nffa.eu PILOT 2021 2026

DELIVERABLE REPORT

WP13 JA3 – Nano-Engineering and pattern transfer methods

D13.1 NEP Session at EMRS Meeting (Workshop on advanced lithography and nanopatterning)

Due date м18



PROJECT DETAILS

PROJECT ACRONYM	PROJECT TITLE Nanoscience Foundries and Fine Analysis - Europe PILOT		
GRANT AGREEMENT NO:	FUNDING SCHEME		
101007417	RIA - Research and Innovation Action		
START DATE			
01/03/2021			

WORK PACKAGE DETAILS				
WORK PACKAGE ID	WORK PACKAGE TITLE			
WP13	JA3-Nano-engineering and pattern transfer methods			
Work Package Leader				

Ivan Maximov (Lund University)

DELIVERABLE DE					
DELIVERADLE DE	TAILS				
DELIVERABLE ID	DELIVERABLE TITLE				
D13.1	NEP Session at EMRS Meeting (Workshop on advanced nanolithography and nanopatterning)				
DELIVERABLE DESCRIPTION	I				
This deliverable report summarizes the main aspects of the workshop that took place at EMRS 2022 Spring Meeting, which was hold on-line May 30 and May 31. All the workshop information is stored at the E-MRS website: <u>https://www.european-mrs.com/new-trends-advanced-lithography-and-pattern-transfer-methods-emrs</u>					
DUE DATE		ACTUAL SUBMISSION DATE			
M18 31/08/2022		31/08/2022			
AUTHORS					

Francesc Perez-Murano (CSIC), Ivan Maximov (Lund University)



PERSON RESPONSIBLE FOR THE DELIVERABLE

Prof. Francesc Perez-Murano (CSIC)

NATURE

- \times R - Report
- P - Prototype
- DEC Websites, Patent filing, Press & media actions, Videos, etc
- O - Other

DISSEMINATION LEVEL P - Public

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- PP Restricted to other programme participants & EC: (Specify)
- RE Restricted to a group (Specify)
- CO Confidential, only for members of the consortium



REPORT **DETAILS**

ACTUAL SUBMISSION DATE 31/08/2022			NUMBER OF PAGES				
FOR MORE INFO PLEASE CONTACT							
Francesc Perez-Murano, IMB-CNM, CSIC Campus UAB. 08193 Bellaterra. Spain		erra.	email:Francesc.Perez@csic.es				
VERSION	DATE	AUTHOR(S)	DESCRIPTION / REASON FOR MODIFICATION	STATUS			
1	29/07/2022	Francesc Perez- Murano (CSIC), Ivan Maximov (Lund University)		Draft			
2 29,	/08/2022	Francesc Perez- Murano (CSIC), Ivan Maximov (Lund University)	Included corrections from E. Narducci and gender distribution of contributors has been included (page 9).	Final.			
				Choose an item.			

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INTRODUCTION

The continuous evolution of techniques and methods for manufacturing and structuring surfaces at the nano-scale has allowed to improve the performance of devices, circuits and systems in aspects such as processing speed or energy consumption. In the future, the evolution of important areas such as semiconductor integrated circuits, quantum computing, biomedicine, energy or mobility will depend on the ability to manufacture devices more efficiently and with a larger degree of accuracy. There is still a lot of room for further evolution and improvements in nanofabrication methods that will bring to exploit the ultimate performance of many different types of devices, even down to the atomic scale.

As part of the dissemination activities of the NEP project, and directed by WP13 "Nano-engineering and pattern transfer methods", a symposium within the E-MRS 2022 Spring Meeting was organized, titled "New trends in advanced lithography and pattern transfer methods" (See figure 1).

The scope of the symposium was to present and discuss the latest advances in the field of ultrahigh resolution lithography and methods of pattern transfer which are presently under different stages of development and that they are going to play a key role in near future technologies. The symposium was planned to cover innovative aspects in consolidated technologies, like advanced optical lithography and ion beam fabrication, along with the progress in emerging methods like selfassembly or scanning probe lithography. Subtractive and additive patterning techniques, including dry etching, deposition, single ion implantation, and others, were discussed.

The symposium was addressed to scientist and engineers interested in structuring at the nanoscale. The program consisted of a mixture of invited and contributed oral presentations and posters, with a broad coverage of the main trends in the field. The symposium was organized by the European Project NFFA-Europe-Pilot (nfffa.eu), which involves twenty-two partners from nine Member States of the European Union and aims to increasing European competitiveness in nanosciences and nanotechnologies.





Figure 1. Screen shot of the website of the e-MRS 2022 spring meeting displaying the organized NEP symposium **New trends in advanced lithography and pattern transfer methods**



WORKSHOP ORGANIZATION

Workshop organizers

The workshop was organized by the following members of NEP project:

Flavio CARSUGHI,

Forschungszentrum Jülich GmbH. Jülich; Centre for Neutron Science at MLZ, Germany

Francesc PEREZ-MURANO,

Institute of Microelectronics of Barcelona (IMB-CNM, CSIC), Spain

Ivan MAXIMOV,

Advanced Lithography Group, Lund Nano Lab, Lund University, Sweden

Yasin EKINCI,

Laboratory for Micro and Nanotechnology, PSI, Switzerland

The NEP project sponsored the workshop.

Organization actions

The organization of the workshop was proposed within WP13 of NEP project as a dissemination activity (this deliverable). The actions to organize the workshop started on August 2021. The first meeting of the organizing committee took place on August 25th, 2021.

Since then, the organizing committee met regularly by video-conference an average of 2 times per month.

The main tasks carried-out by the organizing committee were the following:

- Communication with e-MRS headquarters and NEP management
- Definition of the scope and title of the workshop
- Selection of invited speakers and stablish contact with them
- Dissemination of the workshop with the contact networks
- Revision of the submitted abstracts
- Generation of the scientific program
- Organization of the best poster award
- Chairing the scientific sessions

The logistic for the workshop (Webpage, Internet apps, software for managing abstract submission and revision, management of participant registration, etc) was provided by the E-MRS central organization.



WORKSHOP PROGRAM AND EXECUTION

The final workshop scientific program consisted of a total of 33 contributions: 7 invited talks, 11 contributed talks and 15 poster presentations. 27% of the contribution were given by female researchers. The invited presentation of F. Carsughi about the NFFA-Europe Pilot project provided an overview of the project and contributed to the outreach actions.

Monday May 30

13:15 Welcome and Introduction to the Symposium Chair: Yasin Ekinci, Ivan Maximov

13:30 INV NFFA-Europe Pilot: a great research and innovation opportunity for the European and worldwide nanoscience community. Flavio Carsughi Forschungszentrum Jülich, Germany

13:45 INV Fully Automated Thermal Scanning Probe Lithography for FET BatchFabrication

A. Knoll¹, J. Chaaban², N. Hendricks², E. Cagin², P. Nicollier¹, H. Wolf¹, D.Widmer¹, U. Drechsler¹

1) IBM Research Europe – Zurich, Säumerstrasse 4, 8803 Rüschlikon, Switzerland

2) Heidelberg Instruments Nano AG, Bändliweg 30, 8048 Zürich, Switzerland

14:15 Towards the fabrication of Silicon Nanowires with Quantum Dot as a Platform for experimentation in Quantum Tecnologies

J Llobet, D Bricio, A Kapas, A Guerrero, J Sanchez, A Garcia, M Duch, X Borrisé, J Bausells, F Pérez-Murano Institute of Microelectronics of Barcelona (IMB-CNM CSIC), Bellaterra, 08193, Catalonia, Spain Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Bellaterra, 08193, Catalonia, Spain

14:30 Molecular Gates: Unlocking the Path to High-Resolution Patterning of Dopingand Microstructure in Molecular Semiconductor Films

Aleksandr Perevedentsev, Mariano Campoy-Quiles Institute of Materials Science of Barcelona (ICMAB-CSIC), 08193 Bellaterra, Spain

14:45 Q&A

15:00 INV Beyond Gallium: FIB based local materials property tuning with advanced ion sources

Gregor Hlawacek

Institute for Ion Beam Physics and Materials Research Helmholtz—Zentrum Dresden—Rossendorf 01328 Dresden, Germany

15:30 INV Using a Liquid Metal Alloy Ion Source for FIB patterning of noble metal plasmonic nanostructures.

D. Giubertoni ^(a), A. Cian ^(a), E. Scattolo ^(a), R. Dell'Anna ^(a), G. Paternoster ^(a), J. Rodríguez-Álvarez ^(b,c), A. Guerrero ^(d), X. Borrisé ^(e), F. Perez-Murano ^(d)

(a) Sensors and Devices Center, Bruno Kessler Foundation, Trento, I-38123, Italy,

(b) Departament de Física de la Matèria Condensada, Universitat de Barcelona, 08028 Barcelona, Spain,

(c) Institut de Nanociència i Nanotecnologia (IN2UB), 08028 Barcelona, Spain,

- (d) Instituto de Microelectrónica de Barcelona (IMB-CNM, CSIC), Bellaterra (Barcelona), 08193, Spain,
- (e) Institut Català de Nanociència i Nanotecnologia, Bellaterra (Barcelona), 08193, Spain



16:00 Fabrication of X-ray optical elements by two-photon polymerization 3D printing

Sanli, U. T^{.(1)}*, Kubec, A. ^{1,2),} Qi, P.^{(1),} Seiboth, F.⁽³⁾, Vila-Comamala, J.⁽¹⁾ & David, C.⁽¹⁾ (1) Paul Scherrer Institute, Forschungsstrasse 111, 5232 Villigen PSI, Switzerland (2) XRnanotech GmbH, Forschungsstrasse 111, 5232 Villigen PSI, Switzerland (3) CXNS - Center for X-ray and Nano Science, Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany * Lead presenter.

16:15 Latest results on radiation assisted nanomaterials synthesis and patterning using Deep X-ray lithography

B. Marmiroli ⁽¹⁾, A. Turchet ⁽²⁾, B. Sartori ⁽¹⁾, A. Bharti ⁽²⁾, H. Amenitsch ⁽¹⁾
(1) Institute of Inorganic Chemistry, Graz University of Technology, Graz, Austria,
(2) Elettra-Sincrotrone Trieste, Trieste, Italy

16:30 Diamond optics for X-ray free-electron laser applications

Mamyrbayev, T.⁽¹⁾*, Vila-Comamala, J.⁽¹⁾, Li, H.⁽²⁾, Makita, M.⁽³⁾, Zhu, D.⁽²⁾ & David, C.⁽¹⁾

- (1) Paul Scherrer Institut, 5232 Villigen PSI, Switzerland
- (2) Linac Coherent Light Source, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA
- (3) European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany

16:45 <mark>Q&A</mark>

Poster Session 1 : Flavio Carsughi

17:15 Edge-contact MoS2 transistors made by thermal scanning probe lithography

Ana Conde-Rubio, Xia Liu*, Giovanni Boero, Juergen Brugger Microsystems Laboratory, École Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland

17:15 Flexible PMMA Stencil Lithography for 2D Materials Contacting

Xia Liu, Giovanni Boero, Juergen Brugger Microsystems Laboratory, École Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland

17:15 Fabrication and performance of graphene FETs based on single crystal flakes transferred from SiC wafers and a crosslinked PMMA

Sofia Aslanidou, Elif Ozceri, Alberto Garcia-Garcia, Philippe Godignon, Gemma Rius Institute of Microelectronics of Barcelona, IMB-CNM-CSIC (Spain)

17:15 Negative-tone dry development of PMMA for e-beam lithography

Furkan Ayhan, Thomas Mortelmans, Yasin Ekinci, Dimitrios Kazazis Paul Scherrer Institute, 5232 Villigen, Switzerland, Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland, Swiss Nanoscience Institute, University of Basel, 4056 Basel, Switzerland, Centre Suisse d'Électronique et de Microtechnique, 2002 Neuchâtel, Switzerland

17:15 Direct Nanoimprint on Chalcogenide Glasses substrate for Optical Applications

Sivan Tzadka(1,2), Natali Ostrovsky(1,2), Esti Toledo(1,2), G. Le Saux(1,2), Evyatar Kassis(3), Shay Joseph(3), and Mark Schvartzman(1,2)

1.Department of Materials Engineering, Ben-Gurion University of the Negev, Beer- Sheva, Israel 2. Ilse Katz Institute for Nanoscale Science and Technology, Ben- Gurion University of the Negev, Beer-Sheva, Israel 3. Optical Component Center, Rafael Advanced Defense Systems, Haifa, Israel

17:15 Integration by Focused Ion Beam of plasmonic nanostructures on Si-based device for UV light detection

E. Scattolo (a,b), A. Cian (a), D. Giubertoni (a), G. Paternoster (a), L. Petti (b), P.Lugli (b)

- (a) Sensors and Devices Center, Bruno Kessler Foundation, Trento, I-38123, Italy,
- (b) Free university of Bozen, 39100 Bolzano BZ, Italy



17:15 High aspect ratio fabrication by displacement Talbot lithography, silicon deep reactive ion etching and gold electroplating

Konstantins Jefimovs¹, Zhitian Shi^{1,2}, Lucia Roimano^{1,2,3}, Craig Lawley¹, Daniel Josell⁴, Vitaliy A. Guzenko¹, Marco Stampanoni^{1,2}

1Photon Science Division, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

2Institute for Biomedical Engineering, University and ETH Zürich, 8092 Zürich, Switzerland

3Department of Physics and CNR-IMM- University of Catania, 64 via S. Sofia, Catania, Italy

4Materials Science and Engineering Division, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, USA

17:15 Investigation of interfacial widths and line-edge roughnesses in microphase separated cylindrical block copolymer thin films

Julius Bürger, Harikrishnan Venugopal, Daniel Kool, Teresa de los Arcos, Alejandro González Orive, Guido Grundmeier, Katharina Brassat, Jörg K.N. Lindner

Nanostructuring, Nanoanalysis and Photonic Materials Group, Dept. of Physics, Paderborn University, Paderborn, Germany,

17:15 EUV resist development with interference lithography

T. Allenet, M. Vockenhuber, C-K. Yeh, Y. Ekinci, D. Kazazis Laboratory for X-ray Nanoscience and Technologies, Paul Scherrer Institut, 5232 Villigen-PSI, Switzerland

17:15 Grayscale e-beam lithography for the fabrication of 3D microfluidic devices

Thomas Mortelmans, Dimitrios Kazazis, Celestino Padeste, Xiaodan Li, Per Magnus Kristiansen, Yasin Ekinci Paul Scherrer Institute, 5232 Villigen-PSI, Switzerland, Swiss Nanoscience Institute, University of Basel, 4056 Basel, Switzerland, INKA Institute of Polymer Nanotechnology, FHNW, 5210 Windisch, Switzerland,

University College Dublin, Belfield, Dublin 4, Ireland

17:15 Single-digit nanometer EUV interference lithography

I. Giannopoulos, Y. Ekinci, D. Kazazis Laboratory for X-ray Nanoscience and Technologies, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

17:15 Dopant patterning using monolayer doping and EUV interference lithography Prajith Karadan, Dimitrios Kazazis, Yasin Ekinci

Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

17:15 Fabrication of 1T-TaS2 devices by electron beam lithography for investigation of non-equilibrium phase switching

C. Burri *(1),(2), J. Ravnik ⁽¹⁾, D. Kazazis ⁽¹⁾, D. Mihailovic ⁽³⁾, Y. Ekinci ⁽¹⁾, S. Gerber ⁽¹⁾ (1)Laboratory for X-ray Nanoscience and Technology, Paul Scherrer Institut,Villigen PSI, Switzerland (2)Laboratory for Solid State Physics, ETH Zurich, Zurich,Switzerland (3)Department of Complex Matter, Jožef Stefan Institute, Ljubljana,Slovenia

17:15 Formulating a Dose Insufficiency Model for High-Resolution 50 kV Electron Beam Lithography on Thick Resist Layers

Mattias Åstrand, Thomas Frisk, Hanna Ohlin, Ulrich Vogt KTH Royal Institute of Technology

17:15 Metal Cupferrates as Novel High Resolution Molecular Resists for Electron Beam and Extreme Ultraviolet lithographies

M. S. M. Saifullah, D. Kazazis, V. A. Guzenko, M. Vockenhuber, Y. Ekinci Paul Scherrer Institute, 5232 Villigen, Switzerland



Tuesday May 31

Chair person: Francesc Perez Murano

09:00 INV EUV lithography for more Moore Yasin Ekinci Paul Scherrer Institut

09:30 Al2O3 dot and antidot arrays fabricated by SIS in hexagonally packed PS-b-PMMA BCP thin films

G. Seguini ¹, A. Motta ¹, M. Bigatti ¹, F.E. Caligiore ¹, G. Rademaker ², A. Gharbi ², R. Tiron ², G. Tallarida ¹, E. Cianci ¹, and M. Perego ¹

1 IMM-CNR, Unit of Agrate Brianza, Via C. Olivetti 2, I-20864 Agrate Brianza, Italy 2 Univ. Grenoble Alpes, CEA, Leti, F-38000 Grenoble, France

09:45 Controlled, Rapid Synthesis of Microporous Polystyrene Thin Films

Philip Darragh, Dr. Ryan Enright, Prof. Michael Morris AMBER, CRANN Institute, Trinity College Dublin, Dublin 2, Ireland, Nokia Bell Labs, Murray Hill, New Jersey, USA

10:00 INV Multi-Trigger Resist for EUV Lithography

C. Popescu^(a), G. O'Callaghan^(a), A. McClelland^(a), J. Roth^(b), E. Jacksonb, A.P.G. Robinson^{(a),(b)} (a) Irresistible Materials, Birmingham Research Park, Birmingham, UK

(b) Nano-C, 33 Southwest Park, Westwood, MA, USA. e-mail: a.p.g.robinson@bham.ac.uk

10:30 Nanoimprint as a Large-Area Nanofabrication Technique for Developing Novel Architectures in Flexible Ultrathin Solar Cells

T.S. Lopes ^{1,2,3,4}, J.P. Teixeira¹, B.R. Ferreira¹, M.A. Curado^{1,5}, J.M.V. Cunha^{1,6,7}, K. Oliveira¹, A.J.N. Oliveira^{1,6,7}, A.Violas^{1,6,7,8}, J.R.S. Barbosa¹, P.C. Sousa¹, I.Çaha¹ J. Borme¹, J. Ring⁹, W.C. Chen⁸, Y. Zhou⁹, F.L. Deepak¹, M. Edoff⁸, G. Brammertz^{2,3,4}, P.A. Fernandes^{1,7,10}, B. Vermang^{2,3,4}, P.M.P. Salomé^{1,6} 1-INL – International Iberian Nanotechnology Laboratory, Avenida Mestre José Veiga, 4715-330 Braga, Portugal

2-Institute for Material Research (IMO), Hasselt University (partner in Solliance), Agoralaangebouw H, Diepenbeek, 3590, Belgium

3-Imec division IMOMEC (partner in Solliance), Wetenschapspark 1, 3590 Diepenbeek, Belgium 4-EnergyVille, ThorPark, Poort Genk, 8310 & 8320, 3600 Genk, Belgium

5- CFisUC, Department of Physics, University of Coimbra, P-3004- 516 Coimbra, Portugal

6-Departamento de Física, Universidade de Áveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

7-i3N, Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

8- Ångström Laboratory, Department of Engineering Sciences, Uppsala University, 751 21

9 -Obducat AB, Medicon Village, 223 63 Lund Sweden Uppsala, Sweden

10-CIETI, Departamento de Física, Instituto Superior de Engenharia do Porto, Instituto Politécnico do Porto, 4200-072, Porto Portugal

10:45 Q&A



11:15 INV Bio-inspired directed self assembly as patterning solution: when Topdown meets bottom-up

Raluca Tiron Univ. Grenoble Alpes, CEA, LETI

11:45 Soft nanoimprint lithography of silica sol gel for microelectronic and biological applications

David Sánchez-Fuentes* ⁽¹⁾, R.Rathar ⁽²⁾, L. Picas ⁽²⁾, A. Carretero-Genevrier. ⁽¹⁾

(1) Institut d'Electronique et des Systemes (IES), CNRS, Université de Montpellier, 860 Rue de Saint Priest 34095 Montpellier, France

(2) Institut de Rechercheen Infectiologie de Montpellier (IRIM), CNRS, 1919 Route de Mende, 34090 Montpellier, France

12:00 Laser 3D nanolithography for sub-100 nm additive manufacturing of inorganics

Greta Merkininkaitė, Darius Gailevičius, Simas Sakirzanovas, Mangirdas Malinauskas

1. Faculty of Chemistry and Geosciences, Vilnius University, Naugarduko Str. 24, Vilnius LT-03225, Lithuania 2. Femtika, Sauletekio Ave. 15, Vilnius LT- 10224, Lithuania

 Laser Research Center, Physics Faculty, Vilnius University, Sauletekio Ave. 10, Vilnius LT-10223, Lithuania
 Department of Chemical Engineering and Technology, Center for Physical Sciences and Technology, Sauletekio Ave. 3, Vilnius LT-10257, Lithuania

12:15 Bringing electrochemical 3D printing to the nanoscale

Dmitry Momotenko Department of Chemistry, Carl von Ossietzky University of Oldenburg, Oldenburg, D-26129, Germany

12:30 Q&A and closing remarks

The sessions were followed by a large audience (about 100 attendees). Talks were broadcasted with the pre-assigned schedule using pre-recorded videos. After each session, the Q&A slot provided a convenient framework for discussion, with live participation of the speakers.

The best poster was awarded to Julius Bürger, for the presentation entitled Investigation of interfacial widths and line-edge roughnesses in microphase separated cylindrical block copolymer thin films. The award was announced and the poster displayed at the NEP project website.



Figure 2. Best poster award



CONCLUSIONS AND OUTLOOK

This deliverable reports the main features of the workshop entitled **New trends in advanced lithography and pattern transfer methods** hold as a Symposyum at the **EMRS Spring Meeting 2022**.

The following aspects are worth to be highlighted:

- The workshop was a very good opportunity to disseminate NEP project within the European Community involved in advanced lithography and patterning methods.
- The quality of the talks and poster was extremely high. In this sense, the workshop was very useful to have a deep view of the present status of the state of the art of the topic.
- The numbers of attendees was very high, with a good interaction level during the Q&A slots.

The workshop had to take place on-line, as decided by the e-MRS headquarters for the whole conference, in view of the status of the COVID-19 pandemics as the moment of initiating the organization. Although some interaction was possible on-line, it is much more efficient to have a conference with physical presence. In view of this, a second edition of the workshop with on-site presence would be highly desirable.

