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First NFFA Europe SCIENCE WORKSHOP

27 & 28 March 2017

TRIESTE-ITALY

Your gateway to nanoscience: open-access research at NFFA-Europe facilities

27 MAR

09:00 **Welcome**
Giorgio Rossi
Project Coordinator,
CNR-IOM, Trieste (Italy)

09:20 **Research by NFFA-Europe users**
Luis Fonseca
Transnational Access Activity Manager,
CSIC-CNM, Barcelona (Spain)

Keynote Speaker Presentation
09:45 **Trends in Nanoscience**
Lars Montelius
International Iberian Nanotechnology Laboratory, Braga (Portugal)

10:30 *Coffee Break*

NFFA-Europe User Presentation
10:45 **Metal Enhanced Resists for EUV Lithography - Can We Go Beyond Secondary Electron Blur?**
Carmen Popescu
University of Birmingham (UK)

NFFA-Europe User Presentation
11:05 **Atomic-to-Microscale Evaluation of Large-Area Two-Dimensional Metal Dichalcogenides for Microelectronics**
Kim HoKwon
EPFL, Lausanne (Switzerland)

NFFA-Europe User Presentation
11:25 **Magnetoelectricity in $La_{2-x}Sr_xNaO_4$**
Zacharias Viscadourakis
University of Crete (Greece)

NFFA-Europe User Presentation
11:45 **Extreme Ultraviolet Induced Chemical Reactions in Photoresists and Model Systems**
Sonia Castellanos
Advanced Research Center for Nanolithography - ARCNL, Amsterdam (The Netherlands)

Keynote Speaker Presentation
12:05 **The Nanoscience Data Challenge**
Rainer Stotzka
Karlsruher Institute für Technologie, Karlsruher (Germany)

12:50 *Free time for lunch*

15.30 **Visit to NFFA-Europe Installations and Neighbouring Facilities in Basovizza (Trieste)**

RESTRICTED MEETINGS

13:00/14:15
SIAP Meeting
business lunch at Hotel Savoia Restaurant

14:25/17:25
ARP Meeting
Sala Riviera

14:30/19:00
General Assembly Meeting
Sala Tergeste

20:30 **Workshop Dinner**

28 MAR

09:15 **Welcome**
Giorgio Rossi
Project Coordinator,
CNR-IOM, Trieste (Italy)

09:25 **The Joint Research Activities and the integration of the NFFA-Europe science programmes**
Giancarlo Panaccione
Joint Research Activity Manager
CNR-IOM, Trieste (Italy)

Joint Research Presentation
09:30 **First Prototype for the NFFA Information and Data Repository Platform (IDRP)**
Stefano Cozzini
CNR-IOM, Trieste (Italy)

Joint Research Presentation
09:45 **Towards Zone Plates with sub-10nm Resolution**
Benedikt Rösner
Paul Sherrer Institute (Switzerland)

Joint Research Presentation
10:00 **Adatom Promoted Graphene Growth on Ni Imaged by STM at Video-Rate and Above**
Laerte Patera
University of Regensburg (Germany) and
CNR-IOM, Trieste (Italy)

Joint Research Presentation
10:15 **High Resolution Guiding Patterns for Directed Self Assembly of Block Polymers**
Francesc Perez-Murano
IMB-CNM, CSIC, Bellaterra (Spain)

Joint Research Presentation
10:30 **Nanoimprint Stamps with Ultra-High Resolution: Analysis of Fabrication Approaches**
Ivan Maximov
Lund Nano Lab, Lund University
(Sweden)

10:45 *Coffee Break*

Joint Research Presentation
11:00 **Advanced Nano-Object Transfer and Positioning - Strategy, Status and Application for Single Nanoparticle Tracking During in-situ Catalysis**
Thomas Keller
DESY, Hamburg (Germany)

Joint Research Presentation
11:30 **Ultra-fast Processes in Realistic Materials: Challenges, Perspectives, Users and Communities**
Emmanuel Stratakis
FORTH (Greece)
& Andrea Marini
ISM-CNR (Italy)

12:00 **Round Table on new science @ NFFA-Europe**

13:00 **Conclusions**

13:15 *Free time for lunch*

RESTRICTED MEETINGS

14:30/17:30
JRA1 meeting
Sala Tergeste

14:30/17:45
JRA5 meeting
Sala Riviera

NFFA-Europe User Presentation

Metal Enhanced Resists for EUV Lithography - Can We Go Beyond Secondary Electron Blur?

Carmen Popescu
University of Birmingham (UK)

The last 50 years showed a great progress of microelectronics and pushed the manufacturing techniques to continuous improvement to enable the fabrication of smaller and more complex components. However, the increasing difficulty in maintaining the progress comes from resolution limitation of photolithography. Extreme Ultraviolet Lithography is the leading candidate to replace the photolithography with capabilities of patterning sub 10 nm features without being limited by Rayleigh criterion. However, while the EUV tools are taking more part in the lithography process there still not exist a perfect resist material that demonstrates high resolution, high sensitivity and low edge roughness in the same time. The current trend is to increase the optical density of the material by incorporating a metal. However, this is not enough in the context of the effects of the resist matrix on the propagation and interaction of secondary electrons generated by the photons. We have demonstrated before via preliminary results at PSI that the metal addition significantly affects the pattern quality and we attribute this to secondary electron blur. In this project, we study the effect of metal choice on the performance of an organometallic resist. Various loading levels are being investigated and their effects on sensitivity, resolution, linewidth roughness and resist profile after exposure with EUV-IL and electron beam lithography.

NFFA-Europe User Presentation

Atomic-to-Microscale Evaluation of Large-Area Two-Dimensional Metal Dichalcogenides for Microelectronics

Kim HoKwon
EPFL, Lausanne (Switzerland)

Recently, two-dimensional layered transition metal dichalcogenides (TMDs) have been receiving increasing amount of attention due to its unique properties such as large surface area, electronic properties, and mechanical flexibility. These properties have been intensively sought by various industrial fields where the 2D TMDs can be integrated into the existing and emerging technologies such as field effect transistors and spintronics. Toward this end, large-area deposition technique has been developed via van der Waals epitaxy on single crystalline substrates for molybdenum disulphide monolayers [1,2] that results in single crystalline monolayers with grain size larger than 10 um, which now can approach a record carrier mobility of ~ 1000 cm2/Vs at low temperatures. [3] However, the challenge remains where the 2D materials grown this way are not sufficiently characterized for its intrinsic properties such as atomic structures, doping, and electronic structures, as well as their dependencies on the growth parameters. In this work, we proposed to address this issue by combining two characterization techniques provided by the NFFA infrastructure

- scanning transmission electron microscope (Titan Ultimate transmission microscopy, Grenoble-CEA, France) and photoemission electron spectroscopy and imaging (NanoESCA PEEM/kPEEM system, Grenoble-CEA, France) on the same region of freestanding TMDs. In this scheme, the freestanding 2D materials that were transferred onto conductive silicon nitride grids of 10 - 20 μm diameter could be analyzed first by STEM at 80 kV for their atomic crystalline structure followed by the same area PEEM and kPEEM images. In this way, we could correlate the atomic scale observations (ex. defect densities) with the intrinsic doping and electronic structure of the material that are crucial for our ongoing work on the development of TMD-based applications. Additionally, the freestanding sample was selectively irradiated by an electron beam in the STEM system in order to induce intentional e-beam induced defects. These defects were first imaged by STEM for identification of their atomic structures, and then their influence on the doping and electronic structure was further investigated by the complementary NanoESCA measurements. The results yielded during the session is expected to provide a key understanding on the growth mechanism and defect engineering of the material and new insights for further materials synthesis and characterization of the 2D materials.
In the presentation, I will mainly discuss the experimental methodology that we have employed during the allocated NFFA session and present the achievements and challenges that were encountered during the sample preparation and measurements.

[1] D. Dumcenco, D. Ovchinnikov, K. Marinov, P. Lazić, M. Gibertini, N. Marzari, O. L. Sanchez, Y.-C. Kung, D. Krasnozhon, M.-W. Chen, S. Bertolazzi, P. Gillet, A. Fontcuberta i Morral, A. Radenovic, and A. Kis, ACS Nano 9, 4611 (2015).
[2] K. Kang, S. Xie, L. Huang, Y. Han, P. Y. Huang, K. F. Mak, C.-J. Kim, D. Muller, and J. Park, Natur 520, 656 (2015).
[3] X. Cui, G.-H. Lee, Y. D. Kim, G. Arefe, P. Y. Huang, C.-H. Lee, D. A. Chenet, X. Zhang, L. Wang, F. Ye, F. Pizzocchero, B. S. Jessen, K. Watanabe, T. Taniguchi, D. A. Muller, T. Low, P. Kim, and J. Hone, Nat Nano 10, 534 (2015)

NFFA-Europe User Presentation:
Magnetoelectricity in $La_{2-x}Sr_xNaO_4$
Zacharias Viscadourakis
University of Crete (Greece)

Magnetoelectric effect (ME) can efficiently be defined as the phenomenon of the inducing magnetic moment, by applying an external electric (magnetic field) field, of the induction of electric polarization upon the presence of an external magnetic field. Achieving a coupling between an external magnetic field and the dielectric properties of a material (or vice versa) is a promising tool for further technological applications, such as producing devices for data storage, modulation of optical waves, optical diodes, spin-wave generation, amplification and conversion etc. Motivated by the above potential technological applications researchers intensified their efforts to find out materials that intrinsically exhibit both magnetism and electric polarization (ferroelectricity), which are widely-called multiferroics [1, 2]. However, intrinsic mechanisms, producing coupling between magnetism and ferroelectricity in materials, are limited and new routes are constantly sought.
The La(2-x)Sr(x)NiO4 (LNSO) system has so far been studied for its similarity to the high-Tc cuprates [3, 4]. While undoped La2NiO4 is a Mott insulator, doping with Sr causes the induced holes to segregate into periodic one dimensional “stripes”, below a charge ordering

temperature - Tco. At a lower spin order temperature - Tso, Ni spins order in between the stripes, which act as domain walls for the antiferromagnetic order. Thus, spin and charge order coexist in LSNO, suggesting the possible coupling between them.
Indeed, several previous reports evidently indicate the strong spin-charge correlation in LSNO, over a wide doping range $0.2<x<0.5$. Apart from the fact that Tso and Tco follow the same trend [5], recent ultrafast X-Ray experiments have shown coupled dynamics of spin and charge order parameters [6] for $x=0.25$. Notably recent preliminary pyroelectric current experiments [7] shew that LNSO, $x=1/4$ and $x=1/3$, exhibits a low temperature non-zero spontaneous pyroelectric current, the temperature and the magnetic field dependence of which, shows strong two-dimensional character.
Here, we perform a detailed investigation of the dielectric permittivity of the LSNO system. To this point, the study of the complex dielectric constant $\varepsilon = \varepsilon' + j\varepsilon''$ of LSNO single crystals, with respect to both the temperature and the magnetic field, is thoroughly studied. Special care has taken regarding the direction of the dielectric constant measurements. In particular, ε vs. H measurements, is performed along different crystallographic directions, so as to study the anisotropy (if any) of the dielectric constant. Furthermore, the evolution of the ε as a function of the Sr doping, is studied, since the stripe order is affected by the Sr concentration. Dielectric permittivity investigation is further supported by pyroelectric current experiments. LNSO, $x=1/4$ and $x=1/3$, exhibits a low temperature non-zero spontaneous pyroelectric current, the temperature and the magnetic field dependence of which, shows strong two-dimensional character. The above-mentioned studies will shed light to the possible coupling between the spin stripes and the electric polarization.

[1] S-W.Cheong et al. Nat. Mater. 6, 13 (2007)
[2] M. Feibig J. Phys. D; Appl. Phys. 38, R123 (2005)
[3] E. D. Isaacs et al. Phys. Rev. Lett. 72, 3421 (1994)
[4] G. Coslovich et al. Nat Commun. 4, 2634 (2013)
[5] H. Yoshizawa et al. Phys. Rev. B 61, R854 (2000)
[6] Y. Chuang et al. Phys. Rev. Lett. 110, 127404 (2013)

NFFA-Europe User Presentation

Extreme Ultraviolet Induced Chemical Reactions in Photoresists and Model Systems

Sonia Castellanos
Advanced Research Center for Nanolithography - ARCNL, Amsterdam (The Netherlands)

EUV lithography is emerging as the most promising technique to fabricate nanosized structures on industrial scales. However, this technology is facing a lack of photoresist materials that offer simultaneously good resolution, high sensitivity and low line edge roughness. Hybrid inorganic/organic materials are considered the next step in materials for extreme ultraviolet (EUV) photolithography, beyond the limits of what can be achieved with the traditional chemically amplified photoresists. In ARCNL we investigate how variables defined by the molecular structure, such as the elemental composition of the material and the type of chemical bonding, affect the sensitivity towards EUV light. For that purpose, we have prepared a series of materials with rationally controlled variation of structure and composition to test their efficiency in EUV induced pattern formation. This set of materials include Sn-based metal-organic compounds [1] and Zr- and Hf-based metal-oxoclusters decorated with methacrylate ligands. [2] In addition, we perform some studies on the effect of processing parameters in the solubility switching in order to understand what extra chemical changes are induced by post-exposure backing. These aspects were evaluated by means of interference lithography performed in the SLS-XIL unit combined with AFM and SEM monitoring in the Paul Scherrer Institute. Next, we are investigating the chemical changes by means of spectroscopic techniques like FTIR, UV-vis absorption. The experiments revealed that our Sn-based model photoresists show higher EUV sensitivity than previously reported. [1] We also observed differences in the absorptivity and sensitivity for materials containing different metals, the Sn-oxocages exhibiting values close to commercial EUV photoresists. The identification of the photoproducts obtained in each case will allow us to propose a mechanism that leads to the solubility switch. In this manner, we intend to correlate how the molecular structure governs the efficiency of hybrid EUV photoresist. The results obtained are highly relevant for the future design of efficient EUV photoresists since they help us to understand the EUV induced photochemistry at a molecular level and thus to pin point what components in the materials are the most relevant to tune their performance in EUV lithography.

Keynote Speaker Presentation

The Nanoscience Data Challenge

Rainer Stotzka
Karlsruher Institute für Technologie, Karlsruher (Germany)

Nanoscience is a huge research field which is also represented in the variety and diversity of the data. It ranges from single numbers to complex measurements and simulations resulting in millions of files. Often the data is stored in local computers and fragmented infrastructures. Sufficient data descriptions as metadata enabling data reuse in new scientific contexts seldom exist.
In this talk the prerequisites for data findability, accessibility, interoperability, and reusability are discussed. Metadata and common metadata standards are essential components for fulfilling these. Several organizations, like the Research Data Alliance, the European project EUDAT, and CODATA, provide recipes and infrastructure components for building up discipline-specific and interoperable infrastructures for nanoscience.
The full scientific impact of data can be reached if the data is accessible and reusable according to an open license. In combination with assisting infrastructure tools researchers can be supported in finding and discovering scientific results and disseminating their own findings.

ABSTRACTS

Joint Research Presentation

First Prototype for the NFFA Information and Data Repository Platform (IDRP)

Stefano Cozzini
CNR-IOM Trieste (Italy)

In this short presentation, we illustrate the IDRP prototype developed within our JRA and deployed on the CNR/IOM cloud infrastructure. A typical NFFA-use case based on SEM images will be discussed and all the steps (load/store/register/publish) of the complete data workflow associated with such example will be presented.

Joint Research Presentation

Towards zone plates with sub-10 nm resolution

Benedikt Rösner
Paul Sherrer Institute (Switzerland)

Fresnel zone plates are widely used as lenses for nanoimaging in X-ray microscopy. The diffraction-limited resolution of such a lens is related to the width of its outermost zone, giving rise to the need for fabricating structures in the nanometre regime. I will present recent progress in fabricating zone plates with line widths below 10 nm, down to 6.4 nm. First experiments at 750 eV show promising results in terms of efficiciency, and exhibit competitive resolutions to established zone plate designs.

Joint Research Presentation

Adatom Promoted graphene growth on Ni imaged by STM at video-rate and above

Laerte Patera
University of Regensburg (Germany) and CNR-IOM Trieste (Italy)

Low-coordinated metal atoms have been shown to display enhanced reactivity in many model systems. Here we demonstrate, both experimentally and theoretically, the catalytic role played by single metal adatoms during the spontaneous and technologically relevant process of graphene growth on Ni. The elusive catalytic action of individual Ni atoms at the edges of a growing graphene flake is directly captured by Scanning Tunneling Microscopy imaging at the ms time scale, thanks to the Fast-scan add-on module recently developed as Joint Research Activity within the NFFA-Europe project. Density Functional Theory calculations rationalise the experimental observations. Our results provide a full atomistic description of the growth mechanism, showing that the single atom Ni catalyst acts as a knitting needle, allowing new carbon stitches to be incorporated in the expanding graphene fabric.

Joint Research Presentation

High resolution guiding patterns for directed self-assembly of block polymers

Francesc Perez-Murano
IMB-CNM, CSIC, Bellaterra (Spain)

Directed self-assembly (DSA) of block co-polymers (BCPs) is considered as one of the most prominent methods for large are patterning at single digit resolution. DSA of BCPs is based on creating patterns on a surface that guide the self-assembly of BCPs. We will present our results on developing methods for the creation of sub-10 nm guiding patterns based on advanced top-down lithography, including X-ray interference lithography, electron beam lithography and atomic force microscopy lithography. Issues about metrology for DSA will also be addressed, as for example the use of Grazing Incidence Small Angle X-ray Scattering (GISAXS).

Joint Research Presentation

Nanoimprint Stamps with Ultra-High resolution: Analysis of Fabrication Approaches

Ivan Maximov
Lund Nano Lab, Lund University (Sweden)

In my presentation, I will give a short overview of technolology of nanoimprint stamps with features of the order of 10 nm developed within JRA2 of the NFFA-Europe project. Different methods of fabrication of the ultra-high resolution nanoimprint stamps will be compared and analysed from the point of view of pattern transfer.

Joint Research Presentation

Advanced nano-object transfer and positioning - strategy, status and application for single nanoparticle tracking during in-situ catalysis

Thomas Keller
DESY, Hamburg (Germany)

The NFFA joint research action “advanced nano-object transfer and positioning” addresses the necessary technological development of a reproducible nanopositioning and relocalization of pre-selected areas between nanoscience instruments and nano-focused X-ray beamlines at analytical large scale facilities. The concept, the current status of implementation, and recent achievements of this key technical aspect in nanoscience is reviewed, permitting novel experiments to determine one-to-one structure property relationships of single nano-objects. As a recent science case, it is shown how the advanced nano-object transfer and positioning protocol using electron-beam assisted deposition of a hierarchical marker system has been successfully applied for tracking the structural re-organisation and shape changes of a preselected, single epitaxial Pt catalyst nanoparticle in-situ during catalytic CO oxidation at near ambient pressure using coherent X-ray diffraction.

Joint Research Presentation

Ultra-fast processes in realistic materials: challenges, perspectives, users and communities

Emmanuel Stratakis (FORTH, Greece) and Andrea Marini (ISM-CNR, Italy)

Ultra-fast spectroscopy is a powerful tool for the observation of electronic and atomic dynamical processes. In a basic Pump&Probe experiment a first light pulse (the pump) resonantly triggers a photo-induced process exciting electrons from the valence to the conduction bands. The subsequent system evolution can be monitored by measuring a wealth of experimental observables detected with a delayed weak pulse (the probe). Typical observables are the time-resolved transmitted (or reflected) probe spectrum, rotation (Kerr angle), the time-resolved photo-electrons distribution emitted in the continuum and more. Pump&Probe experiments are currently performed on a large family of materials made available by the growing development of sophisticated experimental techniques. Applications and researchers span different scientific areas like biology, physics, medicine. The community of experimentalists are distributed in in-situ laboratories and/or large user infrastructures (like Free Electron Lasers).

Ultra-fast spectroscopy, thus, would theoretically provide a potential reservoir of users for the NFFA infrastructure. Nevertheless, the specific processes triggered in a typical Pump&Probe experiment makes its interpretation bound to an accurate modeling that, as I will discuss in this talk, lacks of the systematic theoretical and numerical environment that characterize the simulation of equilibrium properties.

By using a paradigmatic case I will discuss the potential misinterpretation of a typical Pump&Probe experiment when the interpretation is not adequately supported by an atomistic simulation. I will also discuss the theoretical and numerical advances made possible by the NFFA/JRA activity and discuss potential links with the experimental community.

The final scenario is that of a rapidly growing experimental field and a much slower development of theoretical and numerical tools. The result is a gap between results and interpretations that the NFFA can potentially contribute in filling.

SOCIAL DINNER

The Social dinner will take place at:

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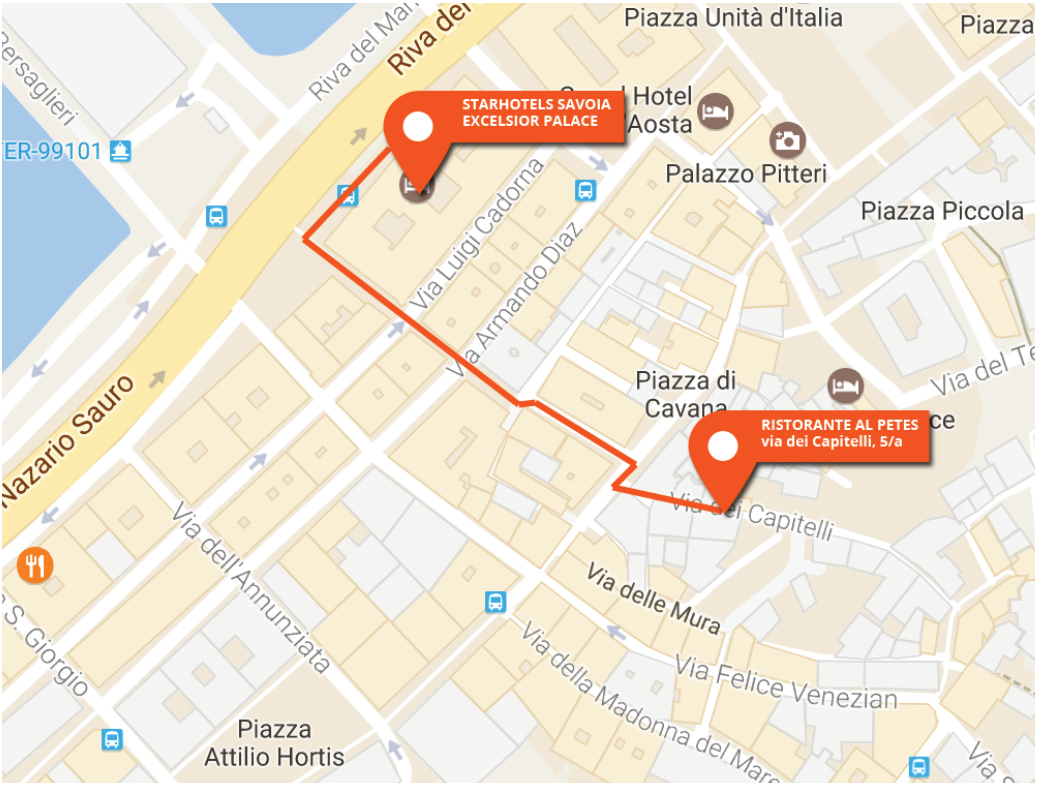

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