si by alternative materials that exhibit a higher mobility. Finally, new materials are also needed for the realization and optimization of new devices such as resistive memory (RRAM) cells, photovoltaic(PV) cells, nano-batteries, micro-electromechanical systems (MEMS) etc.
The development of new materials at imec builds also upon the experience and expertise of the materials and component analysis (MCA) department.

One of our major tools is a 2 MeV (2 Mega electron Volt) accelerator with two dedicated end stations for Rutherford Backscattering spectrometry (RBS) and Elastic Recoil Detection (ERD) experiments. Efforts are ongoing to optimize the detection schemes to achieve a better energy resolution, in ERD by using a gas ionization chamber, and in RBS by implementing a magnetic spectrometer. In addition, PIXE (particle induced X-ray emission) is being introduced to obtain complementary information to ERD and RBS.

A solid training program of three weeks will familiarize you with the fundamentals of Rutherford Backscattering spectroscopy. The training involves also hands-on experience. You will operate the accelerator and perform state-of-the-art experiments. Advanced analysis software is at hand to perform a proper data analysis.

The focus of your work will be to investigate multilayers of high interest composed of $Si/SiO_2/TiN/Ru/TiO_2/SrTiO$. Given the high complexity of the stack, conventional RBS approaches do not allow one to disentangle the various contributions to the experimental spectra. Therefore, we propose 1) to employ a magnetic spectrometer to enhance the detection energy resolution in RBS, and 2) to complement Rutherford Backscattering spectroscopy with particle induced X-ray emission (PIXE) measurements. The former measurements will be performed at the laboratories of imec, whereas the latter will be done in collaboration with Prof. André Vantomme of IKS at K.U.Leuven. The capabilities of each technique to reduce the uncertainties on the end-result are to be formulated. The goal is to formulate a procedure to analyze complex multilayers of the kind mentioned above.

Type of project: thesis or internship or thesis with internship for a period of minimum 6 months

Degree: Master in Science or Master in Engineering majoring in materials science, physics, chemistry, electronics

Responsible scientist(s):
For further information or for application please contact Johan Meersschaut (johan.meersschaut@imec.be).

Software development for automated RBS data acquisition

This subject involves the object-oriented (Windows/Unix) programming within a Microsoft Visual C++ based environment. The software will communicate with various instruments through RS232 and Ethernet.

This project aims at the development of a new software package for control over an Rutherford Backscattering RBS measurement station in a graphical, object oriented, Microsoft Visual C++ programming environment (dialog boxes, menu's, toolbars, property sheets, etc.). For portability reasons (towards Linux in the near future) this package has to be developed based on the Trolltech Qt4 class library (opposite to MFC).

The main tasks will be as follows:

- The first task will be to familiarize with Visual C++ and Qt4, as well as with the basics of operating the tool.
- To study the interface protocol with the instrumentation (stepper motors and multi-channel analyser).
- To implement the protocol into the Visual C++ environment, with an initial basic (simple) user-interface for testing purposes.
- To design and implement a user-friendly graphical user interface to interact with the hardware.

This subject is a challenge for those who wish to specialise themselves in all aspects and capabilities of object-oriented (Windows/Unix) programming within a Microsoft Visual C++ based environment.

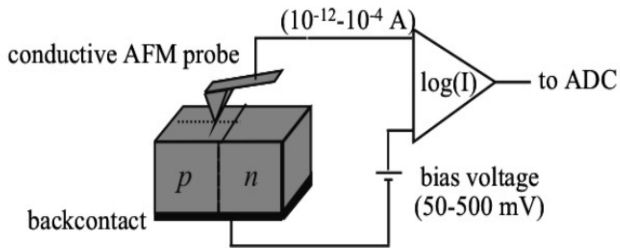
Type of project: thesis (for a period of 1 year) with internship (for a period of 1 month)

Degree: Master in Industrial Sciences majoring in electronics/ICT

Responsible scientist(s):
For further information or for application please contact Johan Meersschaut (johan.meersschaut@imec.be) and Trudo Clarysse (trudo.clarysse@imec.be).

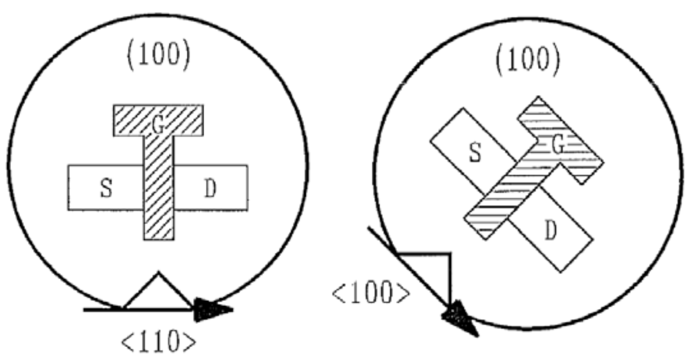
Optimizing the cross-section preparation for short and rotated Si-based devices

Scanning spreading resistance microscopy (SSRM) is a technique based on atomic force microscopy (AFM) used to obtain two-dimensional (2D) carrier maps of electronic devices (MOSFETs, bipolar transistors, FinFETs, TFETs) with (sub-) nanometer resolution. In SSRM, a very small conductive tip is used to measure the local spreading resistance, which is intimately linked to the local resistivity. Sample preparation is a key step in SSRM whereby the device to be measured needs to be cross-sectioned by polishing, cleaving or using a focused ion beam (FIB) for sample milling.



Sample preparation is especially challenging when dealing with short (< 1micron) devices as one then needs to control very accurately the position of the cross-section and to place a back-contact (used to collect the SSRM current) very close to the cross-section without damaging it. The precise control of the erosion rate during polishing is becoming extremely important.

Another emerging problem is the growing use of rotated substrates for improving the mobility in the channel. This is achieved by rotating the substrate by 45° such that the CMOS device channels are located along the <100> direction (and not <110> as in common devices). As a consequence, cleaving cannot be performed perpendicular to the gate anymore and polishing is affected.



The task of the student will be to address these emerging challenges in terms of sample cross-sectioning, analyzing the advantages and drawbacks of the different existing possibilities (polishing, micro-cleaving, FIB milling). Furthermore, his/her task will be to optimize them for obtaining flat (RMS below 0.5nm) and non contaminated surfaces. Finally, the student will investigate the post cross-sectioning characterization (topography, contamination,...) of the sectioned surfaces.

Type of project: thesis or internship

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, material science, chemistry

Responsible scientist(s):
For further information or for application please contact Pierre Eyben (pierre.eyben@imec.be).

Mechanical and adhesion properties of porous low-k materials for back-end-of-line applications

With the continuous downscaling of modern ultra-large-scale integration (ULSI) devices, copper and porous low-k materials are implemented in the back-end-of-line (BEOL). Typically, diffusion barriers are employed to block copper diffusion into the low-k inter-metal dielectrics. However, due to the inherent mechanical weakness of these low-k materials, reliability of Cu/low-k structures is a serious concern. Therefore, achieving sufficient mechanical properties and good adhesion of these low-k materials to the surrounding layers becomes crucial to ensure thermo-mechanical integrity and reliable high-performance electronic devices, especially when the low-k dielectric materials become highly porous.

The main focus of this thesis will be:

- Characterization of mechanical properties of different porous low-k materials using the nano indentation (NI) technique, including both experimental work and theoretical extraction of mechanical properties of low-k films. Also, the different factors that have an impact on the experimental results will be investigated in order to insure reliable NI results.
- Study the adhesion strength of different low-k materials to metal barriers using the 4-pt bending technique. This task includes both experimental work and theoretical extraction of the adhesion energy. Moreover, X-ray Photoelectron Spectroscopy (XPS) will be used to study the interface chemistry in order to explain the observed trends in adhesion performance.

Type of project: thesis with internship for a period of minimum 6 months

Degree: Master in Science or Master in Engineering majoring in material science, physics, engineering

Responsible scientist(s):
For further information or for application please contact Kris Vanstreels (kris.vanstreels@imec.be).

Synthesis and post-processing of graphene

Graphene, an atomically-thin sheet of carbon atoms arranged in a sp^2 honeycomb lattice, has been successfully isolated for the first time only in 2004. The peculiar electronic properties of graphene arise mainly from the configuration of its energy band structure, which, combined with the intrinsically low occurrence of defects and the stiffness of its lattice, allows for the featuring of intriguing 2-D physical phenomena. Graphene has been proposed as a candidate for CMOS and post-CMOS electronics; however, in order to make electronic applications of graphene realistic, one has to necessarily tune its electronic properties, so that, for example, a bandgap is introduced. Another aspect of the current graphene research entails the finding of a synthesis technique alternative to micromechanical exfoliation for graphene production, in order to achieve graphene deposited over large areas, available for CMOS-compatible device fabrication.

The objective of this internship is to develop processes to synthesize graphene by means of Chemical Vapor Deposition techniques, or by annealing of SiC-based film stacks. The candidate will also learn how to manipulate graphene in order to transfer it to alternate supports, and will be involved in the design, fabrication, and characterization of graphene devices. Part of the work will entail the manipulation of graphene produced by mechanical exfoliation, for benchmarking purposes. The challenges involved are:

- fine tuning of process parameters to control the number of graphene layers grown;
- investigation of the influence of the substrate texture/crystallinity on the properties and quality of synthesized graphene;
- study of the interfacial reactions between the substrate and graphene;
- post-processing of as-grown graphene (e.g., transfer, modification, device design).

The work will start from earlier findings within the graphene team.

Type of project: internship

Degree: Master in Engineering majoring in material science, engineering

Responsible scientist(s):
For further information or for application please contact Mirco Cantoro (mirco.cantoro@imec.be) and Stefan De Gendt (stefan.degendt@imec.be).

Characterization of advanced resistance-switching (RRAM) memory cells

Resistive RAM memory, based on resistance switching mechanisms, is emerging as a potential replacement for Flash and/or DRAM applications, due to its high scalability potential, for future 20 nm technology nodes and beyond.
Characterization of the fast resistive element switching mechanism, as well as of the RRAM cell performance require dedicated characterization systems, able to work in the time domain down 10 ns. Furthermore, ability to characterize large amount of samples, requiring wafer-level automation is a must for capturing statistical aspects of device operation and expediting the electrical characterization.

The main task of this internship/thesis is to characterize RRAM cells and assist in data analysis and interpretation. You will apply statistical principles in data collection and will develop characterization methodologies so as to ensure a short response time in characterization. Feedback for process improvement will be a key point, as well.

You must have a good background in semiconductor physics and knowledge of CMOS technology. You must be familiar with LabView and fluent in at least one programming/data analysis environment such as Matlab or similar. You will work in an international R&D team; a good command of English language is required.

The detailed content of the work will be defined in detail at the moment of starting this project.

Type of project: thesis or internship

Degree: Master in Engineering majoring in electronics/electrical engineering

Responsible scientist(s):
For further information or for application please contact Bogdan Govoreanu (bogdan.govoreanu@imec.be).

Electrochemical deposition of copper seed layers for microelectronics applications in copper complexing agents based chemistry

Context

Copper is used widely as metal interconnection in ultralarge scale integrated (ULSI) and 3D Interconnects owing to its low resistivity and high reliability against electromigration. The present damascene and 3D copper interconnections are fabricated by electroplating on a physical vapour deposited Cu seed layer. Bottom-up fill of Cu using additives in acid electroplating solutions has been studied extensively. Although the electrodeposition process achieved the filling of deep and narrow trenches and high aspect-ratio vias with copper, a few critical issues remain to be addressed, which include the need for a uniform and continuous sputtered copper seed layer, and the problem of non-uniform current distribution on the wafer.

The purpose of this work is to develop and characterize a Cu complexing agents based direct plating chemistry that, due to the lower conductivity and different copper nucleation mechanism, is less dependent on the incoming resistivity of the substrate and dependency on the position within the wafer.

The capability to achieve super filling of narrow features in the framework of the advanced interconnects will be explored changing the bath chemical composition at coupon scale.

The effects of chemistry and plating conditions on the deposition rate and super filling mechanism of the alkaline copper plating bath will investigated by electron microscopic and focus ion beam observation of the cross sections of the trenches in patterned substrates and by deposition rate measurements on unpatterned substrates.

Description of the work

The primary objective of the project is to investigate and develop a plating process directly on the thin barrier layers.

The student will test different commercial chemistries and benchmark with a model chemistry. Different barrier and seed layers, such as Plasma Enhanced Atomic Layer Deposited (PEALD) Ru, Ta, TaN, Ti, TiN, Co, W are suitable candidates. The type of work proposed is fully experimental and an intensive use of the potentiostaat for the electrodeposition tests is expected together with the preparation of the chemical solutions in the lab. Among other techniques, Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), X-photon Spectroscopy (XPS), X-ray diffraction spectroscopy (XRD), four point probe Sheet Resistance (Rs) measurement, four point bending adhesion measurement, are suitable candidates to be used for the characterization of the liner material and of the directly deposited copper layer. These analyses will be supported by the Imec characterization team. Given the international character of IMEC, good knowledge of English is necessary.

Previous experience with the use of a potentiostaat is highly appreciated.

Type of project: thesis or internship or thesis with internship for a period of minimum 6 months

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in chemistry, chemical engineering, materials science

Responsible scientist(s):
For further information or for application please contact Silvia Armini (silvia.armini@imec.be).

Electrochemical deposition of copper on resistive

Context

Copper is the material used for integrated circuits manufacturing. As the feature size decreases and aspect ratio increases, copper metallization becomes more difficult. Due to the dimensional shrinkage, new challenges arise in obtaining uniform and continuous barrier/seed layers by PVD means. Therefore, alternative integration schemes are investigated where the copper seed layer is eliminated entirely and platable barrier materials or alternative seed layers are introduced. In this case copper electrodeposition proceeds directly on the platable barrier or non-copper. Ruthenium (Ru) and Ru alloys have emerged as good candidates for direct copper plating. In order to determine whether Ru and Ru alloys are suitable barrier materials for the future technology nodes, the nucleation and growth mechanism should be elucidated at a fundamental level.
The goal of the research is to perform a systematic study of the nucleation and growth processes involved in copper deposition on Ru-based substrates. The obtained knowledge should be used eventually to model the nucleation and growth mechanism and elaborate on the conditions in which copper deposition and superfilling can be effectively achieved.

Description of the work

The primary objective of the project is to investigate the propagation rate of copper on resistive substrates according to changes in the plating bath chemistry. The student will test different plating bath chemistries on different alternative seed materials. The student will use electrochemical techniques to characterize the system such as potentiostatic and galvanostatic measurements and laser setup. The type of work proposed is fully experimental and intensive deposition tests are expected together with the preparation of the chemical solutions in the lab and further analysis with other techniques such as Scanning Electron Microscopy (SEM). This analysis will be supported by the Imec characterization team.

Requirements

- Knowledge in electrochemistry is necessary
- Good knowledge of English is necessary
- Knowledge in programming will be appreciated

Type of project: thesis or internship or thesis with internship for minimum 4 months

Degree: Master in Industrial Sciences or Master in Science majoring in Chemistry, Chemical Engineering, Materials Science

Responsible scientist(s):
For further information or for application please contact Magi Nagar (nagar@imec.be).

II. CMORE

Modeling backside illuminating CMOS imagers using TCAD software

Since the past few years, the technology of complementary metal oxide semiconductor (CMOS) image sensor has taken the place of charged coupled device's (CCD) technology in many applications. One of those being the space investigation, the developed imagers should exhibit very high quality properties in terms of high quantum efficiency, low crosstalk and high radiation tolerance. The Imager team in imec has been involved for the past years in that domain: backside-thinned monolithic and fully-hybrid CMOS active pixel sensors (APS) possessing excellent imaging properties have been successfully designed, fabricated and tested. In order to design and manufacture fully-hybrid CMOS APS possessing excellent imaging properties, different Technology Computer-Aided Design (TCAD) software tools were used. Those powerful tools are able to solve numerically complex physical equations and predict the performance of the device. Also critical microelectroning processing steps can be identified and optimized. Understanding the behavior of our current backside-thinned CMOS imagers and any further improvement requires different simulation models to be studied and developed.

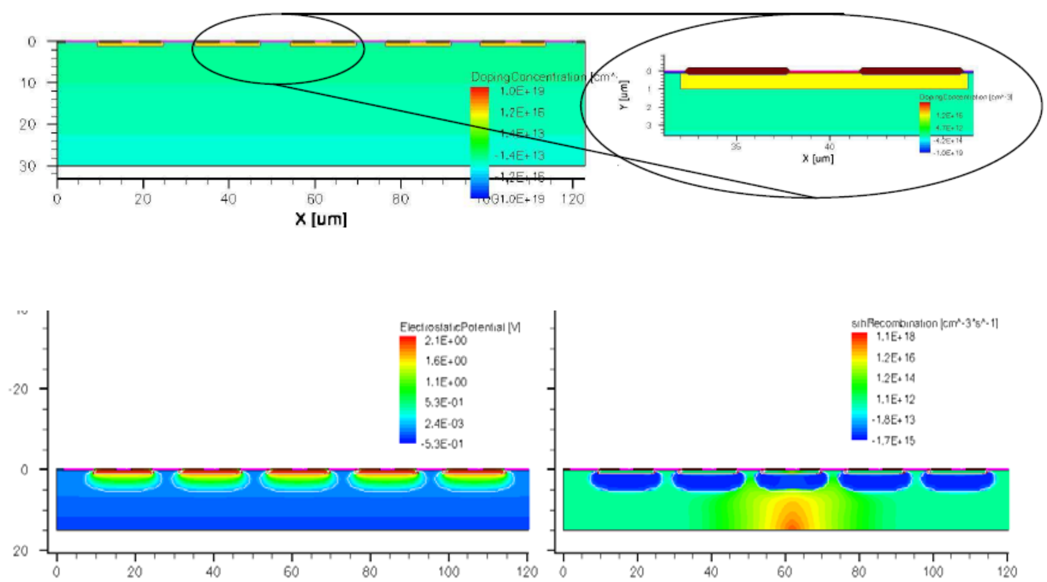


Figure: 2D array of five backside illuminated pixels (top) and simulated results of electrostatic potential and srh recombination (bottom)

The goal of this master thesis is to study physical mechanisms of the photodiodes, get familiar with the TCAD tool software, implement the physical models and the actual device design into the simulator and confirm the accuracy of the developed model by comparing simulations to measurements. Simulations can be done with existing software packages, Process and Device simulators of the Sentaurus Synopsis TCAD software. The student will start from existing CMOS imager models and will focus on specific improvements and modifications. The student will interact a lot with the Imager team at imec.

For this master thesis, you are expected to have a strong interest and/or background in semiconductor physics. Imec will provide training to UNIX/LINUX and to the device modeling techniques. Previous experience with the tools is not required. However, knowledge of TCAD software and/or physics of optoelectronic devices is an advantage.

Type of project: thesis and/or internship for a period of minimum 5 months

Degree: Master in Science or Master in Engineering majoring in electrical engineering, physics

Responsible scientist(s):
For further information or for application please contact Kiki Minoglou (minoglou@imec.be).

Characterization of backside illuminated hybrid CMOS Active Pixel Sensor Arrays

For the past few years, complementary metal oxide semiconductor (CMOS) image sensors have gradually taken the place of charged coupled device's (CCD) technology in many applications. In one of those, being space exploration, these imagers should exhibit near-perfect behavior in terms of high quantum efficiency, low crosstalk and high radiation tolerance. For several years imec's Imager team has been active in that domain: backside-thinned monolithic and fully-hybrid CMOS active pixel sensors (APS) possessing excellent imaging properties have been successfully designed, fabricated and tested.
Currently, an improved version of CMOS APS is under fabrication and will be available shortly. Their performance is expected to be superior to the previous one, since various limitations and problematic areas are taken under consideration during design and processing. To evaluate this enhancement some of the key parameters of detectors arrays should be defined and quantified. Understanding the basic nature of the detector array, investigation of the performance limits and the calibration procedures and subsequent opto-electrical characterization on wafer or on packaged level are the main tasks involved in this thesis. Various semiconductor physical mechanisms will be studied during the measurement of key parameters like inter-pixel electrical crosstalk, conversion gain, quantum efficiency, intrinsic device and off-chip noise, non-linearities, thermal dark signal, transient time phenomena etc.

This topic will focus on the application of characterization procedures on CMOS APS. The work is mostly experimental and the goal is that the student comes to an improvement of the quantitative sensitivity evaluation of the 2D Sensor Arrays. Modifications to the measurement setup and procedures will be implemented and/or proposed.

Type of project: thesis or internship or thesis with internship for a period of minimum 6 months

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in material science, physics, electronics

Responsible scientist(s):
For further information or for application please contact Kiki Minoglou (minoglou@imec.be) and Koen De Munck (koen.demunck@imec.be).

III. Smart Systems

PHY layer modelling and performance analysis of 5G broadband wireless systems

4G wireless standards are currently in the definition or early deployment phase. Their scope of applications varies from indoor to outdoor, low to high mobility, cellular, access and broadcast. Orthogonal Frequency Division Multiplex (OFDM) and variant thereof are widely used in these standards. Very soon, proposals for 5G systems will appear. Improvements on OFDM are possible and are probably in the scope of future standardization.

Filterbank multi-carrier (FBMC) transmission is a candidate PHY technique for 5G systems. Contrary to OFDM where orthogonality must be ensured for all the carriers, FBMC requires orthogonality for the neighbouring sub-channels only. In fact, OFDM exploits a given frequency bandwidth with a number of carriers, while FBMC divides the transmission channel associated with this given bandwidth into a number of sub-channels. In order to fully exploit the channel bandwidth, the modulation in the subchannels must adapt to the neighbour orthogonality constraint and offset quadrature amplitude modulation (OQAM) is used to that purpose. The combination of filter banks with OQAM modulation leads to the maximum bit rate, without the need for a guard time or cyclic prefix as in OFDM. Hence higher efficiency and lower sensitivity to carrier frequency offsets or Doppler spread results.

The performance of wireless communication systems is usually assessed by means of simulations before the communication devices are built. This allows to not only assess the intrinsic performance of the transmission system under some ideal circumstances but also to assess the impact of practical solutions (implementation related) and to compare the performance of several receiver signal processing algorithms.

The proposed thesis consists in several tasks that can be carried out by several master thesis students who will be integrated in existing teams:

- Building a detailed Matlab model of the FBMC physical layer.
- Develop the PHY layer functionalities for the receive side, first in an ideal case, then with non-idealities
- Propose and compare algorithmic solutions for specific functions (synchronization, channel estimation,…).
- Assess the performance of the link, compare and optimize algorithmic choices and assess the degradation due to front-end effects.

Type of project: thesis or thesis with internship for a period of 6 months

Degree: Master in Engineering majoring in electrical/electronic engineering, computer science

Responsible scientist(s):
For further information or for application please contact André Bourdoux (bourdoux@imec.be).

Electrical doping of organic semiconductors

Electrical doping of organic semiconductors (OSC) has been successfully applied in transport layers of organic light emitting diodes and solar cells to improve overall device performance. It has been shown that small amount of doping can lead to an enhanced OSC conductivity of up to six orders of magnitude and an improved injection from metal contacts. Nevertheless, limited fundamental understanding of the doping mechanism hampers development of both new doping materials and their practical applications.

Recently, significant theoretical understanding of the molecular doping has been developed at imec. Obtained findings open several new ways to utilize the molecular doping in an advanced fabrication technology to enhance device performances.

This project is an experimental verification of the theoretical findings and possible technology improvements. The work consisting of the fabrication and measurement of organic electronic devices, namely, diodes, thin film transistors and solar cells. Different types of p- and n- dopants and device structures will be investigated to benchmark theoretical results.

Type of project: thesis

Degree: Master in Engineering majoring in material science, electronics

Responsible scientist(s):
For further information or for application please contact Alexander Mityashin (alexander.mityashin@imec.be).

Organic ion-sensitive field effect transistor

Ion-sensitive field effect transistors (ISFETs) have great potential for replacing traditional pH measurement technology, due to their high sensitivity, small area, and potential for on-chip circuit integration. An ISFET is in fact nothing more than a field effect transistor with the gate electrode replaced by solution, a chemically sensitive membrane, and a reference electrode. In an ISFET, pH detection is achieved by exposing an insulating membrane to the solution under investigation and regulate to the transistor current in response to the ion concentration.

The aim of this project is to build ISFETs by organic thin-film field effect transistors (OTFTs) to achieve high pH sensitivity at low cost. The student will receive basic training about processing an organic device in cleanroom, material analysis and electrical measurement. Different sensing membranes (materials and areas) will be tested.

Type of project: thesis with internship for a period of minimum 6 months

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in material science, physics, electronics

Responsible scientist(s):
For further information or for application please contact Wan-Yu Lin (wan-yu.lin@imec.be).

Realization of an integrated organic memory array

Flash memory devices are widely used in today's electronics. Their working principle is based on a field-effect transistor with a floating gate, on which charges can be stored. By charging or discharging the floating gate, the threshold voltage of the transistor changes and can be read out as a difference in current through the transistor at given bias voltages.

In this master thesis the plastic-technology counterparts of this well-known memory element will be investigated. Organic or plastic semiconductor technology is based on thin-film organic semiconductors. Circuits have successfully been demonstrated, in particular using pentacene as semiconductor. At present there are, however, no examples of circuits comprising re-writeable memory devices. Flash-type transistors are interesting re-writeable memory candidates, in particular when targeting "on-chip" integration with circuits, because their architecture is quite compatible with the transistors used in circuits. However, apart from flash-type memory transistors, several other device architectures and concepts can be imagined to arrive at memory transistors able to store a charge. A possible alternative memory structure is a transistor with a polymer ferro-electric gate dielectric, where the polarization state of the dielectric determines the transistor threshold voltage.

The focus of this master thesis lies in the realization of an integrated organic memory array based on transistors with a ferro-electric gate dielectric and in understanding the charge-storage and polarization-switching concept. The challenge is to conceive device architectures and concepts that are compatible with circuit technology on foil, both in terms of technology and in terms of programming voltages. The materials we will use to fabricate the devices are polymers as well as organic small molecules. Polymers are typically deposited using spin-coating; small molecules will be evaporated using organic molecular beam deposition. In a first stage, a process flow will be developed to integrate organic ferro-electric memory transistors together with existing process flows for organic thin film transistors on foil. Subsequently, organic memory arrays, using these integratable memory devices, will be fabricated and characterized.

Most of the work will be done in the cleanroom of imec. The student will receive a broad training on different cleanroom processing equipment (photolithography, wet benches, metal evaporation) and characterization tools. After a short training period, it is expected that the student can work independently and focused towards the realization of his/her project.

Type of project: thesis

Degree: Master in Industrial Sciences or Master in Engineering majoring in nanotechnology, physics, material science, electrical engineering

Responsible scientist(s):
For further information or for application please contact Sarah Schols (sarah.schols@imec.be) and Benjamin Kam (benjamin.kam@imec.be).

Design of cryogenic digital to analog converter

Low-temperature detectors for X-ray and far-IR imaging and spectroscopy for space exploration and particle experiments require proximity read out electronics cooled to deep cryogenic temperatures, typically below 10K (-263°C). To increase system integrity and reduce its complexity, Analog-to-Digital and Digital-to-Analog conversion should be performed in the cryogenic subsystem as the distance between cryogenic and warm electronics is considerably long.

At present, the only DAC's fully operational at deep cryogenic temperatures (<10K) mentioned in literature, are superconductive circuits (Josephson junctions), whose working temperature is limited to a maximum temperature of 10K. Systems tests at room temperature or intermediate temperature are hence impossible. A cryogenic DAC, operating from room temperature down to deep cryogenic temperature would overcome this problem. An additional key requirement is ultra low power consumption dictated by the maximum cooling capacity of the cryo-cooling system.

The major challenge in cryogenic CMOS circuit design is degradation of the device behavior due to freeze out of free carriers at low temperature. The designer has to take into account the occurrence of temperature induced effects as a negative transconductance regime, an associated current overshoot in the time domain, and the kink at higher drain source voltages with counterclockwise hysteresis (see figure below). All of these phenomena have a deteriorating effect on the performance of room temperature circuits and consequently call for a dedicated design approach.

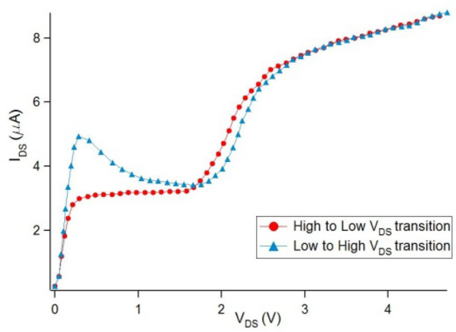


Figure Measurement of typical NMOS IV characteristic at 4.2K

This thesis focuses on the design of a Digital-to-Analog Convertor (DAC) operating from room temperature down to Liquid Helium Temperature, i.e. 4.2K or -269C, processed in a commercially available CMOS technology. The entire design cycle will be completed during this thesis: from the design of the architecture and transistor implementation to lay out of the circuitry. The final objective is the design of a 12 bit DAC operating from ambient temperature down to -269C featuring ultra low power consumption.

Type of project: thesis or internship for a period of minimum 6 months

Degree: Master in Engineering majoring in electronics

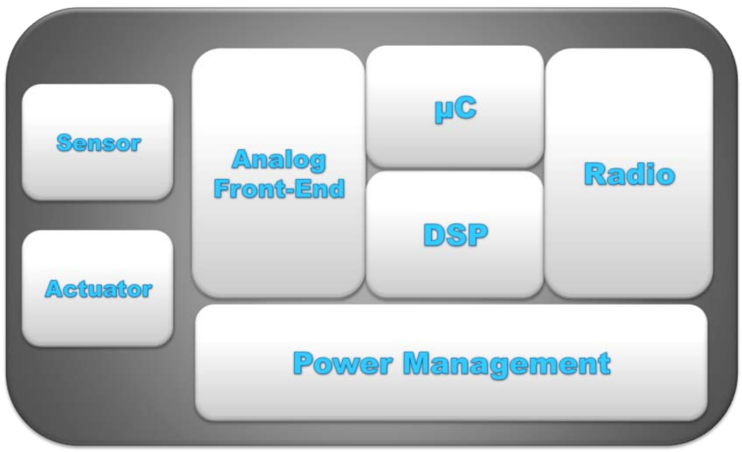
Responsible scientist(s):
For further information or for application please contact Ybe Creten (ybe.creten@imec.be) and Francesco Cannillo (francesco.cannillo@imec.be).

Analog signal processing for medical signals

The ever increasing interest towards smarter, smaller, and autonomous wearable health monitoring for medical and lifestyle applications is driving the research for the realization of ultra-low-power and wireless sensor nodes. These sensor nodes will be responsible for extracting medical signals from the patient and process them to detect the presence medical disorders.
One of the problems in digital signal processing of medical signals is the vast amount of data allocations extensive DSP memory and leading to large power dissipations. An emerging approach to this problem is to shift some of the signal processing from digital domain to analog. In order to realize this goal filters with special transfer functions are required. The topic of this thesis will focus on the implementation of these analog filters first in Matlab and then in transistor level.

Following skills are required for the applicants

- Excellent grades in courses Analog Integrated Circuit Design and/or Analog Filter Design
- Strong background in Linear Algebra
- Strong background in analog filter design
- Experience with MATLAB
- Experience with Cadence Design Environment



Type of project: thesis or Internship with minimum study duration of 6 months

Degree: Master in Engineering majoring in Electrical and Electronics Engineering

Responsible scientist(s):
For further information or for application please contact Refet Firat Yazicioglu (firat@imec.be).

Electro-thermal modeling for advanced photovoltaic modules

Photovoltaic solar panels provide a very attractive solution for future clean energy provision on site. Today's panels provide a relatively high efficiency under optimal conditions and when just fabricated. However, when external temperature, radiation angle, and radiation concentration conditions are varying, also the power efficiency fluctuates quite heavily. Moreover, aging effects do play a role in both the panels and the convertor of the solar energy system. The range of these effects heavily depends on the context in which these panels are used and on the type of technology used.
We will mainly focus on crystalline silicon flat-plate modules using the most cost-effective solar cells.

In this thesis, we want to model the flat-plate modules including several ways to introduce run-time "knob" control. Both electrical and thermal effects will be included.
This will contribute heavily to the energy-yield efficiency over the entire life time of the future solar system, with minimal hardware cost increase. That will result in a large practical impact of the work in this thesis.

Profile: basics of electrical SPICE-level modeling, basics of thermal modeling, strong interest in learning and scope broadening, interest in wide literature study/analysis.

Type of project: thesis of at least 6 months (full-time, at Leuven)

Degree: Master in Engineering, majoring in micro- or nano-electronics

Responsible scientist(s):
For further information or for application please contact Kris Baert (kris.baert@imec.be) and Prof. Francky Catthoor (francky.catthoor@imec.be).

Measurement and calibration of models for advanced photovoltaic modules

Photovoltaic solar panels provide a very attractive solution for future clean energy provision on site. Today's panels provide a relatively high efficiency under optimal conditions and when just fabricated. However, when external temperature, radiation angle, and radiation concentration conditions are varying, also the power efficiency fluctuates quite heavily. Moreover, aging effects do play a role in both the panels and the convertor of the solar energy system. The range of these effects heavily depends on the context in which these panels are used and on the type of technology used.
We will mainly focus on cristalline silicon flat-plate modules using the most cost-effective solar cells.

In this thesis, we want to measure the characteristics of flat-plate modules. Both electrical and thermal effects will be included. The measurements will also be used to calibrate 3D finite-element models. This will contribute heavily to improve the energy-yield efficiency over the entire life time of the future solar system. That will result in a large practical impact of the work in this thesis.

Profile: strong interest in measurement setups and hardware, basics of electrical SPICE-level modeling, basics of thermal modeling.

Type of project: thesis of at least 6 months (full-time, at Leuven)

Degree: Master in Engineering, majoring in micro- or nano-electronics

Responsible scientist(s):
For further information or for application please contact Jonathan Govaerts (jonathan.govaerts@imec.be) and Prof. Francky Catthoor (francky.catthoor@imec.be).

IV. HUMAN++

Mechanical behavior on necking retardation and energy absorption of metal/elastomer bilayers for stretchable interconnect applications

Metal behaves differently with elastomer supported, because of necking retardation and energy absorption. In this master thesis research, the student has to learn the principle of mechanics of materials and digital image correlation technique (DIC). By applying the theory and experimental correlations, the student will have chance to develop or extend the theory in the applications of stretchable electronics.

Type of project: thesis with internship for a period of minimum 6 months

Degree: Master in Engineering majoring in mechanical engineering, material science

Responsible scientist(s):
For further information or for application please contact Yung-Yu Hsu (yung-yu.hsu@imec.be) and Mario Gonzalez (mario.gonzalez@imec.be).

Calcium imaging of electrically stimulated spiral ganglion neurons

The aim of this thesis proposal is to develop technique for calcium imaging of electrically stimulated spiral ganglion neurons (SGN) isolated from guinea pigs. The SGNs will be cultured in vitro on imec chip which is used for electrical stimulation of cells. Demonstration of calcium activity of SGN during electrical stimulation is a principal objective of this proposal. The candidate will review current protocols for calcium imaging of SGN and will propose one for a successful calcium imaging. There is a possibility that successful calcium imaging will not be feasible with SGN from guinea pigs. In this case, the candidate will need to identify reasons for this inability and will propose potential solutions to the problem. Findings from this exploratory work will additionally contribute to our current work on electrophysiological characterization of SGN cultured in vitro on imec chip. The candidate will be guided primarily by Dr. Damir Kovačić and when necessary by Dr. Dries Braeken.

Some knowledge of bioelectronics and the ability to work with Matlab is preferred.

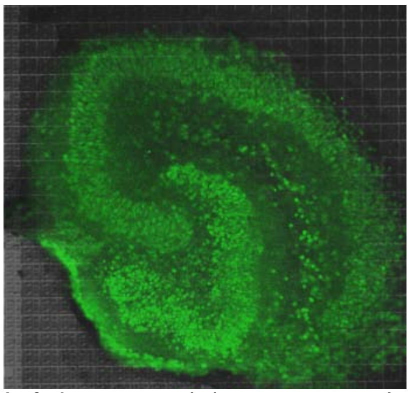
Type of project: thesis with internship for a period of 6 to 9 months

Degree: Master in Science majoring in biomedical science, biology, physics, medicine

Responsible scientist(s):
For further information or for application please contact Damir Kovacic (damir.kovacic@imec.be) and Dries Braeken(dries.braeken@imec.be).

Optimalization of culture conditions for organotypic brain slice cultures on microelectrode arrays

The study of neuronal circuits is of great importance for the understanding of normal and pathophysiological mechanisms in our brain. Neuroscientists often make use of brain tissue slices to study these circuits, because the sliced brain is easily accessible while the original connections between individual cells remain intact. Using brain slices, the effect of potential genetic aberrations or neurotoxic agents on memory formation and consolidation can be investigated. When these brain slices are brought into culture conditions, they can be studied over a much longer time, with minor changes to the original circuit. However, this technique, called organotypic brain slice culturing, is far from easy and many attempts have been made to optimize it.



Left: hippocmapal slice on a microelectrode array; right: custom-made slice tilter in incubator.

In Imec, we developed a new platform that makes this culturing easier and semi-automatic. The slices are grown on microelectrode arrays while they are kept alternatively in air and medium conditions using a slice tilter. This slice tilter is fully programmable, allowing optimization of the protocol. The student will be performing brain slice cultures, immunostaining, live/dead assays and data analysis with the help and guidance of the people working on this matter in the bioelectronic systems group.

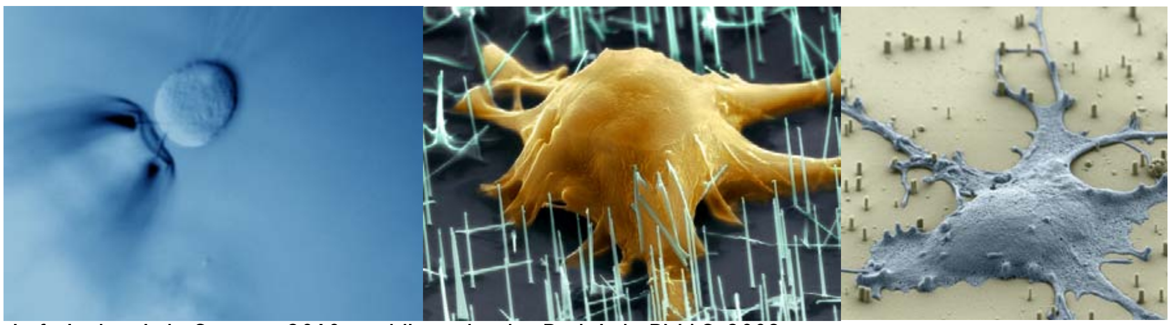
Type of project: thesis or internship for a period of minimum 4 months

Degree: Master in Science or Master in Engineering majoring in biology, biomedical science, bio-engineering

Responsible scientist(s):
For further information or for application please contact Wolfgang Eberle (wolfgang.eberle@imec.be) and Dries Braeken (dries.braeken@imec.be).

Interaction between nano-sized materials and cellular components to create an intimate contact between chip and cell

Due to their size and physical properties, nanomaterials or nano-sized features show a large potential for applications that can benefit from the interaction with cellular components. Nanoparticles or nanotubes have sizes in the range of individual cellular structures, which makes a strong interaction between both possible. Several groups have demonstrated this interaction before in the field of bioelectronics [Tian, Science, 2010]. Nanostructures that are grown or deposited on sensing devices can serve as extremely sensitive probes for measurement of electrical activity with very high quality. This is probably because of the non-invasive yet strong contact with the cell membrane or even intracellular milieu. Some of these nanostructures are not only interesting because of their size but also because of their electrical properties. It has been shown for example that impedances of electrodes can be lowered significantly by growing carbon nanotubes on top of sensing probes [Keefer, Nat. Nanotech., 2008].



Left: Lieber Lab, Science, 2010; middle and right: Park Lab, PNAS, 2009

The bioelectronic systems group in Imec works towards the development of interfaces between integrated circuits and living cells, tissue or the brain. The constant search for new materials and processes to improve the interface between chip and cell is crucial in this field, as well as the understanding of this complex interface. This internship will focus on the biological characterization of cells and tissue with nanomaterials. The student will be performing cell cultures, immunostainings, laser confocal scanning microscopy, etc. and will be integrated in the daily work of the group.

Type of project: thesis or internship

Degree: Master in Science majoring in biological sciences, bio-engineering, biomedical science,

Responsible scientist(s):
For further information or for application please contact Dries Braeken (dries.braeken@imec.be) and Nadine Collaert (nadine.collaert@imec.be).

Parallel implementation of parametric fitting routines for MRI imaging

Within the Bioelectronic system group, we currently develop an active neurophysiological probe for recording and stimulation of the brain. In the context of the project, such probes are tested in rodents, which are then followed up by Magnetic Resonance Imaging (MRI). MRI is an invaluable tool for non-invasive study of the brain. The MRI images can provide functional information, such as the presence of brain edema (T2-maps). This offers the possibility to study the tissue in proximity to the implanted probes using a combination of non-invasive MRI techniques. In the context of the project, the student will be engaged in development and optimization of software tools for computation of parametric brain maps.

The student will get familiar with parallel computer architectures (for example, CUDA). The student will implement parallelization of the computation of MRI parametric maps. The student will demonstrate the use of the software using already present experimental data.

Type of project: internship for a period of 3 to 6 months

Degree: Master in Science majoring in computer science, mathematics, biomedical engineering

Responsible scientist(s):
For further information or for application please contact Dimiter Prodanov (dimiter.prodanov@imec.be).

3D FIB/SEM structural analysis of cells on nano-electronic devices

The device scales of nano-electronics and biology are nowadays meeting each other. It allows developing biosensors that combine electronics and cell structures . It is expected that such devices will become important for future diagnostics.

Understanding and controlling the interface between the electronic device and the cell material is crucial in the development of biosensors. The combination of soft (bio-cells) and hard (electronic device) materials makes the physical analysis of these structures challenging. The classical procedures for cross-sectional structural analysis are based on microtome slicing and optical or scanning electron microscopy imaging for biological materials and on sample cleaving or focused ion beam milling and SEM imaging for silicon devices.

For cell structures on a hard substrate, the microtome as well as the cleaving cannot be applied anymore. Focused ion beam milling (FIB) combined with scanning electron microscopy (SEM) is a possible route to follow for the cross-sectional structural analysis. Challenges are related to the stability of the cells in the vacuum system, damage of the material by the ion beam, contrast inside the cells and at the interfaces with the device below. Acquiring SEM images while slicing with the ion beam through the device gives a view on the 3D structures. Reconstructing the volume

The work will involved : pre-treatment of the samples to ensure their stability in the vacuum and to obtain optimum SEM contrast, study of best experimental procedures for the milling and imaging, "slice-and-view" imaging of the structures and 3D reconstruction of the set of images.

Type of project: internship for a period of 3 to 6 months

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in material science, physics, electronics, bio/medicine

Responsible scientist(s):
For further information or for application please contact Hugo Bender (hugo.bender@imec.be).

Magnetic nanostructures as multicolor contrast agents for magnetic resonance imaging (MRI)

Magnetic resonance imaging is a powerful medical imaging technique, based on the magnetic resonance of hydrogen nuclei (protons) that are omnipresent in the body. Contrast agents (usually magnetic particles or molecules) are frequently used to enhance the contrast, but their effect is limited to an increase or decrease of the signal strength. This leads to a monochrome image, and makes it impossible to distinguish the effect of different contrast agents.

Recently a novel approach has been proposed for contrast agents that result in a well-defined frequency shift. This opens a pathway towards multicolor MRI imaging, where multiple labels (with e.g. different biological functionality) can be imaged and distinguished from each other in a single experiment.

This master thesis will focus on the design and fabrication of these novel magnetic nanoparticles, as well as on their surface functionalization to make them water dispersible. Once the particles have been fabricated, their performance in MRI experiments will be evaluated in collaboration with the Molecular Small Animal Imaging Center (MOSAIC) at the University Hospital Gasthuisberg.

Type of project: thesis

Degree: Master in Science or Master in (Bio)Engineering majoring in physics, biomedical, ...

Responsible scientist(s):
For further information or for application please contact Wim Van Roy (wim.vanroy@imec.be).

Engineered plasmonic nanostructures for highly sensitive biosensing

Nanostructured metals show some extraordinary properties upon illumination with visible or near-infrared light. So called surface plasmons are the result of a collective excitation of the electrons at the interface between a metal and a dielectric and result in strong resonances in the optical and near-infrared region of the electromagnetic spectrum. These structures are particularly interesting for sensing applications, as the refractive index of the dielectric environment has a strong influence on the resonance position. Small local index variations by molecular binding events can result in measurable shifts of the resonance wavelength. Recently we have demonstrated both special designs that allow facile tuning of the resonance wavelength that are based on a coherent interaction between the plasmonic response of different nanostructures in close proximity, and a new measurement technique enabling a much more sensitive determination of small wavelength shifts.

This master thesis will focus on the application of both the new designs and the novel measurement technique to biosensors. In this project, receptor molecules will first be coupled to the gold metal structures using conventional surface chemistries. After this first immobilization, the binding of the analyte of interest –resulting in a change in dielectric constant– will be monitored in real time. As the influence of binding decreases with increasing distance, different receptor molecules will be tested. The sensitivity of the nanostructures will be assessed and changes to the nanostructure design and measurement setup will be proposed.

Type of project: thesis

Degree: Master in Science or Master in (Bio)Engineering majoring in physics, chemistry, biomedical, applied science, ...

Responsible scientist(s):
For further information or for application please contact Liesbet Lagae (liesbet.lagae@imec.be).

Electrical characterization of cancer cells

Cancer remains a prominent health concern afflicting modern societies. Continuous innovations and introduction of new technologies are essential to level or even reduce current healthcare spending. As the analysis of circulating tumor cells is most promising in this respect, this thesis aims to develop a device to characterize these cells using electrical impedance spectroscopy. This non-invasive electrical method may provide cell information through permittivity and conductivity measurements of the cell membrane and -cytoplasm. A close interaction of electrodes with the cells lying on top of the device should yield sufficiently high signal to noise ratios and may eventually enable to differentiate various cell subtypes. This is especially promising as most cells that escape from a primary tumor fail to form metastases, and only a minor fraction of circulating cancer cells generally arrest in the microcirculation to form micro metastases of which few persist to form vascularised macro metastases.

Type of project: thesis

Degree: Master in Bio-Engineering majoring in bio-physics, biomedical, ...

Responsible scientist(s):
For further information or for application please contact Chengxun Liu (Chengxun.Liu@imec.be).

Magnetic beads for the combined capturing and detection of biomolecules in blood

Despite great efforts in various application fields, most biosensors have not met the required sensitivity and specificity to allow for label-free detection. The use of magnetic labels may form an interesting alternative to fluorescent or other labels. Not only can the superparamagnetic beads be sensed at very low concentrations, their use for the isolation of cells, proteins or nucleic acids makes it possible to combine sample (pre)purification steps and multiplexed detection on a single portable system with reduced cost. IMEC has examined both giant magnetoresistive sensors for detection and current carrying conductors for the manipulation of beads. This thesis will investigate the combination of both techniques for the enrichment and detection of bio-analytes directly from clinical samples. By attracting the beads to the sensor surface to overcome diffusion-limited binding and by integrating all steps into a fully functional platform, higher reproducibility and extremely high detection limits are envisaged.

Candidates with chemical background and a high interest in (electronic) engineering are encouraged to apply.

Type of project: thesis

Degree: Master in Science or Master in Bio-Engineering majoring in chemistry, ...

Responsible scientist(s):
For further information or for application please contact Karolien Jans (karolien.jans@imec.be).

Electrochemical stability of self-assembled monolayers on gold

Self assembled monolayers (SAMs) are often used as interface layers for biosensing applications. Consequently, the stability and reproducibility of these monolayers directly influences the biosensor performance. To optimize the SAM deposition, standard techniques such as cyclic voltammetry and impedance spectroscopy, are typically used, but additional electrochemical studies can provide a better insight into the packing density and distribution of pinhole defects into the SAM. By means of creative electrochemical techniques, SAMs can also undergo reductive desorption and oxidative re-adsorption from the surface. This interesting feature can be used for the spatially and temporally controlled release of molecules from individually addressable spots on an electrode surface. Besides better SAM characterization, this control gives a further impulse to the development of smart multiplex biosensor interfaces or drug delivery applications.

In short, the work of the student would consist of a systematic study to evaluate the electrical stability of SAMs on different electrode materials and to improve the control over the reductive desorption and oxidative re-adsorption. This study should help to better control the SAM behavior onto different biosensor interfaces and to allow a further development of multiplex biosensor interfaces.

Type of project: thesis

Degree: Master in Science or Master in Bio-Engineering majoring in (bio)chemistry, biomedical, applied science, ...

Responsible scientist(s):
For further information or for application please contact Karolien Jans (Karolien.Jans@imec.be).

Novel biosensing technique using surface enhanced Raman spectroscopy (SERS)

Raman scattering is a technique used to identify molecules based on their inelastic scattering of light. In general Raman signals are of very low intensity, but absorbance of Raman active molecules on metal nanostructures may strongly enhance the signal. This so called surface enhanced Raman spectroscopy (SERS) makes even single molecule detection possible, making it one of the best methods for label-free biomolecular sensing.

This master thesis will focus both on the fabrication of planar and nanoparticle based SERS substrates as well as on their use for in vitro biosensing. The substrates will be optimized to improve the enhancement factor and reproducibility. Sensing experiments will initially be performed with DNA probes and complementary targets. Additionally, the use of SERS labels will be examined as they provide further advantages including high multiplexing capabilities and narrower bandwidths (compared to fluorescence spectra).

Type of project: thesis

Degree: Master in Science or Master in Bio-Engineering majoring in chemistry, biomedical, applied science, ...

Responsible scientist(s):
For further information or for application please contact Hilde Jans (Hilde.Jans@imec.be).

Multifunctional nanoparticles for SERS imaging and hyperthermia treatment of cancer

Cancer is still one of the most leading death causes in the entire world. Because of this high number, there is a high demand for more precise and sensitive imaging and therapy techniques for cancer. In the latest decennium an increasing interest in nanotechnology occurs for increasing the detection limit to recognize tumor cells which makes faster imaging and treatment of cancer possible.

In this sector of nanotechnology, branched gold nanoparticles show a very promising role for this combined treatment and imaging of cancer. Those particles can be coupled with biological molecules for interacting with receptors which shows a higher expression on tumor cells leading to an accumulation of the particles close to the tumor cells. This accumulation, make the particles ideal for imaging of the tumor cells by the optical technique: 'surface enhanced Raman scattering' (SERS). This is based on the inelastic scattering of light by a Raman label where the SERS signal is enhanced by the golden particle. Every SERS label has a specific spectrum resulting in the multiplexing possibilities using different labels showing great potential in the detection of different cell types or molecules. Besides imaging, the treatment will occurs by hyperthermia since the particles will absorb light at a specific wavelength and convert it into heat. This heat is deadly for tumor cells since they are more sensitive on temperature than normal cells.

In this research, the coupling of the branched particles with the SERS-labels will be investigated. Next the opportunity for other anisotropic gold particles (rods, cages, etc.) will be explored for SERS imaging. Additionally, those SERS possibilities will be evaluated in vitro as the identification of biomolecules, the location of the particles within the tumor cells and the identification of single cells. Furthermore in vivo experiments for SERS imaging will be explored where multiplexing imaging is the final opportunity.

Type of project: thesis

Degree: Master in Science or Master in Bio-Engineering majoring in chemistry, biomedical, applied science, ...

Responsible scientist(s):
For further information or for application please contact Hilde Jans (Hilde.Jans@imec.be).

Development of reliable and scalable multiparameter biointerfaces that can be implemented on different biochip platforms

Microarrays enable multiplex or even high-throughput DNA and protein analyses. Current microarrays are, however, limited to standard glass substrates. Moreover, reliable methods to immobilize DNA or proteins on custom surfaces containing various materials or topologies are limited or non-existing at all. For this reason, novel site-directed immobilization strategies will be examined and will be combined with spotting technologies to realize a reliable multiparameter biosensor interface.

More practically, the work of the student would consist of combining commercial microspotting techniques with different immobilization strategies for both DNA and proteins to functionalize oxide, metal and patterned sensor surfaces with multiple bioreceptors. In addition, we will look into rinsing steps in which the unreacted biomaterial is removed from the sensor without changing the functionality of the space between the droplets. Hereto, a deactivation route for the applied surface chemistry in these areas will be investigated. This research on biospotting should lead to a surface functionalized with known biomaterials in designated areas to enable multiparameter analysis.

Type of project: thesis

Degree: Master in Science or Master in Bio-Engineering majoring in chemistry, biomedical, applied science, ...

Responsible scientist(s):
For further information or for application please contact Karolien Jans (Karolien.Jans@imec.be).

Novel measurement scheme for multiplexed Coulter counting

Coulter counters are very successful commercial devices, used to measure the size and concentration of particles (e.g. cells, viruses, DNA, ...) in a liquid. The measurement principle has essentially remained unchanged since its inception more than 50 years ago: a micro- or nanopore is created between the inlet and outlet reservoirs, and the ionic current is measured. When a particle passes through the pore, the ionic current decreases proportional to the size of the particle.
A drawback of this approach is that the sample volume that can be measured drops dramatically for small particle and pore sizes. The goal of this Master thesis is to develop an integrated electrical (e.g. voltage, impedance) measurement scheme that can monitor the local signal fluctuationover the micro- or nanopore resulting from the particle translocations through the pores, and compare the performance with the traditional measurements of the global ionic current. This approach will allow the parallel read-out of multiple pores, and open a pathway to the massive parallelization of micro- or nanopore based Coulter counters. The work will cover all aspects of the device, including design, fabrication, characterization, and modelling of single and multiple pore devices.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in physics, ...

Responsible scientist(s):
For further information or for application please contact Wim Van Roy (Wim.vanroy@imec.be) and Chengxun Liu (Chengxun.Liu@imec.be).

V. Energy

Solving the Caldeira-Leggett model with balance equations

Treating the electron-phonon interaction as being bilinear in the electron and phonon coordinates, the Caldeira-Leggett model provides an exactly solvable model for studying both transport and power dissipation for electrons in a dissipative environment. On the other hand, a general set of quantum mechanical energy and momentum balance equations has been developed a decade ago to study the non-equilibrium features of an electron gas in the presence of various scattering mechanisms. The resulting kinetic equations heavily rely on a proper choice of the constraints as well as the calculation of the corresponding Lagrange multipliers, that determine the initial density matrix.

In this work the balance equations will be solved for the Caldeira-Leggett model and the solutions will be compared with those that have been obtained by solving directly the Heisenberg equations for the electron coordinates. In addition, the validity of the working hypothesis adopted to construct the initial density matrix will for the balance equations will be assessed. Finally, the potential of this approach to describe also the influence of high-energy photons, e.g. for the creation of electron-hole pairs, will be addressed.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in theoretical physics, statistical physics, quantum field theory

Responsible scientist(s):
For further information or for application please contact Wim Magnus (wim.magnus@imec.be) and Bart Soree (bart.soree@imec.be).

Cu electroplating of metal seed layers separated by laser ablation – development of metallization platform suitable for industrial interdigitated back-contact solar cells

Interdigitated back-contact (IBC) solar cell is a perfect candidate for high efficiency applications due to the rear metallization scheme and therefore maximum cell exposure for photon absorption. Since no metal contacts are present at the front of the cell, IBC cells in general have a high generated current density (J_{sc}). Apart from this obvious advantage, IBC cells also have advantages related to the integration in modules. The series interconnection between various cells can be done at module level, without the need for connecting the front of one cell to the rear of the next one, as is the case in two-side contacted cells. IBC solar cell efficiencies up to 23% have been shown on large area industrially produced cells.

However, such IBC architecture adds complexity to realize the rear metal contacts. In our laboratory we are currently developing an industrial feasible method patterning based on laser treatment to manufacture such cells. One of our options for metallization is based on laser ablation of a thin metal seed layer. Such thin seed metal layers will be further thickened by electroplating to realize sufficiently thick fingers and busbars, suitable for current conduction with minimum loss. Here we take into consideration either wet Cu electroplating or as an intermediate step electro less plating.

This internship will consist of:

- Learn the IBC integration scheme;
- Actively participate and perform experiments;
- Analyze the obtained results;
- Screen possible seed metal layers for laser ablation to get perfect isolation between electrodes;
- Check seed metal penetration into Si during laser ablation process;
- Investigate electroplating or electro less plating on such structures;
- Write a final report describing the work done and summarizes the main conclusions.

Type of project: internship for a period of 4 to 6 months

Degree: Master in Industrial Sciences or Master in Engineering majoring in material science, electrical engineering, applied physics

Responsible scientist(s):
For further information or for application please contact Bartek Pawlak (bartek.pawlak@imec.be) and Niels Posthuma (niels.posthuma@imec.be).

Optical modeling of interdigitated back contact (IBC) silicon solar cells for the optimization of the device structure

Silicon solar cells with interdigitated back contacts (IBC) have shown their excellence in the run towards the highest efficiencies within silicon PV. The results obtained by companies like Sunpower, with the manufacturing of silicon solar cells over 24% efficient in an industrial production line, represent a good example for the community.

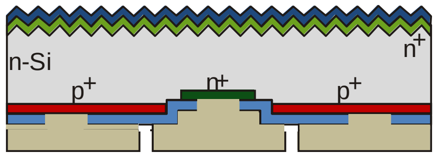


Figure 1 cross section view of an inter-digitated back contact solar cell

In order to optimize the design of our IBC silicon solar cells, imec is looking for people interested in the optical modeling of this type of devices. The final goal is to help us improve the definition of the cell structure by implementing the results of this work in a 2D simulation program already developed for this type of cell, calibrate the results with real devices and start improving the cell design. Therefore, within this project, reliable optical generation profiles corresponding to the different parts of the device should be developed. The work is enclosed in our program for the development of IBC cells and will be closely followed by both the simulation and technology teams.

We are looking for motivated and engaged people willing to work in a multicultural research environment. Knowledge in semiconductor physics is required, and some experience in optical modeling would be preferential.

Type of project: internship for a period of minimum 4 months

Degree: Master in Industrial Sciences or Master in Science majoring in material science, physics

Responsible scientist(s):
For further information or for application please contact Monica Aleman (monica.aleman@imec.be) and Niels Posthuma (niels.posthuma@imec.be).

Automation of organic solar cell processing

The organic photovoltaics group is constantly improving solar cells concerning efficiency, long term stability and future productions costs. One part of this work includes the testing of new materials and compounds delivered by our partners.
The goal of this project is to automate steps within the processing of solution processed organic solar cells. We plan to design and set up a robot that can handle liquid solutions and substrates with microliter volume accuracy and micrometer positioning precision at high speed. The applicant is expected to combine commercially available systems and self-designed parts for a final application. The project is finished by the implementation of the control software for the system.
We are looking for a self-motivated candidate who is interested in combining precision mechanics and programming for a final application. Since we are an international group proficient English language skills are sufficient.

Type of project: thesis or thesis with internship

Degree: Master in Industrial Sciences or Master in Engineering majoring in mechanical engineering, process technology

Responsible scientist(s):
For further information or for application please contact Robert Gehlhaar (robert.gehlhaar@imec.be).

Transparent conductive electrode for organic devices

In order to make ITO free opto-electronic organic devices (LED's and solar cells), there is need to produce as transparent as possible electrode with sufficient sheet conductivity. This can be realized maybe by using different oxides, combination of oxides with semitransparent metallic layers or combination of metallic grids with conductive polymers as PEDOT:PSS. This research focused on making those new types of electrodes and testing them in organic solar cells as a bench mark. Working in lab (practical work and applying a lot of experiments) is a must.

Type of project: thesis or thesis with internship (duration of the project can be one year)

Degree: Master in Industrial Sciences or Master in Science or Master in Engineering majoring in material science, physics, electronics

Responsible scientist(s):
For further information or for application please Afshin Hadipour (afshin.hadipour@imec.be).

Nanostructured anti-reflection coatings for organic solar cells

Organic solar cells offer the potential for low-cost, lightweight energy production, and efficiencies of organic-based solar cells have recently reached 8%. While significant effort has been focused on material and device architecture development, relatively little work has been made on improved light in-coupling strategies. Due to the index contrast between air and glass, reflection off this initial interface can be as much as 8%. As a consequence, less light enters the thin film device structure, and efficiency is reduced. In this topic, we propose to develop nanostructures that are able to effectively couple light into a thin film structure, and reduce reflection by at least a factor of two over the solar spectral region where organic solar cells are functional.

This thesis will involve cleanroom processes relevant to nanopatterning, as well as optical modeling and testing to valorize the antireflective nanostructures.

Type of project: thesis

Degree: Master in Science or Master in Engineering majoring in nanotechnology, physics, materials science, or electrical engineering

Responsible scientist(s):
For further information or for application please Barry Rand (barry.rand@imec.be).

Metallic interaction in non-oxidizing alkaline solution

During cleaning different chemical contaminants have to be removed, typically divided into particulate, metallic and organic contamination. Cleaning sequences are composed of dedicated steps aimed at removing at one or more of these contaminants and are e.g. oxidizing steps to remove organic contamination, acidic steps to remove metals and oxidizing alkaline steps to remove particles. Non-oxidizing alkaline solutions are being used for the anisotropic etching of Si where specifically due to this anisotropic etching characteristic it found applications in the field of Micro-Electro-Mechanical Systems (MEMS). Also in solar cell fabrication this anisotropic etching is used for the formation of random pyramids. In the field of semiconductor devices non-oxidizing alkaline solutions found application for e.g. replacement gate integration schemes.

Metallic contamination has a detrimental effect on the lifetime of minority carriers in a semiconductor material and can act as a recombination center. The impact of metallic contamination on the performance of semiconductor devices has then also been studied, leading to the conclusion that only very low levels of metal contamination are allowed. The interaction of metallic contamination with the Si surface has been extensively studied in the acidic and oxidizing alkaline environment, but is much less understood in non-oxidizing alkaline solutions.

The goal of this research project is to better understand the interaction of metallic contamination in non-oxidizing alkaline solutions and to study the impact of metallic species, pH, light exposure and the addition of chelating agent. The results will help establishing a specification for non-oxidizing alkaline solutions. The student will use Total reflection X-Ray Fluorescence (TXRF) or Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) to determine metallic contamination. This will be combined with Vapor-Phase-Decomposition Droplet-Collection (VPD-DC) to improve the detection limit for metallic contamination. A more detailed background of the project can be obtained by email.

Type of project: thesis or internship or thesis with internship

Degree: Master in Industrial Sciences or Master in Science majoring in (physico)chemistry

Responsible scientist(s):
For further information or for application please contact Kurt Wostyn (kurt.wostyn@imec.be).

Characterisation and simulation of advanced emitters in Si solar cells

To achieve advanced doping profiles in solar cells different techniques are studied. With an industrial supplier, geared towards the high throughput needed in the photovoltaic (PV) industry, the interest in ion implantation revives after years of silence. Looking a bit deeper into the details of the implantation process, the ion beam induced defects deserve attention here as they can have a strong impact on the final junction and device performance. After ion implantation of dopants a thermal step is needed to activate and diffuse the dopants and to remove the ion beam induced damage.

The purpouse of this work is to start building some insight in the junction formation process and its prediction. The prime focus would be to initiate a simulation activity (using Tsuprem or sprocess) targeting an accurate description of the dopant profiles, their electrical activation and the defects remaining after anneal. For that purpose the several characterization techniques will be used before and after activation anneal. The work proposed contains the following aspects :

- Analysis of SIMS profiles which provide dopant profiles as a function of the formation parameters (implant dose, energy, anneal cylce,...). SIMS profiles will be obtained through imec's MCA service system.
- Generation of a simulation script using well established technology simulation programs (Tsuprem, sprocess) leading to an accurate prediction of the implanted and indiffused dopant profiles i.e close agreement with SIMS profiles.
- Assessment of the electrical activation of these dopant profiles by measuring the sheet resistance using the Micro 4 point probe.
- Eventually exploration of Thermaprobe to extract, sheet resistance map, defect density and junction depth.
- Assessment of defect density and its impact on lifetime through Quasi Steady State Photoconductance - lifetime measurements.

The project provides a broad exposure to semiconductor technology, more specifically solar cell fabrication, through the assessment of the experimental matrix, insight in basic technological steps (implant, diffusion) through their modeling and create experience with experimental methodologies (M4PP, QPCD, Thermaprobe).

Type of project: thesis or internship

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering

Responsible scientist(s):
For further information or for application please contact Wilfried Vandervorst (wilfried.vandervorst@imec.be).

Characterization of the local back surface field (BSF) in solarcell structures by scanning spreading resistance microscopy (SSRM)

Scanning spreading resistance microscopy (SSRM) is a technique based on atomic force microscopy (AFM) which measures the two-dimensional carrier distribution inside semiconductor device structures with nanometer spatial resolution. This is done by scanning with a sharp conductive tip over the sample surface while measuring the local spreading resistance which is directly linked to the local carrier concentration. SSRM is today the leading technique for 2D carrier profiling of state-of-the-art nanoelectronics devices such as MOSFETs, bipolar transistors, FinFETs, and TFETs. Recently, the use of SSRM has also been explored for characterizing solarcell structures which have different requirements compared to transistor structures (e.g. multi-crystalline instead of mono-crystalline substrates, larger dimensions of the contact area, rough sample surfaces, different materials, etc.). First results for measuring the carrier profiles on the front- and backside of solarcell structures demonstrate the high potential of SSRM also in this domain.

This topic is focused on studying the formation of local contacts on the backside of the solarcell by SSRM. In this concept, the backside of the solarcell is passivated by a dielectric layer and only locally a contact is created by first opening the dielectric layer by laser scribing, depositing an Al layer onto the backside and then performing an Al-Si alloying step which creates locally a so-called back surface field (BSF). It is a highly doped Al layer which induces an electrical field shielding minority carriers from recombining at the local contact. As a result, the solar efficiency is increased. As this increase in efficiency is directly linked to the doping level and the thickness of the BSF, the understanding and optimization of this local Al BSF is very important. It requires a systematic study on the extent of the Al-indiffusion with regard to depth, conformality of the BSF region, presence of nucleation islands, deviation from <111> directions, role of Al thickness, window size and must be linked to the thermodynamics of Si-nucleation and Al diffusion.

The student will work on the following tasks:

- Gain some theoretical understanding of important process parameters (temperature ramp, thickness, etc.).
- Select relevant samples from a set of samples (design of experiments).
- Perform SSRM to extract indiffusion parameters.
- Translate the results into a parametric description.

For carrying out this work, the student will be trained in working with an atomic force microscopy (AFM) system with a focus on SSRM. He/she will also be trained in using cleaving and polishing tools for sample preparation.

Type of project: thesis or internship

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, material science, chemistry

Responsible scientist(s):
For further information or for application please contact Thomas Hantschel (thomas.hantschel@imec.be) and Pierre Eyben (pierre.eyben@imec.be).

Organic solar-cell material characterization by TOF-SIMS

A significant fraction of the cost of solar panels comes from the photoactive materials and sophisticated, energy intensive processing technologies. Recently, it has been shown that inorganic components can be replaced by semiconducting polymers capable of achieving reasonably high power conversion efficiencies. These polymers are inexpensive to synthesize and can be solution processed in roll-to-roll fashion with high-throughput. There is however still a large number of challenges to be overcome to improve the technology that imply sophisticated material analysis techniques.

TOF-SIMS has long been applied to organic material but has often been limited by its difficult interpretation and by the loss of information during sputter profiling. Recent technological development (C60 sputtering, Cluster ion source, …) and theoretical ones (combination of several spectra from the same surface with different analysis source, known as G-SIMS) have open the possibilities for the characterization of polymer material.

The objective of this work is to investigate the possibilities of TOF-SIMS analysis through this new development for materials related to organic solar cells such as P3HT, PCBM, PEDOT, PSS, CuPc, C60. This project will be mostly devoted to the profiling of these materials in multi layers or in blend. It has been shown that the optimal sputter condition in order to preserve organic information may differ from material to material, but little is understood of the origin of these differences. This will thus not only be devoted to finding optimal conditions, but also to understand (predict) which conditions should be used for an arbitrary material. The most recent innovation in TOFSIMS profiling of organic materials is the introduction of large gas-clusters as sputter source. This thesis will be performed on one of the first commercial source installed in the world on a TOFSIMS instrument.

At the end of this thesis, it is expected on one side that conclusion will be drawn on the usability of TOFSIMS as a valuable analysis technique and on the other side to improve the understanding of physico-chemical effects happening during sputtering in order to narrow down the profiling options of polymers.

Type of project: thesis for a period of minimum 6 months full-time

Degree: Master in Science or Master in Engineering majoring in physics, chemistry, material science

Responsible scientist(s):

For further information or for application please contact Thierry Conard (thierry.conard@imec.be).

Degradation mechanisms in organic solar cells

Organic photovoltaic devices are one of the most promising applications of organic semiconductors. As organic semiconductors can be manufactured by low temperature processes, such as printing from solution based inks, these materials are compatible with flexible plastic substrates resulting in a lightweight, inexpensive and very practical product. Over the last years impressive progress has been achieved in organic photovoltaic device efficiency and promising roll-to-roll compatible deposition techniques have been also reported. This rapid technological development brings applications close-by, and consequently also the importance of device reliability. Cost evaluations suggest that a lifetime of 5-10 years is necessary with current power conversion efficiencies to achieve low prices. Nevertheless, currently only 1 year of outdoor lifetime was reported on polymer solar cells, other studies in accelerated conditions estimated the device lifetime to 2-3 years.

Currently, polymer solar cells are comprised of a multilayer stack of a transparent anode, a polymeric interlayer, a photoactive bulk heterojunction composed of polymer and fullerene capped with an evaporated cathode. Reaction with oxygen and humidity as well as light induces degradation both in the volume and at the interfaces of these layers leading to multiple concurrent degradation mechanisms. Therefore discriminating between the parallel mechanisms is one of the biggest challenges in reliability research. The focus of this master thesis lies in the investigation of the degradation of charge transport and charge extraction in polymer based organic solar cells. Implementation of new device architectures, advanced electrical measurements will assist the distinction between the simultaneously occurring degradation mechanisms.

Most of the work will be done in the state-of-the-art organic device processing lab of imec. The student will receive a broad training on full device processing (spin-coating, metal evaporation) and characterization tools. After a short training period it is expected that the student can work independently and focusing on his/her investigation.

Type of project: thesis or internship for a period of minimum 6 months

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, material science, chemistry

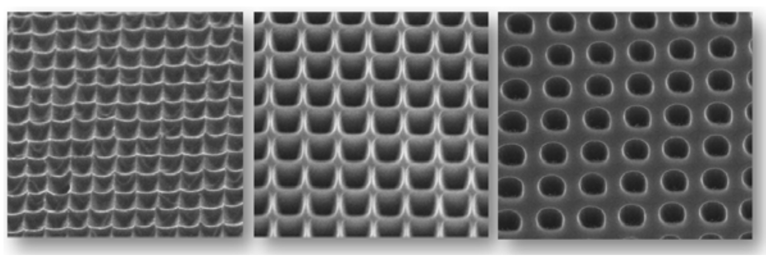
Responsible scientist(s):
For further information or for application please contact Eszter Voroshazi (Eszter.Voroshazi@imec.be).

Photonic nanostructures for efficiency enhancement of ultrathin solar cells

One of the main levers to decrease the cost of silicon photovoltaic cells is to decrease the amount of silicon consumed. However, the thinner the material, the lower its light absorption, particularly at long wavelengths (near infrared), and therefore the lower the cell efficiency. The development of cheaper, thinner solar cells thus requires developing light scattering and light trapping techniques to compensate for these losses.

Amongst all the techniques explored, this proposal focuses on nanopatterning: thanks to the progress of photonics, we are now able to pattern a material in such a way that its optical properties are strongly modified. We can yield increased reflection (and control its directionality) control transmission, and therefore absorption. These techniques have mostly been used so far for specific applications like lasers, and are only starting to be applied to solar cells; there is therefore a need for a simultaneous effort in design, simulation and fabrication. For the latter, nanoimprint lithography is a very promising method for it enables high-resolution with high-throughputs and low-cost. And, just like photonics, it is only starting to be used for solar cells.

In this frame you will participate to the modelling and experimental fabrication of solar cells incorporating light-management features, and to their characterisation. You will learn various simulation tools, and try to integrate light-management effects in the overall simulation of a photovoltaic cell. In parallel, you will participate to the fabrication of thin (industrial) and ultrathin (long-term research) solar cells. You will in particular develop the nanoimprint lithography process and the following plasma-etch step in order to gain control on the patterns. Finally, you will perform optical characterisation of the yielded light trapping, and optical and electrical characterisation of the resulting solar cells. The balance between these three components will be up to your preferences and skills.



Type of project: thesis or internship

Type of work: experimental and simulations

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, material science, chemistry

Responsible scientist(s):
For further information or for application please contact Valerie Depauw (Valerie.Depauw@imec.be) and Ounsi El Daif (Ounsi.Eldaif@imec.be).

Metallic nanoparticles for the efficiency enhancement of thin solar cells

Context

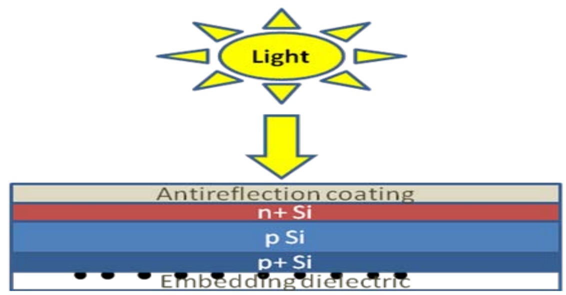
Metallic nanoparticles can have peculiar reflection and ransmission properties, thanks to the plasmon effect. Plasmons are coupled light-matter modes that occur at a metal-dielectric interface. The use of these effects may be beneficial for Silicon solar cells based on very thin layer, as the latter have low absorption efficiency due to the low absorption coefficient of Silicon at high wavelengths. Silicon is at the basis of 90% of commercialised solar cells. However, its fabrication has an important energetic and economical cost. This is why research is presently looking for ways to have solar cell structure based on thinner Silicon layer. But in order to keep the light absorption high, it is necessary to find light scattering and trapping techniques inside the absorbing silicon layer.

Imec frame

Forming nanoparticles at the rear of a solar cell may be an efficient way for the achievement of this aim. IMEC has a unique possibility to perform efficiently such structures, as it combines a knowledge in the fabrication and characterisation of metallic nanoparticles (thanks to a team devoted to plasmonic studies) and fabrication of ultrathin film solar cells thanks to the Thin Film Solar Cell team of the Photovoltaic department.

Internship description

It is proposed to participate to the numerical modelling and experimental fabrication of plasmon assisted solar cells, and to their characterisation. You will learn various optical and photoelectrical simulation tools, and integrate plasmonic effects in the overall simulation of a photovoltaic cell. You will in parallel, follow the fabrication process of solar cells. You will perform optical characterisation of the nanoparticles, and optical and electrical characterisation of the resulting solar cell. The interpretations of the results will be done in close collaboration with both plasmonics and thin film solar cells teams.



Type of project: thesis or internship

Type of work: experimental and simulations

Degree: Master in Science or Master in Engineering majoring in physics, electrical engineering, material science, chemistry

Responsible scientist(s):

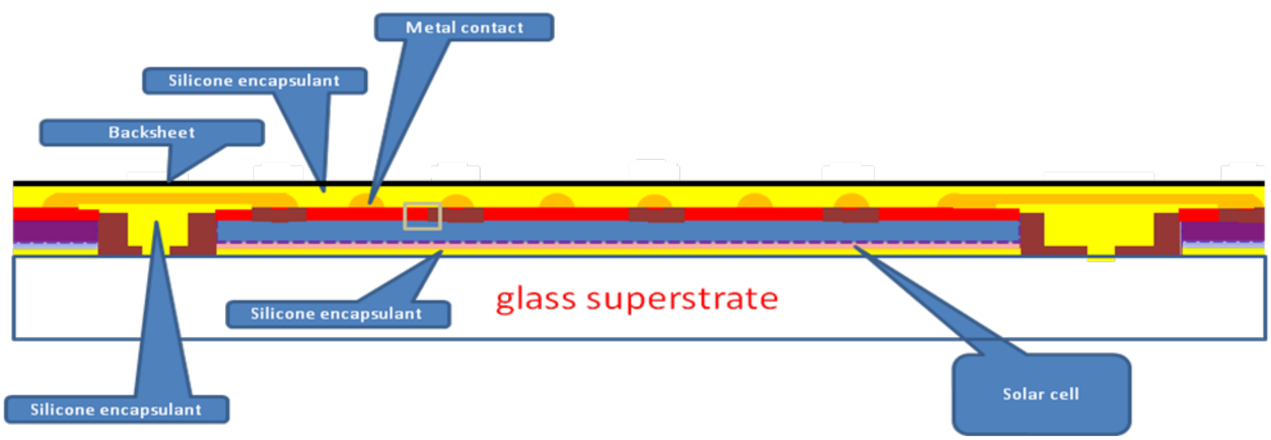
For further information or for application please contact Ounsi El Daif (Ounsi.Eldaif@imec.be).

Light management modelling in novel thin silicon solar cells and modules

Context: Silicon based solar photovoltaic cells represent more than 90% of the photovoltaic panels presently sold in the world; silicon is one of the most abundant materials on earth. In such cells, more than 1/3 of the cost is due to the silicon itself. Indeed, its purification and crystallisation have an important energetic and economical cost. This is why the Photovoltaic research community is presently looking for ways to have solar cell structure based on thinner and thinner Silicon layer. There are nevertheless limitations, existing for thick cells and becoming crucial for thin cells: the thinner the material, the lower its light absorption, in particular at long wavelengths (near infrared), due to the low absorption of Silicon. Thus, in order to keep the light absorption high, it is necessary to find light scattering and trapping techniques inside the absorbing silicon layer.

Imec frame: Imec is developing novel approaches to decrease the cost of silicon solar cells, including going to thinner silicon layers (as thin as 40 um). For such thin cells, the regular light scattering approach used for today's 180 um cells (texturisation of the Silicon surface) will not be sufficiently effective anymore. Further, our approach requires that most ofthe solar cell processing will take place directly on the module (or the solar panel). This implies the use of a-Si:H (rather than c-Si) doped layers with specific metallisation schemes. Therefore, in order to optimise the efficiency of such structures, some theoretical optical studies should be made for several reasons: understanding the optical losses of such structures (power loss analysis), exploring schemes to enhance the light trapping in order to enhance absorption, while keeping good electrical properties. For this imec Photovoltaics group is exploring several ways of increasing the light trapping in the relevant layers of the solar stack. For these cells, promising approaches are (1) nanopatterned diffractive structures : thanks to the progress of photonics, we are now able to pattern in an economical way a material in such a way that its optical properties are strongly modified and light can be reflected almost parallel to the surface (2) Dielectric Bragg reflector that increase the reflection to almost 100 % in the near-IR (3) Metallic or dielectric nanoparticles to scatter light into the layers.

Internship description: In this frame, it is proposed to interns (between 3rd and 5th University or Engineering year or equivalent) to participate to the numerical modelling solar cells with and without light-management features. The students will learn various optical and photoelectrical simulation tools, and try to integrate light- management effects in the overall simulation of a photovoltaic cell.



Type of work: (experimental, theoretical, simulations): simulations

Type of project: internship

Degree: Master in Engineering

Responsible scientist(s):
For further information or for application please contact Ounsi El Daif (eldaif@imec.be).

Formation of local doping structures in crystalline silicon solar cells by silicon epitaxy

Introduction: The most widely used doping technology in bulk crystalline silicon solar cells is diffusion. Other doping technologies with application in photovoltaics are ion implantation, a-Si:H PECVD deposition and Al-alloy formation. At imec, the use of silicon epitaxy (by chemical vapor deposition in the temperature range of 850-950 C) is also under investigation as an alternative technology. Silicon epitaxy overcomes some major challenges of the previous technologies because of specific advantages to the technology:

- Versatile decoupled doped area design regarding thickness and doping in a one-step process:
  - Thickness from nm to µm range.
  - Doping from 10^{16} to 10^{20} at/cm^3 range (limited by solid solubility).
- No introduction of crystal damage in the doping process.
- No additional steps after the doping process to remove any glassy layer or activate dopants.
- Simplified integration of the local formation of doped regions and, thus, reduction of the number of steps required in the process flow of approaches such as the interdigitated back contacts (IBC) solar cells.

In the R&D activities on silicon epitaxy for photovoltaics, the process used as reference for benchmarking is the corresponding to the n-type IBC cells (see **Figure 1**).

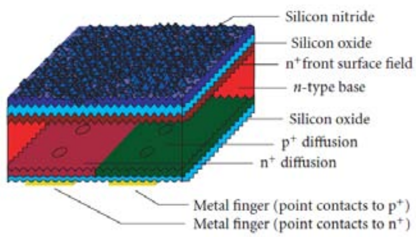


Figure 1. Schematic drawing of an IBC solar cell of SunPower. SunPower holds (June 2011) the worldwide record for commercially-available PV modules with confirmed module efficiencies of 20.7 %. Each module comprises 96 IBC cells with an average solar cell efficiency of 22.4 %.

Why n-type substrates?
The relative tolerance of n-type silicon to common impurities such as iron, results in potentially higher minority carrier diffusion lengths compared to p-type crystalline silicon substrates. Furthermore, n-type silicon does not suffer from the boron-oxygen related light-induced degradation known for p-type crystalline silicon.
Why an IBC structure?
IBC has a collecting junction only on the solar cell rear surface whereas the front surface is well passivated. As a result of this design, this back contact solar cell holds three major advantages:

- Lack of grid shading loss: front contacted cells can have up to 10 % shading loss when using screen printed metal grids.
- The tradeoff between series resistance and grid shading is not present in the IBC design: the IBC cell has the advantage of allowing the rear junction to be optimized for electrical performance, namely a low J_0 junction, while the front surface can be optimized for optical performance.
- Coplanar interconnection: a front contact cell must also use solder connections which run from the front of one cell to the back of the next for series interconnection. This procedure is more difficult to automate than for the case of co-planar contacts.

Research work description:

Goal
Development of a selective epitaxial growth (SEG) process applied to the formation of the local doped structure comprising the collecting pn junction in n-type IBC cells.

Vision

The development coming from this investigation will allow the simplification of the IBC solar cell process flow and, therefore, the reduction of the final cost of these devices. Moreover, the versatility in the design of doped layers by epitaxy, as well as their high crystalline quality opens new opportunities in the solar cell design as well as increase the potential for improved performance.

Proposal

The basic work description will comprise:

- Dielectrics (SiO_x, SiN_x, AlO_x) patterning by photolithography (*after training*).
- Selective epitaxial growth (SEG) evaluation and optimization on different dielectrics (*with supervisor*).
- Characterization of the process selectivity (microscope, SEM…) as well as the quality of the epitaxial layer (R_{sheet}, SIMS, SRP) in order to get a process compatible with the solar cell requirements (*after training*).

This investigation will be performed within the Solar Cells research team of imec and the potential candidate should be a highly motivated person, a hands-on like person with interest in experimental activities and a person with initiative.

Type of project: thesis or internship

Degree: Master in Science or Master in Engineering majoring in physics, material science, chemical engineering or electrical engineering

Responsible scientist(s): For further information or for application please contact Maria Recaman Payo (maria.recamanpayo@imec.be).

Formation of porous silicon layers for thin film silicon solar cells

Research work description

Porous silicon layers are used as optical functional layers in advanced thin film silicon solar cells. Electrochemical etching (anodisation) is a cheap and reproducible way of creating such porous silicon layers into highly doped silicon substrates. The etching process takes place in a liquid containing water, HF and an alcohol (surfactant).
The layer porosity, a crucial property of the porous Si layer, is determined by processing parameters like the anodisation current density and the HF-concentration.

Typically, the composition of the etching liquid in our labscale processing tool is about 1:1:1 volume ratio of water:HF:alcohol. However, in order to make the porosification process industrially compatible, the concentrations of both the HF and the alcohol must be drastically reduced, keeping the resulting porosity constant.

The goal of the internship is two-fold:

- Investigate the porosity-type and porosity of the porous silicon layers etched at low concentrations of HF and alcohol.
- Assess a number of surfactant replacements for the alcohol currently used.

The work will be performed in a clean-room environment on a small lab-scale etch tool. Cross-section SEM will be used as most important analytical technique to assess the resulting porous Si layers.
This investigation will be performed within the Solar Cells research team of imec and the potential candidate should be a highly motivated person, a hands-on like person with interest in experimental activities and a person with initiative.

Type of project: thesis or internship

Degree: Master in Science or Master in Engineering majoring in physics, chemistry, material science, chemical engineering or electrical engineering

Responsible scientist(s): For further information or for application please contact Jan Van Hoeymissen (jan.vanhoeymissen@imec.be).

Life-time measurements and modeling of organic photovoltaic solar modules

Organic photovoltaic solar cells provide a very cheap and attractive solution for future clean energy provision on remote sites. Today's cells and materials provide a reasonable efficiency but due to various degradation mechanisms (induced by the exposure to air, water, heat) they rapidly fail.
Insight into these steady-state mechanisms has been developed and is also part of an ongoing research at imec.
Contrary to laboratory ageing in real-life context, especially outside, weather conditions are constantly evolving (clouds, shadow, light, heat etc.).
This does not only lead to fluctuation in power conversion efficiency but also has considerable influence on device degradation. These rapid changes may even aggravate device failure, but for the moment they are not well studied.
However, theoretical models suggest that device degradation could be effectively mitigated by dynamically adjusting device operation in correlation with the changes of the environment. For example, in case of partial shadowing of the solar cell, it may be beneficial to suspend device operation momentarily. Otherwise even short-term overheating accelerates device failure and considerably reduces device lifetime on the long-term. Such a smart control can be realized at a minimal hardware cost but could substantially improve device lifetime i.e. considerably reduce its final device cost. Hence this works bears the promise of important practical implications.

This thesis is comprised of both a practical and a theoretical part.
The practical part involves adaption of an existing device lifetime measurement system to record dynamic changes of device performance and environmental conditions. For this work a basic knowledge of especially electrical measurement and partly also semiconductor device physics is required. Knowledge of Labview is a plus. As a result of this work the student will record the dynamic electrical response of the solar cells and could later verify the impact of the simulator.
The theoretical part of the work comprises the investigation of the impact of various dynamic parameters and means to mitigate them by controlling and interacting with the devices. This part of the work will be only worked out at the initial stage (continued in follow-up activities).
It will most likely be performed at Matlab level so some knowledge of Matlab or other script languages is desirable.
Combination of the two parts will demonstrate the future potential of smart PV controllers.
In this first thesis, we plan to mainly focus on the practical part. The theoretical part will be further elaborated especially in follow-up work.

Type of project: thesis for minimum 6 months (full-time at Leuven)

Responsible scientist(s): For further information or for application please contact Eszter Voroshazi (Eszter Voroshazi@imec.be), Prof. Jan Genoe (Jan.Genoe@imec.be), Prof. Francky Catthoor (Francky.Catthoor@imec.be).

Vapor phase deposition of organic semiconductors for heterojunction solar cells

Organic electronics offer interesting perspectives for applications requiring large-area coating of flexible substrates, such as rollable displays, electronic paper, RFID tags and organic solar cells. The active layers of these devices consist of semiconducting polymers or small molecules: relatively inexpensive materials that can be processed at low temperatures and with low-cost deposition techniques.

Organic vapor phase deposition (OVPD) is a relatively new deposition technique that combines the scalability of printing techniques with the high purity and good morphology control typical for vacuum sublimation processes. In OVPD, the organic small molecules are thermally evaporated and then transported by an inert carrier gas in a hot-wall reactor towards a cooled substrate where condensation occurs. The use of a carrier gas enables high deposition rates, and provides additional morphology control.

Therefore, OVPD allows the formation of a controlled heterojunction between a p- and n-type semiconductor, which is key to further enhancement of the performance of organic solar cells. Light absorption in an organic photovoltaic cell does not lead to the creation of free charge carriers, but results in the formation of a bound electron-hole pair, an exciton. These excitons can only dissociate at the interface between donor (p-type) and acceptor (n-type) material, and their diffusion length is limited to 5-10 nm. To combine a high light absorption with a sufficient amount of resulting free charge carriers, a donor-acceptor interface with features matching the size of the exciton diffusion length is required. In order to optimize a mixed donor-acceptor structure, a detailed study of the relation between OVPD process parameters and the resulting thin film morphologies is essential.

In this thesis, the aim is to investigate the influence of OVPD deposition parameters on the growth of mixed layers of a promising donor-acceptor pair, namely chloro-aluminum phthalocyanine and fullerene, for the development of a controlled bulk heterojunction solar cell with optimized performance.

This project requires the daily use as well as maintenance and development of the OVPD tool, clean room work, device fabrication and characterization, mainly by optical and electrical measurements. Therefore, we are looking for a candidate with a background in materials science or electrical engineering who is passionate about experimental research and has a highly practical, problem solving attitude.

Type of project: internship (1 Feb 2012 – 31 May 2012)

Degree: Master in Engineering majoring in Materials science, Electrical Engineering, Nantechnology

Responsible scientist(s): For further information or for application please contact Karolien Vasseur (karolien.vasseur@imec.be).

2D modeling and simulation of heterojunction a-Si :H /c-Si interdigitated back-contact solar cells

Amorphous/crystalline heterojunctions including an intrinsic thin layer (HIT) are a high-potential technology for next generation silicon solar cells. At the same time, an interdigitated back-contact structure appears the main tendency of the different silicon roadmaps (e.g. ITRPV), and it has already shown efficiencies up to 24%. Therefore, coupling these two concepts may represent a winning choice in the future of solar energy.
However, the behavior of the amorphous silicon embedded in an interdigitated structure is not yet fully understood, especially in relationship with 2D phenomena.
Numerical simulation is a powerful tool in order to achieve this objective and shape the directions of the experimental research. Therefore, IMEC is currently looking for well-motivated people to develop a 2D model of an HIT i-BC solar cell, and perform electrical simulation toward an optimization of the geometry of the cell.
In this internship, targets are:

- Integration of the a-Si:H into Sentaurus Database;
- Development of a 2D HIT i-BC model for electrical simulation with Sentaurus Database;
- Simulation of the optimized structure.

Starting point of this work is the previous-built IMEC background on i-BC homojunction simulations and on characterization and modeling of a-Si:H.

The perfect candidate will have:

- background on numerical simulation and source coding;
- competences in semiconductor physics and electronics;
- motivation to work in a highly-stimulating, international environment;

Knowledge in Photovoltaic and previous experiences with Sentaurus Device will be considered a plus.

Type of project: thesis or internship of ≥ 4 months starting from the beginning of 2012.

Degree: Master in Science or Engineering, majoring in Computer Science, Physics, Electronics, Nanotechnology

Responsible scientist(s):
For further information, please contact Stefano Granata (stefano.granata@imec.be) or Koen Van Wichelen (koen.vanwichelen@imec.be).

VI. INVOMEC

Design-for-X modellering voor elektronische modules

Onder Design-for-X worden alle ontwerpaspecten van een elektronisch product verstaan die buiten het zuiver elektrische ontwerp vallen. Hieronder vallen zaken zoals de maakbaarheid van het product (DfManufacturing), de bedrijfszekerheid (DfReliability), de testbaarheid (DfTest), enz. Sinds de invoering van de Restriction on Hazardous Substances (RoHS) richtlijn (1/7/2006) heeft DfX voor elektronica sterk aan belang gewonnen. De RoHS richtlijn verbiedt immers het gebruik van het traditionele SnPb soldeer. De nieuwe loodvrije soldeermaterialen hebben echter een hoger smeltpunt en andere mechanische eigenschappen. Hierdoor is het assembleren van elektronica veel kritischer geworden en wordt de bedrijfszekerheid van elektronica ernstig bedreigd indien geen aangepaste DfX maatregelen worden getroffen.

Het eindwerk kadert binnen de onderzoeksactiviteiten van het EDM programma van imec dat zich richt op het uitwerken van ontwerp- en kwalificatierichtlijnen voor Printed Board Assemblies (PBA) voor de Vlaamse elektronica-industrie en elektronica-implementatoren.

Een belangrijke uitdaging van het onderzoeksproject is het kwantificeren van verschillende ontwerpopties ook indien het gaat om op het eerste zicht moeilijk kwantificeerbare grootheden zoals kwaliteit en bedrijfszekerheid. De richtlijnen worden daarom ondersteunt door een aantal kwantificatiehulpmiddelen onder de vorm van rekenbladen die gebaseerd zijn op modellen van de elektronische module, de productieomgeving, de falingsmechanismen, de testmethoden, enz. Het eindwerk richt zich op het uitwerken van de rekenbladen (Excel) en het evalueren van de gehanteerde modellen en methodiek. Hierbij komen volgende aspecten aan bod: Printed Circuit Board (PCB) en PBA technologie en productiemethoden, falingsfysica en –statistiek, kostberekening, logistiek van de elektronische toeleveringsketen, enz. De studenten zullen een grondig inzicht verwerven in de niet-elektrische aspecten van de elektronische productontwikkeling. Dit is van toenemend belang in de elektronicasector maar ook daarbuiten omwille van de steeds verder doordringen van elektronica in traditioneel niet-elektronische toepassingen zoals machinebouw, automobiel, bouwsector, textiel, enz.

Type of project: eindwerk

Degree: Industrieel Ingenieur

Responsible scientist(s): Voor meer informatie of om te solliciteren, contacteer Geert Willems (Geert.Willems@imec.be).

VII. NERF

Optimization surface enhanced raman spectroscopy for brain imaging

The main objective of Yaksi lab at NERF is to understand the fundamental principles underlying the function and development of neural circuits in a small genetically tractable model organism, zebrafish. In order to monitor, dissect and perturb the neural circuits of the adult and larval zebrafish brain, we use: two-photon and widefield microscopy, optogenetics, electrophysiological recordings, molecular genetics and behavioral assays. Ultimately, these experiments will help us to understand the fundamental principles of sensory information processing in the brains of vertebrates, including humans.

Currently the field of sensory neuroscience is lacking methods to monitor the release of neuro-modulators in the brain. Unlike conventional neurotransmitters such as glutamate (excitatory) and GABA (inhibitory), we know very little about the release and effects of neuromodulators (e.g. dopamine, serotonin, Oxytocin). These neuromodulators control important behaviors and involved in reward system of our brain, child care, attraction etc. The lack of current understanding in these systems is mainly due to the absence of methods for monitoring the release of neuromodulators in the brain in vivo with high spatial and temporal resolution.

Surface enhanced RAMAN spectroscopy combined with gold particles (developed at imec in the group of Drof Lisebet Lagae) shown to be effective in detecting different types of biological substances in their surroundings. The proposed project aims to optimize these tools to detect release of neuromodulators in living zebrafish brains. Zebrafish larvae are completely transparent which allow us to use all kinds of optical techniques (e.g. spectroscopy and microscopy) to monitor and manipulate biochemistry of brain. Moreover due to its small size and aquatic life, large libraries of chemicals can easily be delivered to zebrafish, just by soaking them. Finally, materials with various particle sizes and shapes can be delivered inside the embryos merely by injection the chemicals to the animals at one cell stage of development, since zebrafish develop completely outside mother's body. Once these tools are optimized in this small genetically tractable model organism (zebrafish) we will also modify some of these applications to be used in mammals, by combining imec technologies with NERFs expertise.

The proposed project will be a joint effort from two groups at imec and NERF. The master students will work with the Laboratory of Prof. Lisebet Lagae (imec) for the production of the nanoparticles and he/she will work with the laboratory of Dr. Emre Yaksi (NERF) to optimize the delivery and use of these particles for detecting neuromodulators in the zebrafish brain.

Type of project: thesis

Type of work: experimental, simulations

Degree: Master in Nanosciences or Master in Nanotechnology majoring in bioengineering, physics, chemistry

Responsible scientist(s):
For further information or for application please contact Liesbet Lagae (Liesbet.Lagae@imec.be).

WWW.IMEC.BE

ASPIRE INVENT ACHIEVE