2016 has been another intense year at LPICM, with 6 new PhD students joining the lab, 25 interns, and new projects. In particular, the launching of a first world class in-situ TEM (NanoMax) and of a new platform for reliability tests on nanosensors (Platine).

The research activities in NanoSil, NanoMaDe, OLAE and AOP have kept innovation at high level with about 100 publications, 6 patents, and a book on polarimetry. Many new projects have been launched, in particular PERSIL on tandem silicon/perovskite solar cells involving NanoSil and OLAE teams.

The perspectives are bright in plasma processes thanks to tailored voltage waveforms, ab initio molecular dynamics applied to silicon clusters and 2D materials, hybrid carbon nanotubes and silicon nanoparticles for Li-ion batteries, functionalized carbon nanotubes for sensors, the rise of perovskites for solar cells with a new IPVF funded project, and last but not least, the first in-vivo cancer diagnostics based on Mueller matrix polarimetry. Moreover, collaborations have expanded, in particular with the opening of an international laboratory in collaboration with NAIST.

All this would not be possible without the constant support from our support teams. BEER, G2I and Administration are the pillars on which the research can relay and expand. Thank you for your constant support.

But let’s move to the report and enjoy a brief summary of the exciting research going on at LPICM.

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NANOSIL

Plasma Processes
& Nanostructured Materials
for Photovoltaics &
Optoelectronics
Introduction

The heart of the research activity of the NanoSil group continues to be plasma processes and nanostructured materials for large-area optoelectronics, particularly for photovoltaics. With this core expertise, we perform research going from fundamental plasma studies, to processing onto materials and devices, and through to characterization.

This year saw the end of two projects (ANR Projects Nathisol and CleanGraph), the start of two more (PERSIL and MOMENTOM) while other projects continued to progress and produce good scientific results (ANR Projects APOCALYPSO, Platofil, Solarium, INDEED and IMPETUS).

Our most important industrial partner in our work continues to be Total, with whom we work in PVSiXT, our joint PV research team. As well, intensive collaborative work continues in the Ile-de-France Photovoltaics Institute (IPVF). In addition to these partners, our important industrial collaborators in 2016 included EDF, Air Liquide, SOLAYL, SOLEMS, and many international collaborations.

From all the great work that went on this year, here are a few highlights!

Erik Johnson, Group Director of NanoSil

Electrode Selective Deposition

Ph.D. student Junkang WANG (CSC) demonstrated the first useful application of plasma excitation using Sawtooth Voltage Waveforms: a selective deposition process. The asymmetric waveform preferentially excites the plasma near one electrode, and results in a deposition on one electrode, whilst the other remains pristine. One can also perform an etching process on one electrode, without touching the other. This discovery raises the possibility of cleaning-free reactors.


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Modeling of Overcoordinated Silicon Nanoclusters

Over-coordinated nanoclusters form spontaneously by self-assembly and are considerably more stable than their tetrahedral counterparts because of electron delocalization. Electron Localization Functions (ELF) are displayed to compare to several metal clusters. In all cases, only a few adjacent cluster atoms are bonded by strongly localized electrons (dark red color), while most atoms share delocalized electrons comparable to a homogeneous electron-gas (green-blue colors).

Observation of the metastable hexagonal phase of silicon in nanowires

The diamond-hexagonal (dh) structure does not appear in the phase diagram of silicon. However, calculations show that dh Si nanowires (NWs) would have a direct band gap, and correlatively higher optical absorption and luminescence yields than standard SiNWs. We have demonstrated that Si NWs having the dh phase can be produced by the vapour-liquid-solid method in a PECVD reactor: TEM characterizations using the [1-210] zone axis show that the structure of several NWs is essentially dh. This is the first unambiguous proof of the natural occurrence of this metastable phase to our knowledge.
Combining nanowire and heterojunction technology

Silicon heterojunction technology represents an important branch of high efficiency crystalline silicon solar cell research. We have taken advantages of this technology and applied it to silicon nanowire (NW) arrays providing strong light trapping. Our core-shell devices based on metal assisted chemical etching of Si wafers have pushed forward the efficiency of such Si NW based devices to 12.9 % (device and its performance shown in the figure), beyond the previously reported values.


keV Ion Bombardment and c-Si Passivation

Counterintuitively, damaging the amorphous passivation layers of heterojunction solar cells allows to make them better and more robust. A. Defresne showed that while the p-type a-Si:H passivation layer used in HIT structures does not withstand the temperatures above 200 °C, necessary to anneal the TCO layers and metal contacts, irradiation by an argon ion beam allows one to anneal a solar cell precursor up to 400°C while maintaining a lifetime above 1 ms. For pi/n/in samples irradiated at 10 keV, one can obtain higher lifetimes aor irradiation and annealing than in the asdeposited state.

AIP Advances 6 (2016) 125107

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Organic and Large Area Electronics
Organic, hybrid large area devices have numerous advantages such as low cost of production, ease of design, light-weight deployment, and flexibility. The OLADE research team focuses on chemical synthesis, integration and physical modelling of organic, hybrid and printable materials, in connection with the design of high performance electronic large area devices and systems. Based on a fundamental approach such as the synthesis of new molecules and polymers and the modelling of charge transport, as well as on three specific technology facilities (ORGATECH, CHIMORGA and PLATINE), OLADE team aims to design reliable components for energy harvesting (perovskite and tandem solar cells), efficient light emission (OLEDs) and sensors (biomedical and smart-city). OLADE researchers collaborate with CEA and IFSTTAR in the framework of ORGASACLAY and NACRE joint research teams respectively.

**OLAE Expertise:**
- New semi-conducting and luminescent materials for coating large areas
- Design, characterization and reliability of innovative components (OLED, PV, TFTs, sensors)
- Carrier transport and interface characterization
- Physical and compact modeling of components (SPICE, finite elements)
- Design of analog and numerical circuits

**OLAE Materials:**
- Organic and hybrid Polymers and molecules
- Hybrid perovskite
- Carbone nanotube ink

**Applications and devices:**
- Devices for energy (solar cells and OLED)
- Sensors (biomedical applications and smart cities)
- Large area electronics

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In collaboration with Silvaco Europe, through Horizon 2020 Marie Skłodowska-Curie Research and Innovation Staff Exchange (RISE) Program (2015–2019) entitled DOMINO 645760 (Design Orientated Modeling for flexible electronics), we recently succeed in modeling transfer and output characteristics of OFETs based on a finiteelement method (FEM). The essence of the results is the use of the Gaussian density-of-states model for describing energetic states of disorder in organic semiconductors as well as the expanded range of disorder that ensures the convergence of numerical calculations. The simulated transfer characteristics show a non-linear dependence of drain current on gate bias (Fig. 1).

Fig. 1. (a) Schema diagram for the device structure of OFETs in bolom-gate top-contact configuration and drain current path and (b) simulated transfer characteristics in linear and log scale. (The width of Gaussian density-of-states is set $\sigma = 0.20$ eV)

In addition, simulated current density in the device provides physical background for the equivalent circuit model of current path between source and drain in OFETs (Fig. 2).

Fig. 2. (a) Contour and vector plot of current density in OFETs ($L = 30 \, \mu m$) and (b) equivalent circuit model for current path between source and drain and (c) close up at the source.

European Union’s Framework Programme
H2020-MSCA-RISE-2014
Universal Compact model for Organic solar cells

A precise description of the electrical behavior of organic solar cells (OSCs) becomes necessary with pre-industrial large scale modules. This work carried out within the framework of the European project SMARTONICS allowed:

- The realization of a compact universal model of CSOs for all operating regimes.
- A complete and versatile method of extracting parameters.
- Fine recognition of all the resistances of the modules (contact, connection, surface and structure).

European Union’s Seventh Framework Programme
NMP.2012.1.4-1

Flexible organic electronics for intelligent stent

Within this collaboration with the startup INSTENT, the intended application is the production of an instrumented stent capable of detecting, via flexible organic electronics and by impedance spectroscopy, the cell growth and hence its integration in the wall of the artery.

- Optimization of the use of nano-printing techniques for sox lithography and nano-stamping for the reduction (flexibility, conformability) of the sizes of the fundamental structures (electrodes, channel,...) of the conductive tracks and components (dipole, Diode, TFT).
- The realization and optimization of the characteristics of these conductive tracks and components in terms of reliability and held to mechanical stress. (Platinum)
- The integration of transistors for the design, manufacture and characterization of the electronic systems constituting the front-end electronics of the sensors (low-noise amplifier, analog-to-digital converter and RFID transmission)
Zinc oxide (ZnO) is a widely used as transparent conductive oxide because of its tunable optoelectronic properties, particularly in the field of the solar energy. In this study this compound has been applied as hole-blocking layer in a planar perovskite based solar cell in substitution for the classical titanium dioxide (TiO$_2$) bilayer. The introduction of an intrinsic ZnO between the perovskite layer and the highly doped n type contact leads to a large reduction of the recombination at this interface.

A fine optimization of the ZnO layer properties together with that of the perovskite deposition leads to the measurement of a power conversion efficiency of 14.2 % on a 0.175cm$^2$ cell.

Moreover the evolution of the cell performance has been measured over more than two months for both an encapsulated and a non-encapsulated devices.

If the decrease of the fill factor with time, possibly related to the degradation of the cell contact, is observed the short circuit current (>18mA.cm$^{-2}$) and the open circuit (>1V) potential stay remarkably constant.

RSC Adv., 2016, 6, 67715-67723

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Polarized light with TADF

This work describes the first thermally activated delayed fluorescence material enabling circularly polarized light emission through chiral perturbation. These new molecular architectures obtained through a scalable one-pot sequential synthetic procedure at room temperature (83% yield) display high quantum yield (up to 74%) and circularly polarized luminescence with an absolute luminescence dissymmetry factor of $1.3 \times 10^{-3}$. These chiral molecules have been used as an emissive dopant in an organic light emitting diodes exhibiting external quantum efficiency as high as 9.1%.

Bistetracenes: Two-Dimensional OS with High Carrier Mobility and Air Stability

Organic semiconductors (OS) are key to the development of light weight and flexible electronics. TIPS-pentacene (TIPS-PEN) is benchmark for OSs. However, there is a major concern with TIPS–PEN: its low photo-stability due to a low degree of aromaticity. We concentrate on the rational design of OSs based on bistetracene derivatives with tailored optical properties, increased stability, up to 21 times compared to TIPS–PEN, and mobility over 0.1 cm²V⁻¹s⁻¹. The introduction of TIPS– groups in different positions alters more the energy level of the LUMO than the HOMO and the photostability depends strongly on the LUMO energy level. The best OFET performance with mobility over 0.1 cm²V⁻¹ s⁻¹, has been found in solution processed devices.
Perovskite/nanocrystalline-silicon tandem solar cells

A major boost in photovoltaic power conversion efficiency can be achieved from combining different solar cells with complementary absorption ranges. However the challenge is to make such tandem solar cells with high efficiency at low production cost, with the major barrier being a low-cost, good quality, large bandgap material.

The past three years have seen the rapid emergence of a new class of solar cells based on hybrid perovskite materials with solar cell efficiency up to 20%. Perovskites are ideal candidates to make tandem solar cells with silicon bottom cells since they use low deposition cost and the band gap can be tuned advantageously.

However, the pairing with high quality monocrystalline silicon is not evident, as the relative increase in efficiency (above the 25.6% available in the lab) may not offset the increased cost. The PERSIL project aims to investigate and develop the potential of these new perovskite-based solar cells as well as their application in tandem devices in combination with low-cost nanocrystalline-silicon bottom cells.

The main objectives of PERSIL are 1) fabrication and characterization of perovskite cells, 2) fabrication and characterization of silicon/perovskite tandem cells with efficiency up to 25%, 3) investigation of the tandem cell stability and scalability.

**ANR 2016 PERSIL project**

In collaboration with Silvaco Europe, through Horizon 2020 Marie Skłodowska-Curie Research and Innovation Staff Exchange (RISE) Program (2015–2019) entitled DOMINO 645760 (Design Orientated Modeling for flexible electronics), we recently succeed in modeling transfer and output characteristics of OFETs based on a finite-element method (FEM). The essence of the results is the use of the Gaussian density-of-states model for describing energy states of disorder in organic semiconductors as well as the expanded range of disorder that ensures the convergence of numerical calculations. The simulated transfer characteristics show a non-linear dependence of drain current on gate bias (Fig. 1).

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In collaboration with Silvaco Europe, through Horizon 2020 Marie Skłodowska-Curie Research and Innovation Staff Exchange (RISE) Program (2015–2019) entitled DOMINO 645760 (Design Orientated Modeling for flexible electronics), we recently succeed in modeling transfer and output characteristics of OFETs based on a finite-element method (FEM). The essence of the results is the use of the Gaussian density-of-states model for describing energy states of disorder in organic semiconductors as well as the expanded range of disorder that ensures the convergence of numerical calculations. The simulated transfer characteristics show a non-linear dependence of drain current on gate bias (Fig. 1).

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**Fig. 1.** (a) Schematic diagram for the device structure of OFETs in bottom-gate top-contact configuration and drain current path and (b) simulated transfer characteristics in linear and log scale. (The width of Gaussian density-of-states is set $\sigma = 0.20$ eV).

**Fig. 2.** (a) Contour and vector plot of current density in OFETs ($L = 30$ $\mu$m) and equivalent circuit model for current path between source and drain and (c) close up at the source.

In addition, simulated current density in the device provides physical background for the equivalent circuit model of current path between source and drain in OFETs (Fig. 2).
NANOMADE

NANOMATERIALS AND DEVICES
Overview

Controlling nanomaterials synthesis in-place (at the heart of future devices) and with tailored properties is one of the nanotechnology’s essential challenges. Through an established nanomaterials expertise and unique synthesis capacity (carbon nanotubes an nanofibers, inorganic nanowires, graphene and graphene related 2D carbon layer, transition metal dichalcogenides, nanoparticles and various types of core-shell hybrid nanostructures), NanoMaDe addresses these challenges by combining the fundamental studies of the growth mechanism of nanomaterials with the development of innovative synthesis tools and processing methods for fabricating devices of multifunctionality for electronics and nanoelectronics, energy and environmental applications.

Collaborations

Joint research team "NanoCarb":
a 14 year collaboration with TRT
- carbon nanotubes based Vacuum electronics (involving also Thales Electron Devices)
- Optoelectronic devices based on 2D nanomaterials Chaire "André Citroen" at Ecole Polytechnique (renewed 2016)
- automotive related nanosensors and nanoelectronics IMD – "Sustainable Mobility Institute" (founded in 2009 by Renault and ParisTech)
- "Battery technology" strand: nano-enabled electrochemical energy storage systems for future electrical vehicles Chaire "André Citroen" at Ecole Polytechnique (renewed 2016)
- automotive related nanosensors and nanoelectronics Joint research team "NACRE"
- implementing nanotechnologies for urban instrumentation

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New experimental facilities

The recent PHY-MECA 83 building hosts several new experimental facilities:

- An environmental (UHV and synthetic gas atmosphere) electrical characterization bench for future nano-sensors development. This facility developed with support from Chaire "André Citroen", DGA and "Sensecity" EquipEx has been recently finalized and allowed first nanosensors NOx detection in ppm ranges.

- Homemade UVH-MBE materials deposition system: multilayer deposition with atomic monolayer precision, to control the key step catalyst preparation for the synthesis of high-quality carbon nanotube carpets.

- Low-Pressure, Electric Field assisted CVD system: coupled to "FENIX" for in-situ characterizations and accepting up to 4 inch substrates, this new reactor will be dedicated to the exploration of the newly patented carbon nanomaterials synthesis technique in high vacuum and free radicals/under electric field conditions. ("3DRX-online" project and "Nanocarb" collaboration)

In situ & real time nanomaterials growth process characterization

"FENIX" facility has been successfully implemented in the new PHY-MECA 83 building. Fenix enables a particularly interesting approach, the in-situ real time monitoring by surface analysis (angle resolved XPS, UPS, high resolution Auger spectroscopy and reflection low energy EELS), as well as high resolution LEED and mass/ion energy spectroscopy. With the availability of more than 8 focused matter beams (vapors, free radicals, ions), this facility will allow future breakthroughs on understanding the growth mechanisms of graphene and other ultrathin 2D materials (e.g. MoS$_2$, WS$_2$, PtS$_2$ etc) and heterostructures, their doping, surface interactions or defects creation.
Nanostructure are Li-ion batteries

Through their extremely large specific surface area, current collectors with tailored length/diameter aligned CNTs carpets, represent an ideal support matrix to accommodate a wide range of active materials (anode or cathode) for achieving improved electrochemical performance in Li-ion batteries. Our goal is to demonstrate that electrodes of hierarchic, core-shell nanostructures directly grown onto metal foils and consisting of vertically aligned carbon nanotubes decorated with silicon nanoparticles (VA-CNTs/Si) for anodes and lithiated metal oxides or sulfur nanoparticles for cathodes in Li-ion electrochemical storage systems, can meet simultaneously high energy and high power density, high rate capability and durability.

Towards deterministic synthesis of single-wall carbon nanotubes

Using prussian blue analog nanoparticles precursors we have developed a new generic, and versatile method to design specific bimetallic nano-catalysts for the deterministic single wall carbon nanotubes growth (semiconductor vs. metallic selectivity).

For different types of nano-alloy systems, by changing CVD growth temperature we succeeded to modulate the percentage of semi-conductor type in the assynthesised nanotubes. For the best nano-alloy system, a modulation from 45% to more than 85% could be obtained according to Raman spectroscopy. The nanotubes were furthermore integrated into high-quality SWNT-FET transistors with off/ ratios outpassing eight decades.
AOP

Applied Optics & Polarimetry
The Applied Optics and Polarimetry (AOP) group at LPICM, has more than fifteen years of experience working with polarized light and developing applications to study the optical and electronic properties of materials sensitive to the polarization of light. An important activity of the group has been devoted to the development of innovative spectroscopic, or imaging polarimeters, and polarization sensitive nano-Raman microscopes, which have been patented and some of them have been transferred to industry.

The spectroscopic polarimeters developed by AOP members, cover a very broad spectral range, from the ultraviolet to the far infrared. The spectroscopic polarimeters have been used to study the optical properties of multiple types of materials and nanostructures, in particular those used in photovoltaic solar cells, as well as in low-emissivity coatings used to save energy in buildings. The knowhow developed in the group allowed to create collaborations and partnerships with companies such as Horiba Scientific, Saint-Gobain or with public research laboratories from the CNRS, CEA or the SOLEIL synchrotron.

The group has developed two types of imaging polarimeters.

- Polarimetric Microscopes are able to take images in real and reciprocal (Fourier) planes. They are used to develop applications in optical metrology of diffraction gratings and also fundamental studies of scattered light by nanostructured surfaces in collaboration with laboratories in France, Spain, Finland, Norway and Sweden.

- Imaging polarimeters have been used in medical imaging to explore the potential of polarized light to detect and stage the cervical or colorectal cancer. A long-term collaboration has been stablished with three hospitals in France and one in Belgium for pre-clinical studies of real tissues.

The studies of nanostructures (nanotubes, nanowires, etc.) fabricated at LPICM or in other laboratories, were the driving force for the development of a unique instrument, - polarization-sensitive Raman spectrometer coupled to an AFM microscope. The system is ideal to study the physical and chemical properties of single molecules deposited on SERS substrates with a subwavelength resolution of a few tens of nanometers. The system has also been used to study stressed semiconducting nanostructures in close collaboration with CEA – LETI researchers.

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Theory of polarimetry constitutes a research field on its own and is of paramount importance for the physical interpretation of the experimental data. Professor R. Ossikovski co-authored with Prof J. Gil the book on basic concepts of polarization phenomena from the viewpoints of the states of polarization of electromagnetic waves and the transformations of these states by the action of material media. Through selected examples, it also illustrates actual and potential applications in materials science, biology, and optics technology.

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Light Scattering from Textured Surfaces with Mueller Scatterometry

Light Scattering from Textured Surfaces

A PhD student, M. Sang Hyuk Yoo built and tested a new polarimetric scatterometer working in forward configuration for the measurements of anisotropic scattering samples. He studied the optical response of solar cells having textured surfaces and evaluated the impact of surface texturing in light trapping efficiency.

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Tip Enhanced Raman Spectroscopy

The NanoRaman (TERS) commercial setup (HORIBA), was fully operational throughout 2016. Measurements were performed both in conducting mode (Scanning Tunneling Microscopy, STM) and in non-contact mode (Atomic Force Microscopy with tuning forks), used on non-conducting sample.

Localized chemical and electrical measurements on azobenzene thiol monolayers on gold were performed by combining TERS with scanning tunneling microscopy (STM). TERS spectra were acquired while changing the tip-surface distance and increasing the bias applied to the tip. These experiments, accompanied by an appropriate theoretical model, provided striking evidence for bias-induced bending of the azobenzène thiol molecules under the tip, a yet unreported nanoscale phenomenon.

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Infrared Mueller Ellipsometer with Synchrotron Light - Technology Transfer

Applications
Polymers and organic materials
- Crystallinity
- Chemical bond orientation

Transparent conductors
- Carrier concentration
- Electrical conductivity

Optical Metrology
- Thin film thickness / homogeneity
- Diffraction and Plasmonic gratings

Characteristic
Spectral range: 2-16µm
Accuracy: better than 0.5%
Angle of incidence: 65 - 75°
Scanning imaging accessory
Spot size ± 30µm

The project in collaboration with the SMIS beamline group at the SOLEIL synchrotron has successfully started.

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Infrared Mueller Ellipsometry

Study of oxygen induced crosslinking in organic polymers with clorosilane

Ellipsometry has been used to measure the dielectric constant of normal and crosslinked PMMA. The presence of absorption bands at 900 and 1050 cm\(^{-1}\) related to Si-OH and R-SiO bonds, in PMMA layers exposed to oxygen during sol-gel polymerization shows that efficient crosslinking has been reached.

S. Jung et al., ACS Appl. Mater. Interfaces, 8 (2016) 14701.

Mueller matrix shows high anisotropy and dichroism. Different optical models produce equivalent results because IR wavelengths are sensitive to average size of sample topographic features.

In-plane components of the optical tensor show positive and negative values -> Hyperbolic material.

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Electric Field Measurement in CO$_2$ Plasma with Imaging Mueller Ellipsometry

Ellipsometry has been used to measure the dielectric constant of normal and crosslinked PMMA. The presence of absorption bands at 900 and 1050 cm$^{-1}$ related to Si-OH and R-SiO bonds, in PMMA layers exposed to oxygen during sol-gel polymerization shows that efficient crosslinking has been reached.

S. Jung et al., ACS Appl. Mater. Interfaces, 8 (2016) 14701.

Study of oxygen induced crosslinking in organic polymers with chlorosilane

Development of an innovative and efficient way to measure the electric field using an electro-optic crystal as a probe in contact with the plasma. The electro-optical crystal becomes birefringent when exposed to a given electric field. We use imaging Mueller ellipsometry to measure the optical properties of the electro-optic crystal and to relate them to the magnitude of the electric field applied to the crystal.

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Mueller polarimetric colposcope

The instrument prototype has been tested in vivo for cervical cancer detection during the surgery in Obstetrics and Gynecology Department of the University Hospital of Kremlin-Bicêtre. The work is ongoing on the instrument improvement (reduction of acquisition time, increase of signal to noise ratio, choice of optimal measurement wavelength).

The upgraded version of Mueller polarimetric colposcope was also tested in vivo on 10 patients at the CHU Brugmann in Brussels, Belgium as a tool for the detection of the risks of premature delivery.

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Flexible Mueller polarimetric micro-endoscope

The first flexible Mueller polarimetric micro-endoscope enabling the acquisition of polarimetric images through a monomode optical fiber was built in the frame of ANR IMULE project in a partnership with ttlim laboratory, University of Limoges and French hospital Institut Mutualiste Montsouris, Paris. Polarimetric images of biological samples have been obtained with the new micro-endoscope ex vivo and compared with the images obtained using a Mueller polarimetric microscope.


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Nanowire modeling & characterization

Vertical silicon nanowire arrays represent a promising structure for improved light trapping in silicon solar cells. Such arrays can be fabricated using metal assisted etching coupled with nanosphere lithography. We have developed a new optical model to characterize such vertical arrays, which includes effects coming from imperfections due to the fabrication process.

Figures show diffraction pattern measured by angle resolved Mueller matrix ellipsometry in Fourier plane and in the real plane in the place where two domains of periodic silicon nanowire arrays meet each other.


Optical in-situ characterization of silicon nanowires during growth

We have developed optical models for in-situ optical characterization of nanowires during their vapor-liquid-solid growth in plasma enhanced chemical vapor deposition reactor. Models allow to define critical parameters during the growth for a better control of the growth process.


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The first European workshop on Biophotonics and Optical Angular Momentum (BIOAM-2016) brought together scientists working in scientific fields related to optical angular momentum (spin and orbital), including fundamental aspects, polarimetric instrumentation and applications in biomedical photonics and super-resolution microscopy.

We organized the forum for researchers from both academia and industry to exchange expertise, to identify new directions and perspectives in the field of OAM studies and to build an international research network for addressing the upcoming challenges, with special emphasis on biomedical applications of OAM. The workshop was organized within the framework of ANR TWIST4NET project https://bioam-2016.sciencesconf.org/

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New Platforms
NanoMAX : In-situ growth of nanomaterials in a ultrahigh resolution TEM

The NanoMAX microscope is a prototype developed on the basis of a FEI Titan ETEM (Environmental Transmission Electron Microscope) equipped with a spherical aberration-corrector of the objective lens. Thanks to a differential pumping system it allows up to 3mbar of gas in the sample chamber. The main originality of the project lies in the ability of NanoMAX to bring precursors on the sample in the form of beams, while maintaining a high vacuum (a guarantee for a controlled growth). These beams can be either gaseous molecules (for example methane as precursor for the carbon nanotubes synthesis) or gaseous radicals (cracked molecules). With these, NanoMAX can partly mimic the environment existing in LPICM macroscopic reactors which use plasmas.

Moreover, these beams can be made up of individual atoms: the first experiments of molecular beam epitaxy (MBE) ever carried out in-situ in a transmission electron microscope were obtained in NanoMAX in November 2016. This in situ growth capacity is unique worldwide.

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Platform for In-Situ reliability assessment of nanodevices

Developed in 2016, in collaboration between LPICM, LSM and IFSTTAR, the core of PLATINE is an experimental platform enabling the application of multiphysics loadings, i.e. electrical, mechanical, thermal, environmental, on nanodevices, while their electro- thermo mechanical response is monitored at various scales. This platform is essential to pinpoint where and why failure occurs in the devices, as well as to assess systematically device lifetime. The platform will provide capabilities for ex-situ analyses of the micro and nanoscale mechanisms responsible for failure initiation. Additionally, the PLATINE platform is crucial to provide relevant data for the development and the assessment of fatigue models and lifeDme predictions tailored to the physics of nanodevices.

Project sponsors:

- Ecole Polytechnique fundraiser
- Région Ile de France, via the SESAME funding
- Mairie de Paris, via PARIS2030 funding
- Direction of Research at Ecole Polytechnique
- DGA
- Labex Charmmmat

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Research Support Teams
Research Equipment & Design Department (BEER) is one of the 3 support teams of the laboratory. This team is composed of six members and is at the service of the 4 PICM research groups.

Our missions:

- Conceptualization, design, fabrication and validation of vacuum deposition reactors.
- Numerical simulation of deposition processes.
- On-demand fabrication of custom mechanical parts.
- Maintenance and management of the research platforms.
- Safety: Training of users and maintenance of installation systems.
numerical simulations:

Examples of gas flow structure in a gas injection "Shower head PECVD reactor"

Highlights for 2016:

- Modernization of a reactor for depositing thin layers (ARCAM100).
- Implementation of equipment at the 406 and for the future experimental rooms of the wing 4.
- Development of a new technology platform (PLATINE) for the test of nanosensors.
- Computational Fluid Dynamics modeling.

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“Le groupe Instrumentation & informatique” has service missions (IT asset management) and maintenance missions (maintenance of optical characterization tools and measurement tools). The group is also engaged in R & D operations for all of the laboratory’s scientific teams. The group is composed of 4 people; two are mainly involved in IT asset management, one is involved in the management of the optical characterization instrument park and one is more dedicated to the realization of characterization test bench.

The group’s missions are as follows:

IT asset management.

Installation & maintenance of optical characterization tools and measurement tools.

Development and monitoring of security and processes PLC devices.

Realization of characterization test benches.

Instrumentation, data acquisition.
The main achievements for 2016 are:

- The end of the “retrofit” of the PECVD ARCAM100 deposition reactor: with the help of the BEER group, we have redefined all aspects of control of the reactor and developed a software to control the entire reactor (vacuum, gas and safety management) by the use of LabVIEW® System Design Software. We chose to use a SB-RIO board from National Instrument® as an interface system with the reactor.

- Since mid 2016 we are also involved in the retrofitting of 3 other PECVD reactors: PLASFIL, PHILIX and ATOS. In this case we decide to use a Beckhoff® industrial programmable controller as interface with reactors. The software will also be developed with LabVIEW®.

- The development of a new version of the acquisition system (hardware and software) for the polarimetric colposcope in order to perform in vivo measurement during surgery for AOP team.

- The development of a Kelvin probe test bench to characterize SAM (Self Assembled Monolayer) for the OLAE team.

- Commissioning a calculation server for the research and modeling work of the NANOSIL team.

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Administration & Management

Administration of LPICM and management of human and economic resources: personnel, budgets, research contracts, travel arrangements, organization of conferences and workshops.

Key figures for 2016

- **120 people**
- **Over 25 nationalities**

<table>
<thead>
<tr>
<th>Base funding 2016</th>
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<tbody>
<tr>
<td>Ecole polytechnique</td>
<td>83 K€</td>
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<td>CNRS</td>
<td>92 K€</td>
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</tbody>
</table>

* 50 contracts for a total amount of **2 214 K€**
* 570 purchase orders for equipment and running costs
* 217 travel files for missions

+ 75 files for access to Ecole polytechnique and PICM
+ 20 recruitments for research positions
+ 20 files for "titres de séjour" (convention d’accueil)

Administration for FedPV

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In order to inform permanently, LPICM strengthens its communication on its strategic direction policy addressing the scientific world as well as the general public.

Web site: https://portail.polytechnique.edu/lpicm/en

In terms of communication, year 2016 has been particularly rich on the national and international level.

Among the many visits, exchanges and media events, we can note:

**Media:**
- Movie with ERC TOTAL on "the photovoltaic research engineer jobs" supported by the ministries of education and labor.
- TV program "E = M6" (October 2016): « promises of Microtechnology ».

**National:**
Visit of administrative services and human resources of the CNRS regional delegation (DR04).

**International:**
Visit of BEIDA Delegation from Beijing University (China) in the context of the Polytechnique research management (June 2016).

In order to encourage vocations in research, LPICM has also organized many student visits:

- Master students plasmas (nov. 2016).
- Delegation of polytechnique students - X 2015 (may 2016)
- Visit of the students of senior high school of Brétigny (june 2016).

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Collaborations
Nara Institute of Science and Technology (NAIST, Japan), École Polytechnique, and CNRS, partner to create an International Collaborative Laboratory (ICL) for High Efficiency Perovskite/silicon solar cells. The creation of this collaborative lab is the result of an 8-year collaboration between researchers from the Laboratory of Physics of Interfaces and Thin Films LPICM (X-CNRS) and from the Information Device Science Laboratory of NAIST.

The objective is to build tandem solar cells combining a small band gap silicon absorber with a higher band gap material called organometal halide perovskites. These devices have the potential to outperform single junction silicon devices while benefiting from the low cost of perovskite materials and processing.
Prizes & Distinctions
Prizes & Distinctions

Bastien Bruneau. Thesis Award Ecole Polytechnique. "Control of radio frequency capacitively coupled plasma asymmetries using Tailored Voltage Waveforms"


Arthur Marronnier. "My PhD in 6 minutes - 1st Prize, Paris-Saclay University"


Rafael Peyronnet. "Fioh International Education Forum on Environment and Energy Science" organized by Tokyo Institute of Technology. Two awards from the "Academy for Co-creative Education of Environment and Energy Science" (ACEEES) :1) Best collaboration Award avec Wataru Tsunoda (PhD student in Japan) et Jianghao Li (PhD student in China), and 2) Solar Energy best presentation Award.


Publications
Publications by NANOSIL members in 2016


43. B. Bruneau, T. Lafleur, J.-P. Booth, and E. Johnson «Controlling the shape of the ion energy distribution at constant ion flux and constant mean ion energy with Tailored Voltage Waveforms,» Plasma Sources Sci. Technol. 25 (2016) 025006
Publications by NANOSIL members in 2016

Proceedings


Publications by NANOSIL members in 2016

Proceedings


Publications by NANOSIL members in 2016

Conferences


2. H. VACH (Keynote Speaker) Ultrastability due to electron delocalization in aromatic silicon clusters 2nd EMN Meeting on Quantum Technology Phuket, Thailand, April 8-11 (2016).


5. H. VACH, Aromatic Silicon Nanocrystals - outstanding properties and future applications, EMN Meeting on Quantum Technology, Beijing, China, April 14-17 (2015).


Publications by NANOSIL members in 2016

Conferences


15. Pere Roca i Cabarrocas : "Silane plasmas: From nanocrystals to thin films and Epitaxial Growth". 11th Workshop on Si-Based Optoelectronic Materials and Devices". Nanjing University, 16-19 June 2016.


Publications by OLA members in 2016

Bibliography OLAE 2015-2017 - Articles in Peer-Reviewed Journals


Bibliography OLAE 2015-2017 - Articles in Peer-Reviewed Journals


Publications by OLAЕ members in 2016


Publications by NANOMADE members in 2016


4. “Silicon nano-trees as high areal capacity anodes for lithium-ion batteries” Leveau L.; Laïk B.; Pereira-Ramos J.P.; Gohier A.; Tran-Van P.; Cojocaru C.S. Journal of Power Sources 316 (2016) 1–7; DOI: http://dx.doi.org/10.1016/j.jpowsour.2016.03.053


6. “Connecting wire-based solar cells without any transparent conducting electrode” Le Duc Toan, Eric Moyen, Mihai Robert Zamfir, Young Woo Kim, Jemee Jo, Young Hee Lee, and Didier Pribat CrystEngComm., 18, 207 (2016). Inside front cover

Publications by NANOMADE members in 2016


Book Chapters


PATENTS

Publications by AOP members in 2016

Books


Patents


Articles in Peer-Reviewed Journals


Publications by AOP members in 2016


11. E. Slikboer, O. Guaitella, A. Sobota, “Time-resolved electric field measurements during and aor the initialization of a kHz plasma jet—from streamers to guided streamers”, Plasma Sources Sci. Technol. 25, 03LT04 (May 17, 2016).


