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Pulse School

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Book of abstracts

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MONDAY

Yukio Saito

Monday, 9 - 10:30 am
2:45 - 3:45 pm

Crystal in and out of equilibrium

Yukio Saito

Department of Physics, Keio University

Innovation in technology is often achieved by invention of new materials, and if it is in a crystalline form, its growth in a high quality is a key issue. In the present course, fundamental idea of crystals in and out of equilibrium is discussed [1].

In the first part, equilibrium aspects of the crystal are discussed such as phase equilibrium, equilibrium crystal shape (ECS) and the Wulff theorem, and a thermal roughening transition.

In the second part, kinetic aspects of crystal growth are discussed, such as an ideal growth laws (Wilson-Frenkel and Hertz-Knudsen) and non-ideal growth laws governed by nucleation and growth or spiral growth. Morphological instabilities and related dendritic growth will be briefly referred.

References

1. Yukio Saito, Statistical Physics of Crystal Growth (World Scientific, 1996)

Peter Voorhees

Monday, 11 - 12 am
Tuesday, 11:30 am- 12:30 pm

The dynamics of epitaxy

Peter Voorhees

Northwestern University

The growth of a crystal by deposition from the vapor on to a surface will be discussed. To fix ideas, we shall begin with the classical Burton-Frank-Cabrera model for crystal growth. Using this as a background, the effects of random deposition on the roughness of the surface, a continuum model of this process that follows from the Karder-Parisi-Zhang equation, and the scaling laws that describe the evolution of surface roughness will be discussed. At higher temperatures growth frequently occurs by the motion of atomic steps across the surface. The equations governing the dynamics of step motion will be developed. Using these equations, we shall discuss the step-bunching instability and the physics governing step-step interactions, the growth of circular steps, and the morphological stability of a step (step meandering). The goal of this lecture is to provide the background for the lectures that will be given later in the week for those who are new to field.

Leo Miglio

Monday, 4:15- 6:15 pm

3D growth induced by elasticity

Leo Miglio

University of Milan-Bicocca

The self-assembly of heteroepitaxial semiconductor quantum dots can be understood in terms of a spontaneous mechanism, where the hierarchy of energies (bulk covalent, surface and elastic ones) gives rise to the transition between two-dimensional to three-dimensional (nucleation of quantum dots), and to the morphological evolution with size (pyramids, domes, barns...). In this lesson, we will approach the prediction/interpretation of the experimental findings for the prototypical Ge/Si system, showing that simple analytical models nicely explain most of the phenomenology. In competition to this elastic strain-release effect, SiGe intermixing and, eventually, plastic relaxation play an important role, especially if device applications are envisaged. Therefore, the lesson will be concluded by a discussion of these mechanism on the basis of current models.

Alain Portavoce

Monday, 6:15 - 7 pm

Introduction to Atom Probe Tomography: characterization of nanostructures

Alain Portavoce

Institut Matériaux, Microélectronique, Nanosciences de Provence, CNRS

Atom Probe Tomography (APT) is a chemical analysis technique allowing for three-dimensional characterization of (usually) inorganic materials at the atomic scale. Originally, APT was developed for metallic materials as an extension of field ion microscopy (Müller, Panitz, and McLane, 1967). It is only still recently (∼2004) that commercial three-dimensional laser-pulsed APT microscopes were developed to analyze non-metallic materials such as semi-metals, semiconductors and dielectrics. However, due to its unique ability to characterize atomic distribution in the three-dimensional space, the number of APT tools is growing rapidly worldwide, and APT is becoming an essential tool for nanostructure characterization.

The goal of this lecture is to give in less than an hour the basic knowledge for understanding what is an APT measurement/experiment and how can be interpreted standard APT data, especially in the case of nanostructure analysis. A simple model considering athermal field evaporation will be presented allowing for the basic understanding of low-temperature field evaporation occurring during laser-pulsed APT experiments. Thus, the APT experimental set up, as well as the algorithm allowing the three-dimensional "reconstruction" of the initial sample atomic distribution to be performed will be presented. Common aberrations that can be observed in APT volumes will be discussed before to describe the usual technique for sample preparation, as well as the common data treatments allowing the atomic distribution and the structure of the samples to be investigated. Finally, examples of nano-structure analyses will be presented.

TUESDAY

John Venables

Tuesday, 9 - 11 am

Nucleation theory

John Venables

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Also at London Centre for Nanotechnology, University College, London, UK
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Epitaxial Crystal Growth has been in the spotlight recently with the award to Akasaki, Amano and Nakamura of the 2014 Nobel Prize for Physics. This culminated in the development of thin film diodes made from Al-Ga-In Nitrides, which are luminescent in the blue. Coupled with fluorescent material contributing in the yellow, these films produce the efficient white light that we now see in torches, headlamps, displays and increasingly in general lighting. The point of this example is simply to underline that the key breakthroughs were all in the crystal growth area. These concern nucleation, growth and epitaxial orientation of the films, coupled with control of defects and impurities, which resulted in superior electrical and optical properties for diodes and lasers [1].

The details of the particular crystal growth methods (e.g. MOCVD) and precursor molecules are fascinating, but are challenging to model: I will learn more from other speakers here. I have developed simple nucleation and growth models, rate and rate-diffusion equations in particular, to understand how atomic layers and thin films differ from the bulk (e.g. coordination, reconstruction, vibrations, etc). These models involve specific atomistic energies and frequency factors, and can connect with microscope-based experiments, often involving statistical mechanics applied locally [2,3].

In this particular talk, examples will be given for metals (Ti, Ag) on Si(001) and (111) and Ge/Si(001), along with background references [3,4] and some MatLab codes. Nucleation at defect sites is also covered, in relation to studies of Pd/MgO (001) and the emerging field of Atomic Precision Manufacturing. Rate and rate-diffusion equations can be useful intermediaries with electronic structure calculations, and so close the experiment-theory circle. The relationships with complex models appropriate to real-world methods and practical semiconductor materials are discussed in outline.

References

1. The 2014 Physics Nobel Prize lectures by Isamu Akasaki, Hiroshi Amano and Shuji Nakamura are at http://www.nobelprize.org/nobel_prizes/physics/laureates/2014

2. J.A. Venables, Introduction to Surface and Thin Film Processes (Cambridge University Press, 2000, chapters 1 and 5); see http://venables.asu.edu/book/index.html; J.A, Venables, Phys Rev. B **36**, 4153 (1987)

3. J.A. Venables, P.A. Bennett, H. Brune, J. Drucker, J.H. Harding, Phil. Trans. R. Soc. Lond. A (2003) **361**, 311-329; J.A. Venables, L Giordano, J.H. Harding, J. Phys. Cond. Matter **18** S421 (2006).

4. M.R. McKay, J.A. Venables and J. Drucker, Phys. Rev. Lett. **101**, 216104 (2008); Solid State Comm. **149**, 1403-1409 (2009), see also ref 2, chapters 1 and 7.

Armando Rastelli

Tuesday, 2:30 - 4:30 pm

Controlling position and electronic structure of quantum dots by combining bottom-up and top-down approaches

Armando Rastelli

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This lecture focuses on the epitaxial growth and control of semiconductor nanostructures capable of confining the motion of charge carriers in three-dimensions, i.e. on quantum dots (QDs). The investigation of such systems is mostly driven by the perspective of using them as building blocks for applications in the fields of quantum information and communication.

Quantum dots with excellent electronic and optical properties can be obtained by exploiting self-assembled (bottom-up) mechanisms, which lead to spontaneous nanostructure formation during growth. The most studied method relies on the Stranski-Krastanow (SK) growth mode, which commonly occurs during lattice-mismatched heteroepitaxy, and is addressed in other lectures of this school.

In view of future applications relying on single QDs, bottom-up approaches have however two limitations: (1) the position of the QDs on the substrate is random (at least on macroscopic scale); (2) the structural properties of QDs vary from dot to dot due to the stochastic processes involved in their formation. Point (1) prevents the realization of devices requiring the position of specific dots to be precisely known, while (2) leads to unacceptable fluctuations in the electronic and optical properties of the QDs.

In this lecture I will first recall basic features of self-assembled QDs. In a first part I will discuss and highlight the similarities of two QD systems relying on the SK mode: SiGe dots on Si(001) and InGaAs dots on GaAs(001) substrates. In a second part I will discuss alternative bottom-up approaches focusing on unstrained GaAs QDs in AlGaAs barriers. I will then move to experimental methods, which are currently used to control the position of QDs on a substrate followed by the control of the electronic structure of individual QDs. In both cases top-down methods are needed to (1) guide the formation of QDs at predefined positions and to (2) alter the electronic properties of the QDs to overcome the problems related to the limited capability of controlling the exact structural properties of each QD. The most used approach to address point (1) relies on substrate patterning prior to QD growth, while point (2) is addressed after growth by exposing the QDs to external perturbations, such as laser irradiation, electric and strain fields with proper magnitude and directions.

Michele Amato

Tuesday, 5 -7 pm

Physical properties of nanostructures : theory and simulations

Michele Amato

Institut d'Électronique Fondamentale, Université Paris-Sud

The end of the last century has seen a progressive interest in materials and devices with reduced size and dimensionality. The trend predicted by Moore's law has posed strict requirements on the electronic properties of materials that cannot always be satisfied by traditional semiconductors [1]. Nanostructures and nanomaterials have been considered the key development for the next generation technology, due their ease of processing, unique properties and compatibility with the existent Si microelectronics [2-4]. This great interest is mainly due to the fascinating physics that governs the behavior of the matter at nanoscale and that is intrinsically associated with the reduced dimensionality, i.e. the quantum confinement.

In the first part of the talk I will briefly describe one of the most powerful method to calculate nanostructures properties along with the basic theoretical concepts of quantum confinement. First, ab initio methodology based on Density Functional Theory (DFT) [5] will be introduced highlighting its capability to predict properties without the use of empirical parameters. Then, by choosing Si nanowires as reference model [3], I will explain the effect of quantum confinement on the electronic structure, the transport properties as well as the dopant incorporations with respect to the bulk material.

The second part of the talk will consist of an overview of the computational modeling of a particular class of nanostructures, Silicon-Germanium Nanowires (SiGe NWs) [6]. I will outline how by bringing together two similar elements –Si and Ge, neighbors in the periodic table–, a rich variety of new chemical and physical properties emerge, stimulating both fundamental and application-driven research in nanoscience. Indeed I will show that substituting some of the atoms of a pure Si NW with Ge in random as well as ordered configurations of different compositions, can strongly affect some fundamental properties such as electronic structure, scattering processes and doping effects.

References

[1] S. E. Thompson and S. Parthasarathy, Mater. Today **9**, 20 (2006).

[2] N. Daldosso and L. Pavesi, Laser Photonics Rev. **3**, 508 (2009).

[3] R. Rurali, Rev. Mod. Phys. **82**, 427 (2010).

[4] L. Khriachtchev, S. Ossicini, F. Iacona, F. Gourbilleau, Int. J. Photoenergy **1**, 2012 (2012).

[5] J. P. Perdew, S. Kurt, Primer in Density Functional Theory, Springer, Berlin (2003).

[6] M. Amato, M. Palummo, R. Rurali, S. Ossicini, Chem. Rev. **114**, 1371 (2014).

WEDNESDAY

Anne Ponchet

Wednesday, 9 - 11 am

Structural and chemical properties of epilayers in heteroepitaxy

Anne Ponchet

Centre d'élaboration de matériaux et d'études structurales, CNRS

A possible definition of heteroepitaxy is the growth of an A crystal (the so-called epilayer) onto a B crystal (the so-called substrate) where the B crystal imposes to the A crystal at least one element of crystalline symmetry. Keeping in mind this definition, we will review the physical origin of the structural and chemical properties of an epilayer compared to the bulk state.

A and B crystals can differ by their crystalline lattice, their lattice parameter and/or their chemical composition. Many of the structural properties of the epilayer come from the necessary accommodation of the A crystal to the B crystal through an interface. For instance, a suitable epitaxial relationship can allow the crystalline system of A to accommodate that of B, if different. The difference of lattice parameters (lattice misfit or mismatch) is accommodated by elastic strain of the epilayer and/or plastic relaxation through misfit dislocations located at interface. The difference of chemical composition induces specific interfacial bonding and/or intermixing at interfaces. In addition, as epitaxial growth is an out-of-equilibrium process, the epi-layers can adopt metastable phases which do not exist in bulk state. Finally interfaces and surfaces them-selves play a major role in the growth modes, in particular through the classical concepts of wetting/dewetting involving energies of the A and B surfaces and of the A/B interface. Due to the crystalline character of the materials, faceting also has an important impact on the morphology.

The talk will be illustrated by examples taken in various systems, most often studied by transmission electron microscopy, which is one of the most powerful and versatile tool to study these properties at different scales.

Francesca Cavallo

Wednesday, 11:30 am- 12:30 pm

Growth on exotic substrates

Francesca Cavallo

Center for High Technology Materials and Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque, NM-87106

The subject of this course is epitaxial growth on substrates with at least one dimension in the nanoscale. I will illustrate the basic mechanism of epitaxy on nanomembranes (NMs) and nanoribbons (NRs), describe a few examples, and provide a comparative analysis with growth on conventional bulk substrates. I will show that, due to their unique elastic properties, NMs and NRs substrates enable global and local strain engineering, as well as hybrid materials integration via epitaxial growth. Finally I will present a few potential applications and future directions of growth on these exotic substrates.

THURSDAY

Bernardette Kunert

Thursday, 9 - 11 am

Integration and application of epitaxial systems: III/V on Silicon for optoelectronics

Bernardette Kunert

IMEC

This course is divided into two parts: Fundamentals and Optoelectronic devices.

The content of the first basic part is the origin of crystal defects and their impact on optoelectronic device performance. In addition the main challenges of metal organic vapor phase epitaxy (MOVPE) of III/V hetero-structures on Silicon will be discussed.

The second part is an overview of III/V optoelectronic device application on Silicon. Different laser and multi-junction solar cell integration concepts will be introduced and compared.

Anna Fontcuberta i Moral

Thursday, 11:30 am-12:30 pm

Optical properties of nanostructures

Anna Fontcuberta i Moral

École Polytechnique Fédérale de Lausanne

In this course we will present some of the main techniques for characterizing the functional properties of nanostructures, illustrated with examples on III-V nanowires and related heterostructures. We will start by explaining simple electrical characterization of nanowires, including pn junctions. We will follow by the optical methods including photoluminescence, cathodoluminescence and Raman spectroscopy.

Ernst Bauer

Thursday, 2:30 -3:30 pm

The study of epitaxy with Low Energy Electron Microscopy (LEEM)

Ernst Bauer

Arizona State University

LEEM is one of the most powerful methods for the study of epitaxy from the vapor phase. It owes its power to the high surface sensitivity, fast image acquisition time, good spatial resolution and structurally and chemically sensitive contrast. Combined, these properties allow the study of the growth and annealing of epitaxial systems in real time.

After a very brief recount of epitaxy studies with electron beam methods the lecture will first present the properties of LEEM, which define its possibilities and limitations. Instrumentation will also be discussed briefly. Most of the talk will be used to illustrate the application of LEEM in epitaxy with selected studies (metals, semiconductors, graphene, organics), mainly of monolayer by monolayer growth and the transition to three-dimensional growth. Kinetic and/or thermodynamic parameters, which determine the growth, can be deduced from detailed studies, as illustrated with an example. In cases, in which reaction with the substrate occurs, the combination with spectroscopic XPEEM is useful for the identification of the reaction products as shown for a metal on semiconductor system.

When spin-polarized electrons are used for imaging not only the crystal structure and orientation can be imaged but also the magnetic domain structure, with a high brightness source also in real time. Only the principle of contrast formation and a brief illustration will be given as magnetic epitaxial systems will be discussed in Dr. Fruchart's talk.

References

1. Ernst Bauer: Surface Microscopy with Low Energy Electrons, Springer, New York 2014.For epitaxy in particular chapters 5.2, 5.3. This book describes also spectroscopic XPEEM.

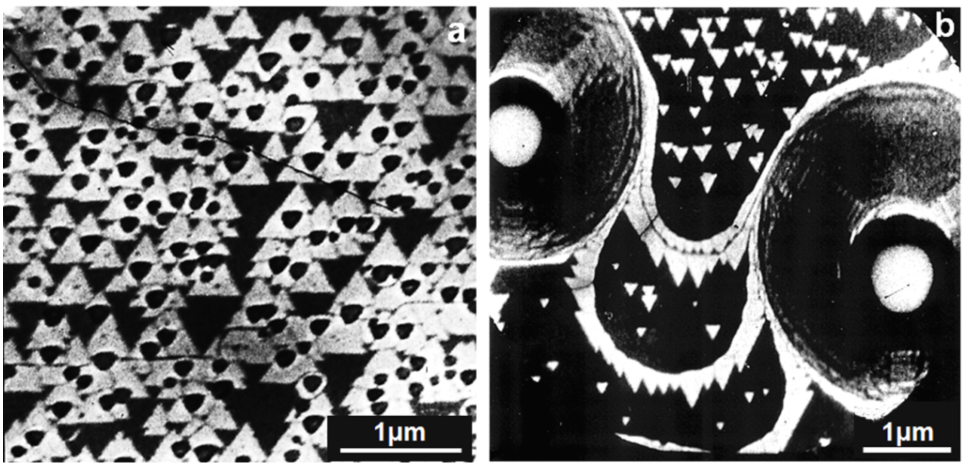

Figure 1: LEEM of epitaxial $CoSi2$ on Si(111).

Gilles Renaud

Thursday, 3:30 -4:15 pm

X-ray diffraction and unique objects

Gilles Renaud

Institut Nanosciences et Cryogénie, CEA, Grenoble

Nanoparticles have new physical properties that are intimately linked to their size, shape, internal atomic structure and composition. Characterizing these structural properties, if possible in situ and/or operando during their growth or operation is thus of prime importance. X-rays have been used for decade to study ensemble of nanoparticle, which thus had to be made as identical to each other as possible, while investigating single nanoparticles was reserved to electron-based tools. These later however could seldom be used in situ, operando. With parallel development of 3rd generation synchrotron X-ray source and now 4th generation X-ray free electron laser (FEL), of devices to focus even hard X-rays down to the nanoscale and of powerful and fast 2D X-ray detectors, it has recently become possible to investigate the structural properties of single nano-objects, with precisions that become close to those of electron microscopy techniques, with the advantage of being able to handle very different kind of sample environments, allowing to play easily with extern al parameters such as temperature, pressure, reactive gaseous or liquid environment, as well as studying nanoparticles embedded in real fonctionning devices such as microelectronic chips.

The principle and examples of the main experimental techniques will be reviewed and some examples given. These techniques can be listed as 1) Scanning Fluorescence Microscopy providing maps of composition, 2) X-ray nanotomography, which allows a complete 3D reconstruction of nano-objects yielding 3D information on shape, strain or composition, 3) Scanning Diffraction X-Ray Microscopy, providing maps of structural information such as strain, composition, tilts, the presence of defects .4) Scanning Laue X-ray Diffraction, providing 2D and even 3D information on shape, orientation and strain in nano-micro-structured materials, and finally the fast developing techniques using 5) Coherent X-rays to recover the phase of the diffracted intensity in the so-called Coherent X-Ray Diffraction Imaging (CDI) technique, thus allowing to deduce a complete 3D information on shape and strain of nanostructures as small as 100 nm, with a resolution as good as 5 nm, tending to 0.1 nm in the future, with the use of X-FEL sources. Complementary techniques such as 6) Fourier Transform Holography and 7) Bragg Ptychography will also be briefly introduced.

With the development of many dedicated X-ray beamlines and instruments around the world, these techniques are developing very fast and more complicated samples such as bio-molecules are being investigated, as well as samples in complex environments.

References

A useful introduction to modern X-ray physics can be found in:

[1] Modern X-ray Physics by J. Als-Nielsen and Des McMorrow, Wiley, 2011

Recent advances in these fields have been gathered in a few references:

[2] Nanobeam X-Ray Scattering by J. Stangl et al, Wiley-VCH, 2014

[3] I. Robinson and R. Harder, Natur. Mater. **8**, 291 (2009)

[4] G. Ice et al., Science **334**, 1234 (2011)

[5] W. Yang et al, Nature comm. **4**,1680 (2013)

[6] M.A. Pfeifer et al., Nature **442**, 63 (2006).

Jean-Christophe Harmand

Thursday, 4:45 -5:45 pm

Growth of nanowires

Jean-Christophe Harmand

Laboratoire de Photonique et de Nanostructures, CNRS

Semiconductor nanowires present intriguing features and their growth is governed by mechanisms which can differ significantly from those at play in standard two-dimensional growth. The course will concentrate on these mechanisms which are specific to nanowire growth and which determines their morphology, chemical composition, growth kinetics and crystal structure:

- The presence of a catalyst particle is requested in most cases. The catalyst material alloys with the nanowire constituents and then constitutes a reservoir of species available for growth. The important and multiple roles of this reservoir will be described.
- Rapidly, the growing system presents various types of surfaces and interfaces (the substrate surface, the nanowire sidewalls and the catalyst surface). These different sites are not equivalent for the incident gaseous species. The impact on adsorption, surface diffusion, condensation or re-emission rates of these species will be discussed.
- Unlike the bulk material, a nanowire of semiconductor can adopt different crystalline structures depending on growth conditions. The reason for this polytypism is intimately related to the nucleation of each monolayer at the interface between the nanowire top facet and the catalyst particle. I will present our current understanding of this crystal phase issue.

These different phenomena will be illustrated with examples, from III-V nanowire growth mostly.

Olivier Fruchart

Friday, 5:45 -6:30 pm

Epitaxy and magnetic materials

Olivier Fruchart

CNRS, Institut NEEL, Université Grenoble Alpes, Grenoble, France

Epitaxy of magnetic materials started has been used as soon as ultra-high vacuum technology was developed, around fifty years ago. For most materials magnetism is a rather robust property, so that oriented single crystal materials are not necessary to develop specific properties. Thus, epitaxy has been essentially used to deliver model systems, and perform fundamental inverstigation of low-dimensional and interfacial magnetism. While for several decades the issues investigated pertained mostly to magnetism, epitaxy is currently being used in spintronics, entangling magnetism and transport properties. In both fields, epitaxial or textured magnetic materails are now being implemented in devices. I will provide examples of some fields where epitaxy enabled specific progress in the field :

- Self-organization to deliver dots, wires and columns, for investigations of magnetic domains and magnetization reversal.
- Magnetic ordering in low dimensions : ordering temperatures, critical exponents, metastable crystal structures and magnetic phases.
- Surface / Interface magnetic anisotropy, from fundamentals to applications in random access memories.
- Interlayer exchange coupling and tunneling magnetoresistance, where epitaxy brought enhanced effects, exploiting the anisotropy of band structure and the Fermi surface.
- A recent and fast-rising topic : the so-called Dzyaloshinskii-Moriya interaction, and exchange-like term occurring specifically at interfaces (or more generally in crystals with absence of inversion symmetry), favoring spin spirals, cycloids and skyrmions, instead of the usual ferromagnetic or antiferromagnetic states.

References

[1] U. Gradmann, Magnetism in ultrathin transition metal films, 1-96 , in Handbook of magnetic materials 7, K. H. J. Buschow (ed.), Elsevier Science Publishers B. V., (1993) : a reference for low-dimensional and interfacial magnetism

[2] O. Fruchart, A. Thiaville, Magnetism in reduced dimensions, C. R. Physique **6**, 921 (2005) : a light review of nanomagnetism

[3] C. R. Physique **6** (2005) : a set of topical reviews of spintronics

[4] X. Z. Yu, Y. Onose, N. Kanazawa, J. H. Park, J. H. Han, Y. Matsui, N. Nagaosa, Y. Tokura, Real-space observation of a two-dimensional skyrmion crystal, Nature **465**, 901 (2010) : a seminal paper in the field of magnetic skyrmions

[5] W. Jiang, P. Upadhyaya, W. Zhang, G. Yu, M. B. Jungfleisch, F. Y. Fradin, J. E. Pearson, Y. Tserkovnyak, K. L. Wang, O. Heinonen, S. G. E. te Velthuis, A. Hoffmann, Blowing magnetic skyrmion bubbles, Science **349**, 283 (2015) : an example of magnetic skyrmions obtained in ultrathin stacks

FRIDAY

Thierry Baron

Friday, 8:30 - 10 am

Heteregeneous integration and applications in electronics

Thierry Baron

Laboratoire des Technologies de la Microélectronique, CEA, LETI

Integration of nanomaterials, i.e., nanocrystals, nanowires and also thin films of SiGe and III-V semiconductors in nanoelectronics could allow to boost the performances of integrated circuits. In this lecture, we will mainly discuss about (i) the Si and Ge nanocrystals growth for memory devices, (ii) the Si and SiGe nanowires growth for low power devices and sensors, and (ii) SiGe and InGaAs thin film growth performance boosting of MOSFET transistors.

Didier Dutartre

Friday, 10 - 11 am

Industrial Applications of Si-based Epitaxy in Electronics

Didier Dutartre

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Si, SiGe, SiC and Ge heteroepitaxial depositions (epi) are of great interest in Si technologies as they allow dramatic performance improvements or even new devices fabrication at a minimal additional cost.

In this lecture, the various epi-techniques will be briefly reviewed and will be benchmarked for an industrial usage; and RTCVD that is found to present more advantage than competitors is indeed the most developed/adopted one. Then, taking the ST-Crolles example, important today epi-applications will be presented. This allows the main requirements/challenges of industry to be listed and discussed. And among them, we will focus more deeply on the temperature control in RTCVD tool, probably the main difficulty of the technique, and on the "small size effects" that did not receive much attention in industry despite they became very important in advanced devices.

In the final part, we will summary the recent and future trends in epi processes.

Irene Paola de Padova

Friday, 11:30 am-12:30 pm

sp2 materials

Irene Paola de Padova

Instituto di Struttura della Materia, Roma

Silicene, germanene, phosphorene and stanene sheets are 2D layered materials beyond graphene, which discovery has been a starting point for exploiting the matter physics frontiers, both from theoretical and experimental point of view. They are the new emergent elemental 2D systems, expected to exhibit topological insulator character, a new highly promising phase of matter, which nowadays could play a fundamental role in the future nano-micro-electronics, spanning from energy saving to FET and smart devices.

The course will include

- Introduction to 2D materials beyond graphene: silicene, germanene, phosphorene and stanene;
- Confined states in silicene nano ribbons (SiNRs);
- Core level photoelectron spectroscopy and ARPES on single and multilayer SiNRs/Ag(110) and multilayer silicene/Ag(111).

Jean-Yves Duboz

Friday, 2 - 3 pm

Epitaxy in the development of LEDs

Jean-Yves Duboz

Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications

LEDs, in particular LEDs based on AlGaInN, have experienced a rapid and spectacular development in recents years which allows solid state lighting to be a reality. In the lecture, I will explain the basic physics in action in an LED, and its key parameters. I will show that most critical aspects of the LED performance are addressed during the epitaxy, even if epitaxy is not the only important step in the LED fabrication. I will discuss issues related to substrate choice, growth technique, polarity, InGaN alloy, doping. I will finish with some economical aspects related to epitaxy.

Aristide Lemaitre

Friday, 3 -3:45 pm

Applications of epitaxial semiconductor heterostructures for fondamental research

Aristide Lemaitre

Laboratoire de Photonique et de Nanostructures, Marcoussis

In 1969, Esaki and Tsu envisioned the synthesis of semiconductor superlattices made of alternating layers with different dopings or compositions. Their original idea was to shrink down the superlattice period below the electron mean free path to enter the quantum regime in reduced dimensionality. High vacuum epitaxial techniques made this proposal realized experimentally a few years later. Since then, physicists have made tremendous progresses in designing and fabricated novel heterostructures to explore new concepts and devices for both fundamental and applied research in electronics and photonics.

In this lecture, I will describe first how semiconductor heterostructures give us this unique opportunity to tailor the electronic and optical properties in quantum wells, wires and dots. I will show how we can now confine electrons, photons and phonons in 0D, 1D and 2D thanks to major advances in epitaxial techniques, as improved interface abruptness, lower impurity background, band structure alignement, strain engineering, doping, self-assembly. I will also introduce some of the quasi particles found in these structures like excitons, polaritons, polarons which are ubiquitous in these systems.

Then I will present recent outstanding results and challenges in fundamental physics that relied on epitaxial semiconductor heterostructures, such as single photon and electron sources, cristalline Bragg mirrors, microcavity polaritons, ultra-high mobility 2D electron gaz, mesoscopic circuits...

List of posters

Session	Surname	Name	modeling and experiments
1	Jeanne	BECDELIEVRE	Core-shell nanowires for piezotronics
2	Rozenn	BERNARD	GaP/Si Antiphase domains annihilation at the early stages of growth
1	Daria	BEZNASIUK	Towards axial Si/GaAs nanowire heterostructures
2	Guillaume	BINET	Study of Semi-Insulating Buried Heterostructure 1.3µm Electro-Absorption Modulated Laser
2	Valeria	BRAGAGLIA	On how to fabricate single crystalline and highly ordered GeTe-Sb_2Te_3 alloys on Si (111)
1	Stefano	CURIOTTO	Self-propelled motion of Au-Si droplets on Si substrates and Si nanowires growth
2	Roy	DAGHER	CVD growth of graphene on SiC(0001) in hydrogen-argon atmosphere
1	Zhenning	DONG	Ga-Catalyst GaAs Nanowires grown on Silicon by HVPE
2	Maria	FAHED	V/III flux ratio effect on faceting for nanoscale selective area growth of InAs and InP by molecular beam epitaxy
1	Zhihua	FANG	High Si incorporation in MBE - grown GaN nanowires
2	Luc	FAVRE	Quantitative study of Ge diffusion in strained Si during epitaxial growth
2	Janina	FELTER	Applicability of nucleation theory to the initial growth of molecular islands
2	Chantal	FONTAINE	GaAs nanowires with oxidation-proof arsenic capping for the growth of epitaxial shell
1	Xin	GUAN	GaAs nanowires with oxidation-proof arsenic capping for the growth of epitaxial shell
1	Nicolas	JAMOND	GaN nanowires based piezogenerator
1	Hanno	KÜPERS	Growth approaches for GaAs/(Al,Ga)As core-shell nanowires in molecular beam epitaxy and their impact on the luminescence
2	Martin	LANIUS	Growth and Characterization of Ultrathin Topological Insulator Sb_2Te_3 /Bi_2Te_3 heterostructures on Si(111) grown by means of Molecular Beam Epitaxy
2	Kee Han	LEE	Diamond heteroepitaxy on up-scalable Ir / $SrTiO_3$ / Si (001)
1	Jean-Baptiste	LERAN	III-V Nanostructures Grown by Molecular Beam Epitaxy
1	Kailang	LIU	Nucleation behaviors and interactions of SiGe/Si (001) islands:
2	Kevin	LOUARN	III-V based Tunnel Heterojunction for Multijunction Solar Cells
1	Dominique	MANGELINCK	3D Analysis of II-VI nanostructures by atom probe
2	Enrica	MURA	Influence of hydrides on InP self-assembled nanostructures grown by MOVPE
1	Thomas	PHILIPPE	Phase-Field Modeling of Nanowire Growth

1	Giacomo	PRIANTE	Axial heterostructures in self-catalyzed nanowires
2	Søren	ROESGAARD	Light emission from silicon with tin-containing nanocrystals
2	Julius	ROMBACH	Electrical conductivity and gas-sensing properties of doped and undoped single-crystalline In_2O thin films: bulk vs. Surface
2	Marco	SALVALAGLIO	Phase-field modeling for the morphological evolution of three-dimensional crystals
2	Eduard	STERZER	Novel precursors for Ga(NAs) MOVPE growth with potentially less carbon incorporation for optoelectronics application
1	Davide	TEDESCHI	Nanowires Are Not So Cool
2	Jenny	TEMPELER	Directed Self-Assembly of Germanium Quantum Dots with E-Beam and EUV Interference Lithography
1	David	VAN TREEK	Electroluminescence and current-voltage measurements of single (In,Ga)N/GaN nanowire light emitting diodes in the nanowire ensemble
2	Patrick	VOGT	Comprehensive In-Situ Study of the Reaction Kinetics for the MBE growth of Ga2O3
1	Qian	ZHANG	Mechanisms of Morphological Evolution on Faceted Core-Shell Nanowire Surfaces

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