2D Materials Research Activities at the NEST lab in Pisa, Italy

Stefan Heun

NEST, Istituto Nanoscienze-CNR and
Scuola Normale Superiore, Pisa, Italy

National Enterprise for nanoScience and nanoTechnology

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National Enterprise for nanoScience and nanoTechnology

Outline

- CNR Nano
- NEST Pisa
- My Research Activities

Outline

- CNR Nano
- NEST Pisa
- My Research Activities

Institute of Nanoscience

CNR NANO
ISTITUTO NANOSCIENZE CONSIGLIO NAZIONALE DELLE RICERCHE

Established on February 2010

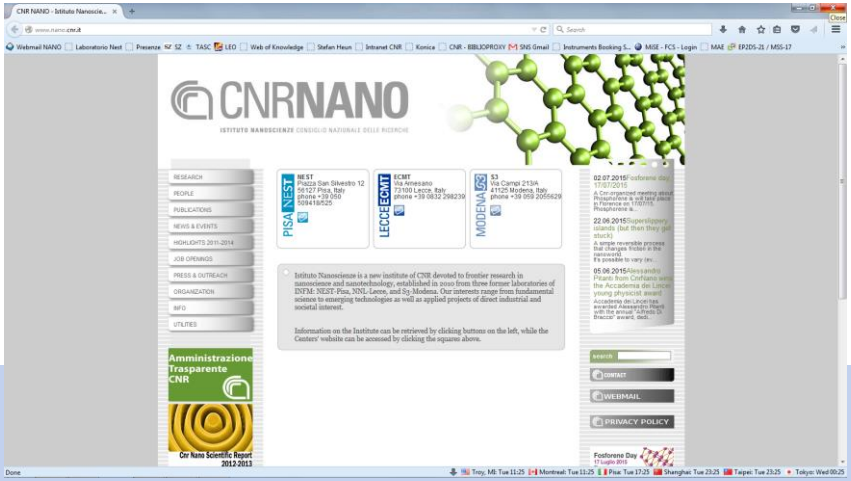
Pisa: L. Sorba

Lecce: D. Pisignano

Modena: E. Molinari

Adm. Genova (with Nano, SPIN, IOM)
project admin, recruitment

www.nano.cnr.it



Mission

CNR NANO
ISTITUTO NANOSCIENZE CONSIGLIO NAZIONALE DELLE RICERCHE

The primary objective of the Institute is the fundamental **study and the manipulation of systems at the nanometric scale**. Its wide and multidisciplinary research activities include:

- Synthesis and fabrication of nanostructures and devices.
- Experimental and theoretical-computational studies of their properties and functionality.
- Knowledge and expertise are used to develop applications in several fields, from energy and environment to nanomechanics, nano(bio)technologies, and nanomedicine.
- Special attention to projects and advanced technologies of industrial interest.

Institute of Nanoscience

CNR NANO
ISTITUTO NANOSCIENZE CONSIGLIO NAZIONALE DELLE RICERCHE

Interdisciplinary research activities where physicists, chemists and biologists do science at the nanoscale.

Strong interaction between theory and experiments

Strong interaction with the Universities (SNS, Unimore, Salento)

NEST
SCUOLA NORMALE SUPERIORE PISA

UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

UNIVERSITÀ DEL SALENTO

Equipment intensive

CNR NANO
ISTITUTO NANOSCIENZE CONSIGLIO NAZIONALE DELLE RICERCHE

Nanofabrication:

bottom-up: growth (CBE, CVD) and chemical and bio synthesis

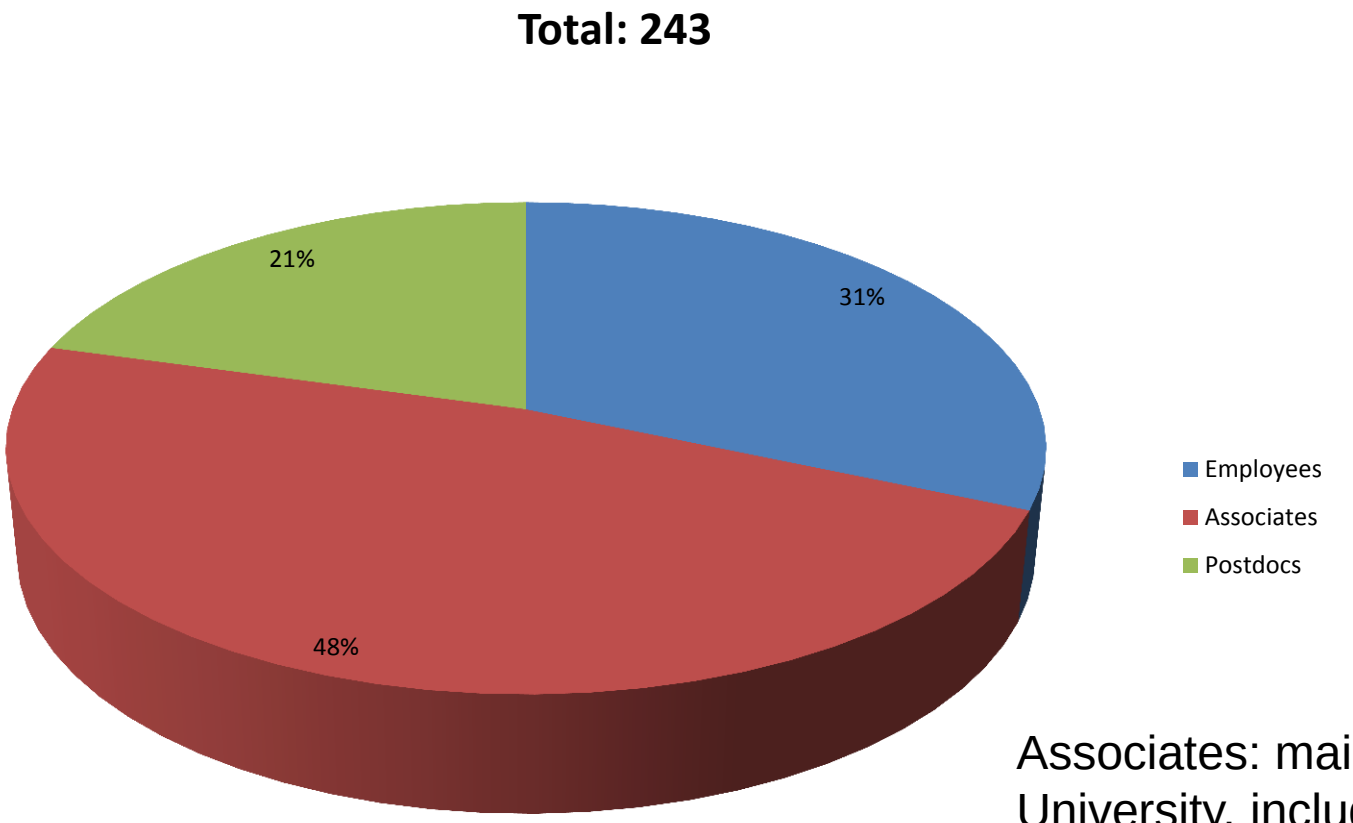
top-down: clean rooms, EBL, FIB

Microscopies : SEM, TEM, AFM, SNOM, STM, two photon microscopy, single molecule imaging, scanning gate microscopy

Spectroscopies: Transport and optics at low T and H fields, electron spectroscopy, optical tweezers

Theory: Cluster, dedicated agreement with CINECA

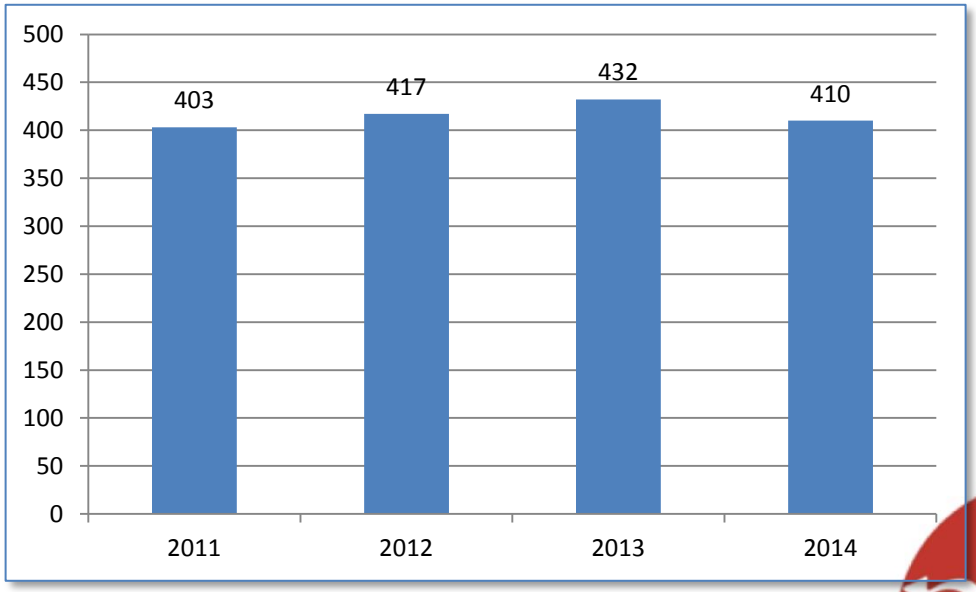
Personnel 2014



Associates: mainly from University, including students (Master and PhD)

Publications Nano

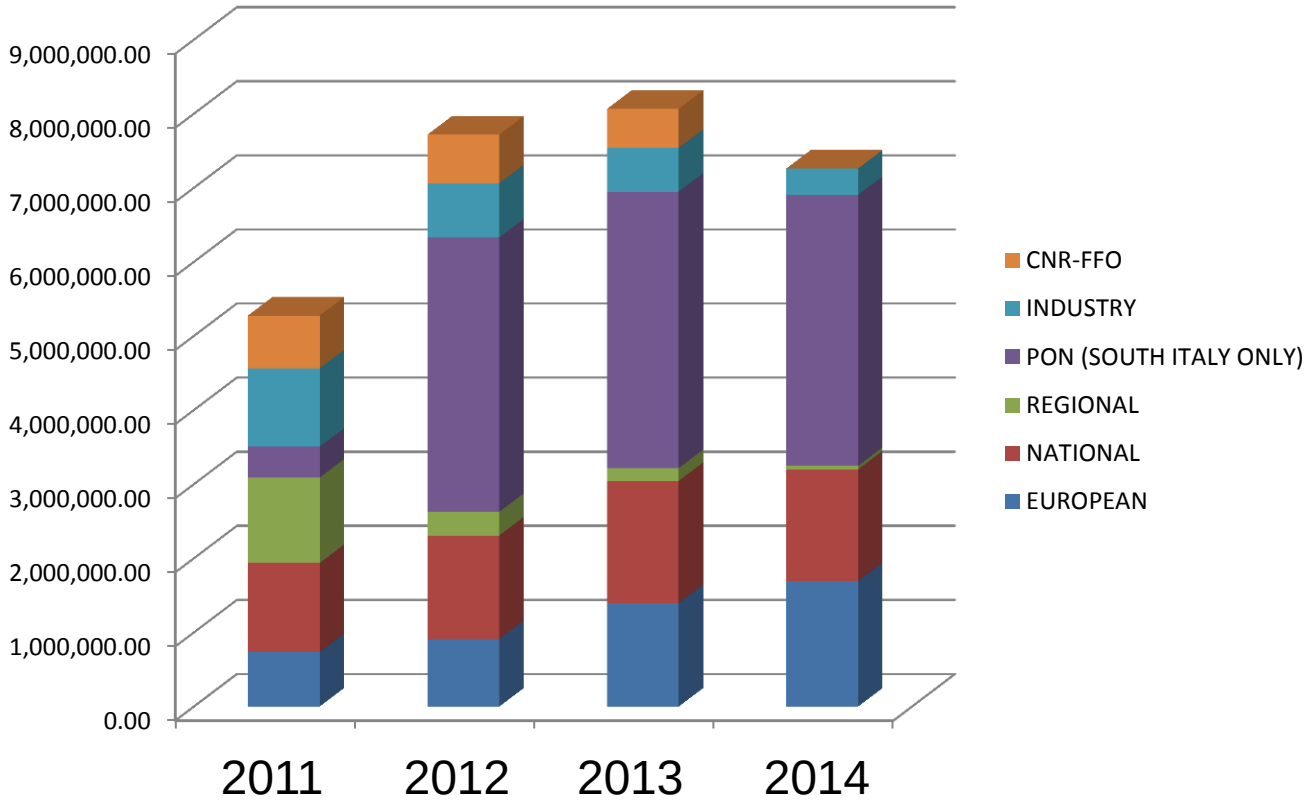
CNR NANO
ISTITUTO NANOSCIENZE CONSIGLIO NAZIONALE DELLE RICERCHE



Istituto Nanoscienze is the Cnr institute with the highest number of publications in 2012 in the Nature Group journals according to the recently published Nature Publishing Index.

Funding 2011 – 2014

CNR NANO
ISTITUTO NANOSCIENZE CONSIGLIO NAZIONALE DELLE RICERCHE



Scientific Council

CNR NANO
ISTITUTO NANOSCIENZE CONSIGLIO NAZIONALE DELLE RICERCHE

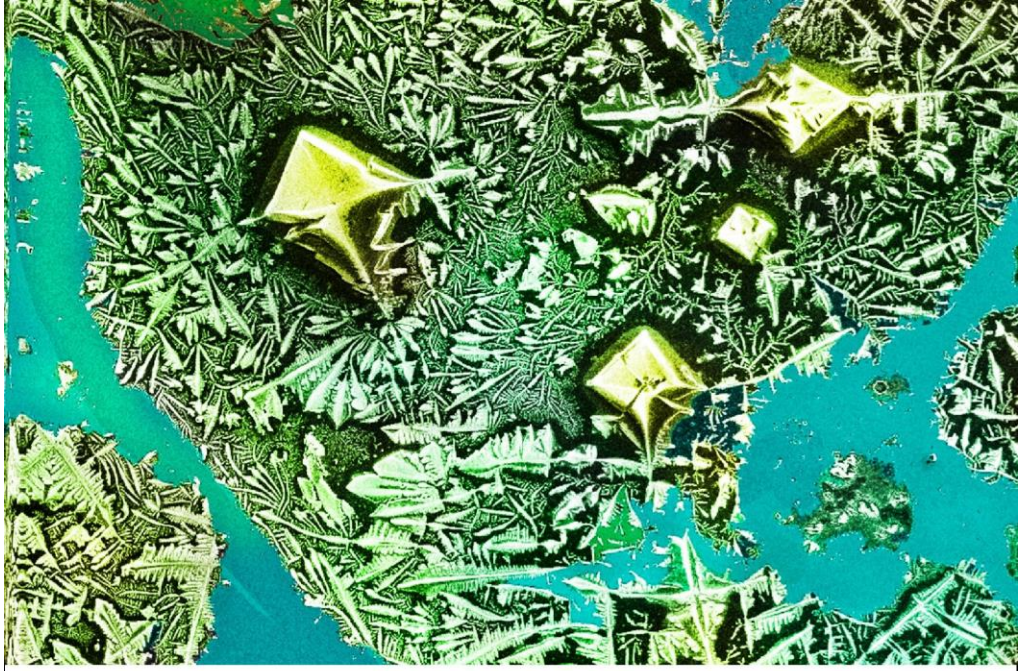
Prof. Annalisa Fasolino
Theory of Condensed Matter, Institute for Molecules and Materials
Radboud University Nijmegen, The Netherlands

Prof. Olle Inganäs
Director, Center of Organic Electronics, Dept. of Physics, Chemistry and Biology IFM,
Linköping University, Sweden

Dr. Gerhard Meyer
IBM Zurich Research Laboratory, CH-8803 Rüschlikon, Switzerland

Prof. Stefano Sanvito
Computational Materials Science group, Trinity College Dublin, Ireland

Prof. Vinhod Subramaniam
Scientific Director of the MIRA Institute for Biomedical Technology
Technical Medicine at the University of Twente, The Netherlands



Scientific Report

2012-2013

CNRNANO

ISTITUTO NANOSCIENZE CONSIGLIO NAZIONALE DELLE RICERCHE

Outline

- CNR Nano
- NEST Pisa
- My Research Activities

NEST Pisa

National Enterprise for nanoScience and nanoTechnology

NEST

NEST Pisa

National **E**nterprise for nano**S**cience and nano**T**echnology

NEST is an interdisciplinary research and training centre where physicists, chemists and biologists investigate scientific issues at the nanoscale.

Research themes @ NEST Pisa

NanoPhysics

1. Quantum transport and phase coherent effects in superconductors
2. Physics of low-dimensional semiconductor systems
3. Graphene (**Flagship**)

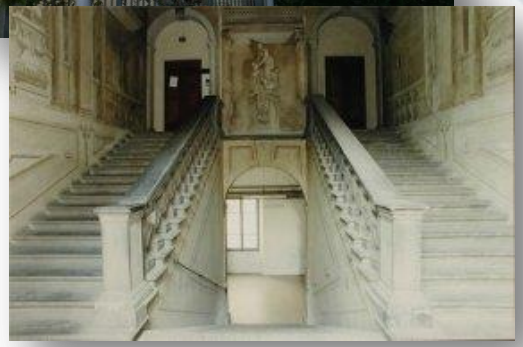
Advanced Photonics

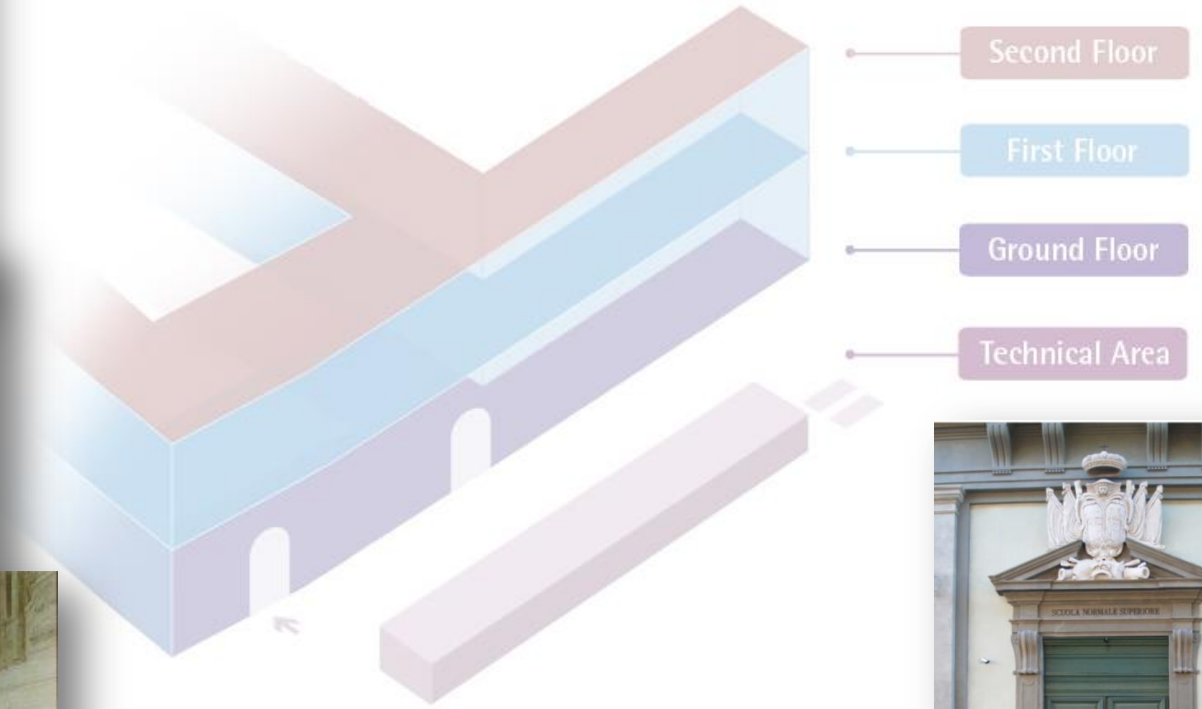
4. Intersubband polaritonics
5. Silicon-Germanium optoelectronics
6. THz photonics
7. OptoElectronics Materials: from nanoscale to bulk single crystals

NanoBioScience

8. Visualizing brain function and structure in the living mouse
9. Lab-on-a-chip technologies
10. Nanoscale and single-molecule spectroscopy and imaging of soft matter

NEST Pisa

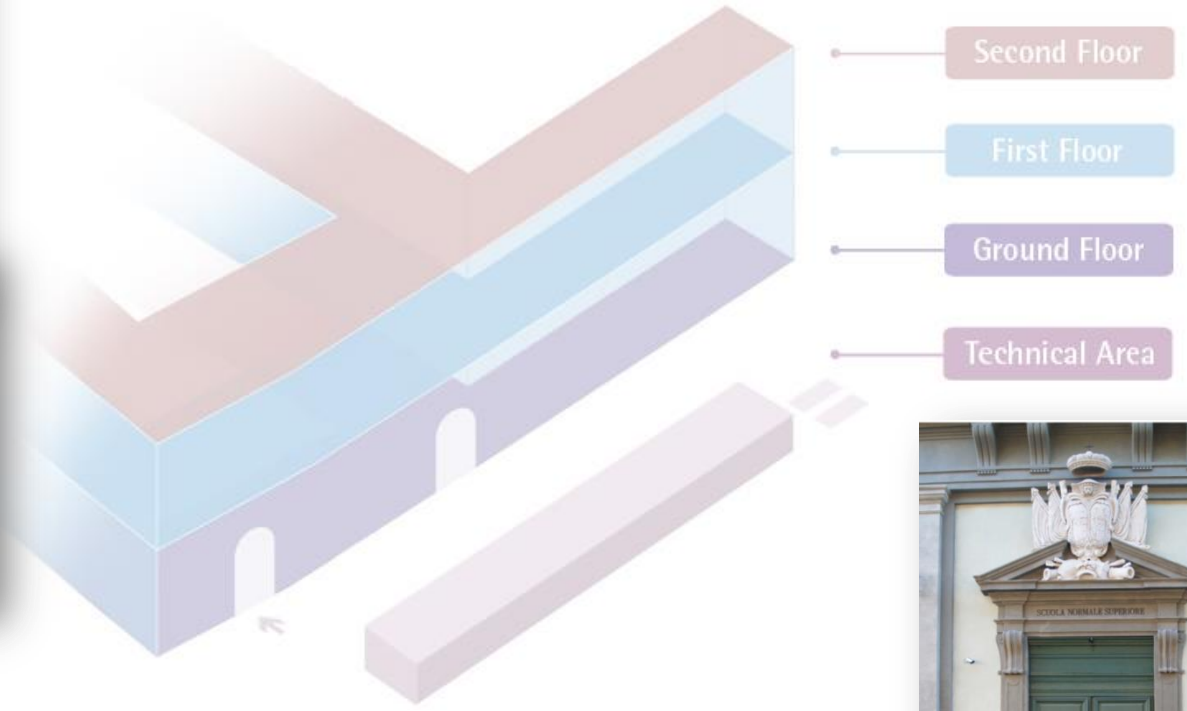




National Enterprise for nanoScience and nanoTechnology

NEST

NEST Pisa



NEST

SCUOLA NORMALE SUPERIORE PISA

iit @NEST

ISTITUTO ITALIANO DI TECNOLOGIA

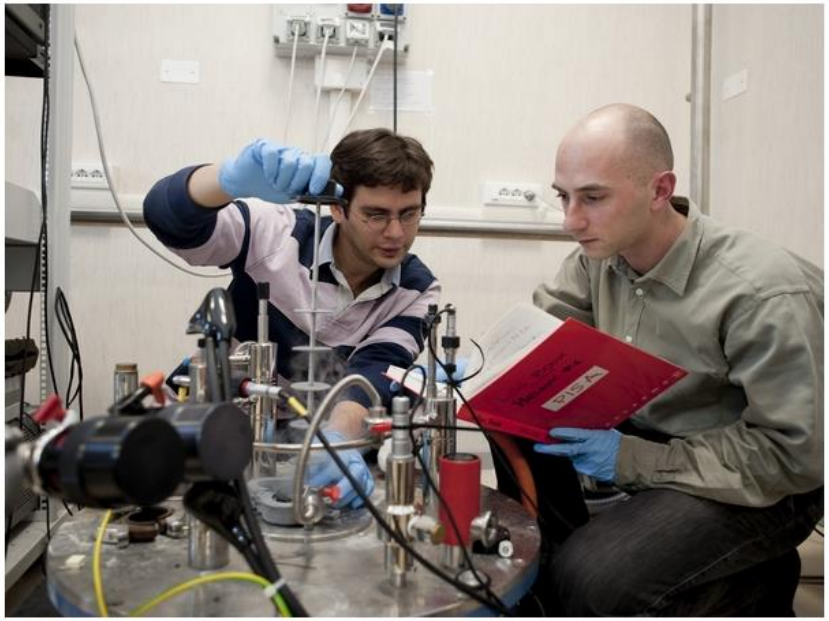
CNRNANO PISA NEST

National Enterprise for nanoScience and nanoTechnology

NEST

Facilities @ NEST

Facilities @ NEST



0.1 Low-temperature magneto transport and optics

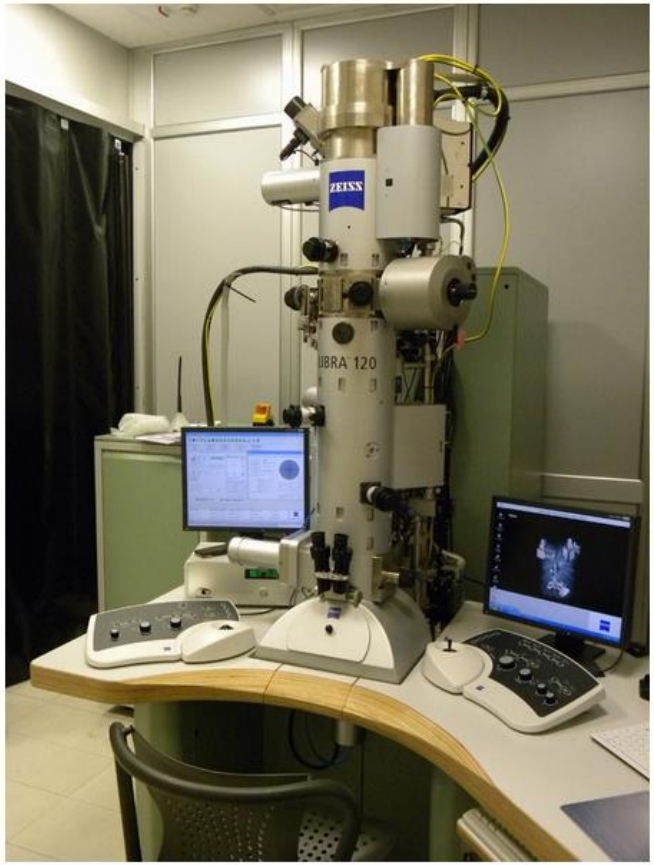
Facilities @ NEST

0.2 Scanning Gate Microscopy

Facilities @ NEST

0.3 CVD-based growth of graphene nanostructures

Facilities @ NEST



0.4 Transmission Electron Microscopy Lab

Facilities @ NEST

0.5 CBE, Plasma Etching and Deposition

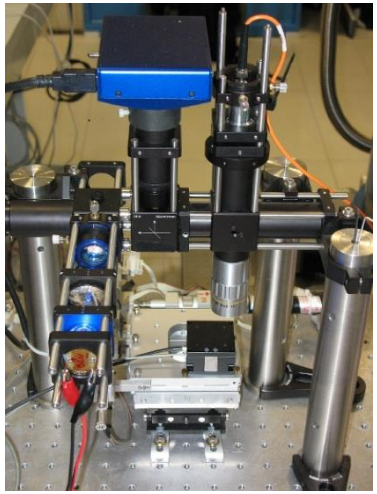
Facilities @ NEST

Theory (DFT)

Facilities @ NEST

0.6 Coherent Raman Spectroscopy

Facilities @ NEST



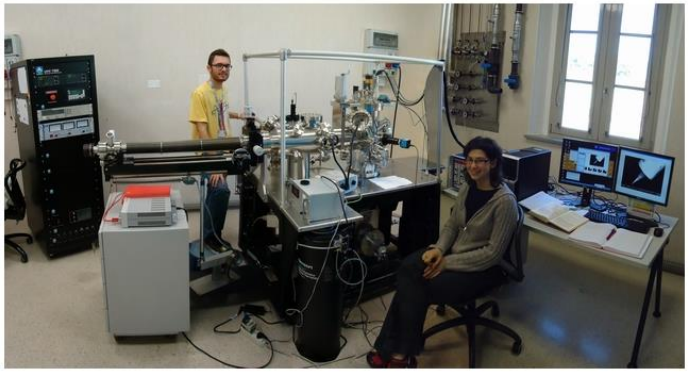
Micro-Raman

0.6 Coherent Raman Spectroscopy

Facilities @ NEST

0.7 Superconductivity

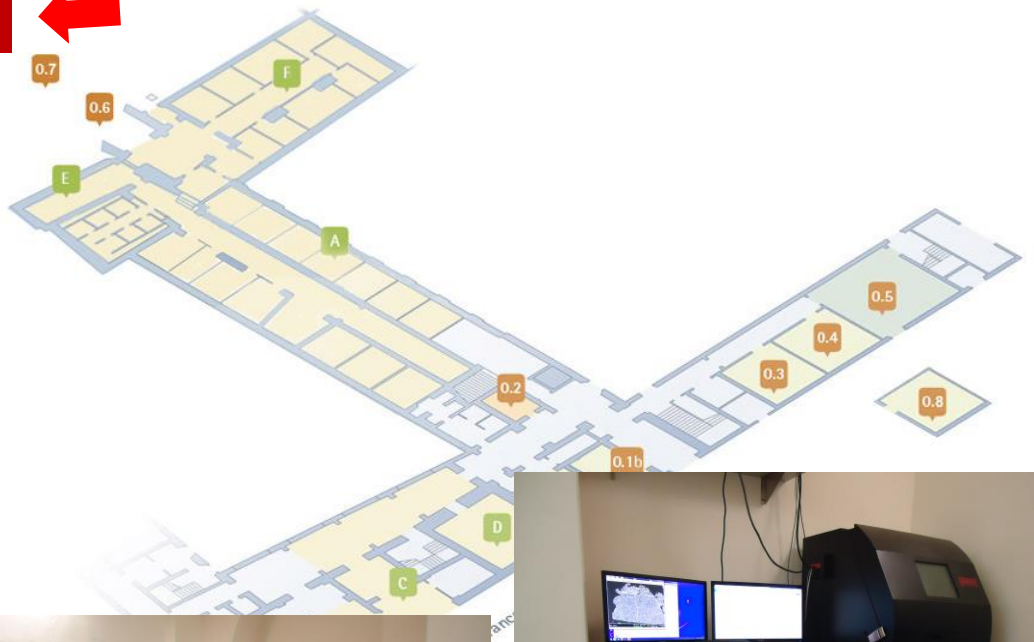
Facilities @ NEST

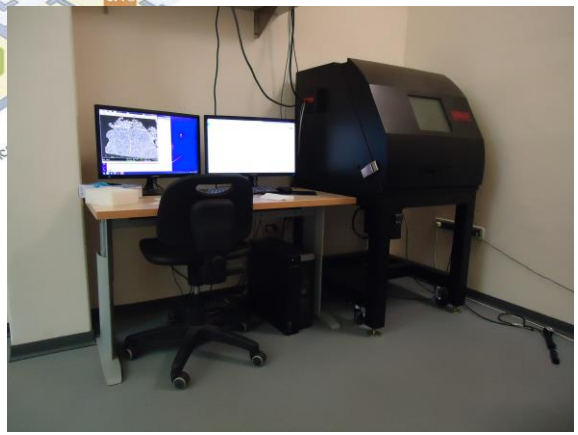


UHV-VT-STM

4K UHV-LT-STM

Micro-Raman





AFM

National Enterprise for nanoScience and nanoTechnology

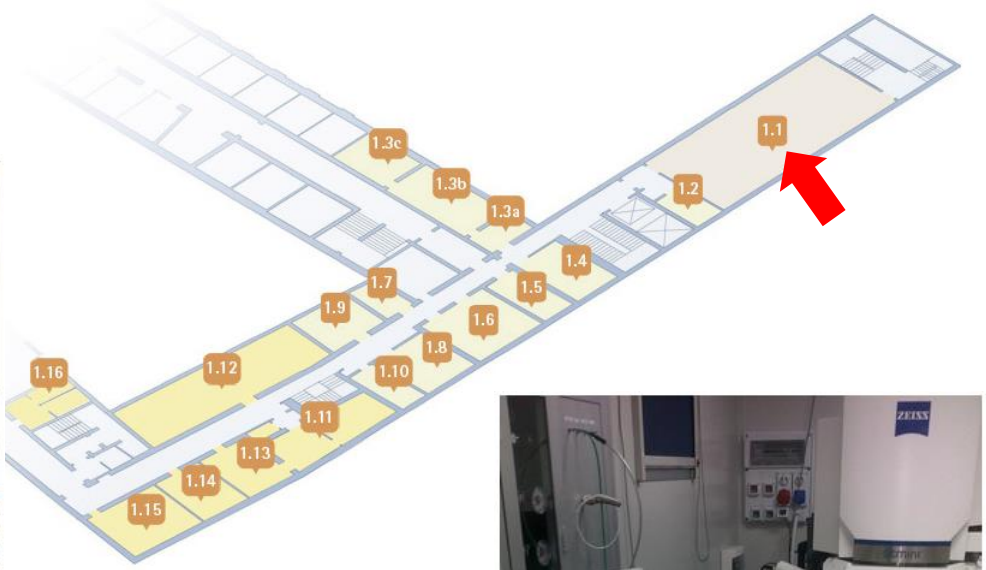
NEST

Facilities @ NEST

Facilities @ NEST

1.1 Clean Room Facility

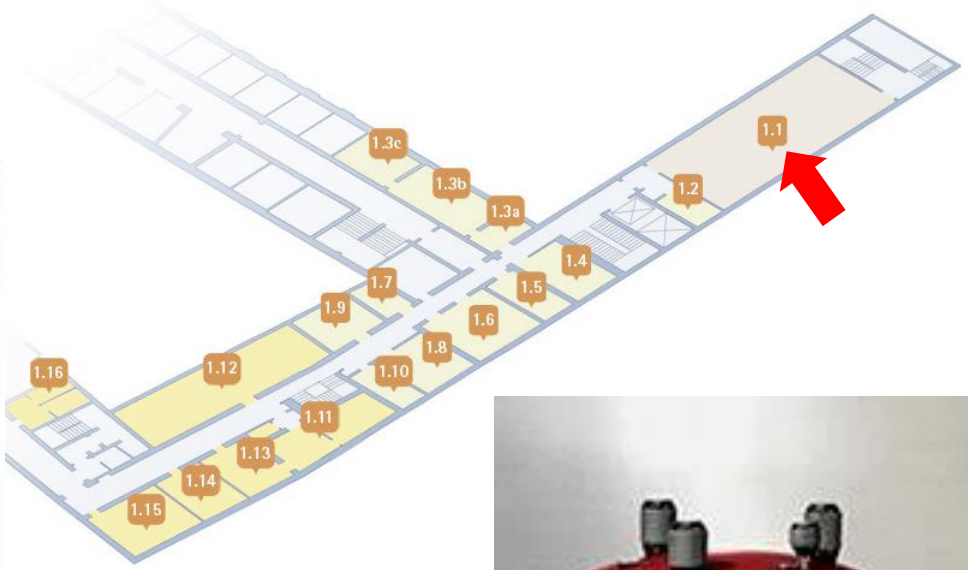
Facilities @ NEST



1.1 Clean Room Facility

SEM

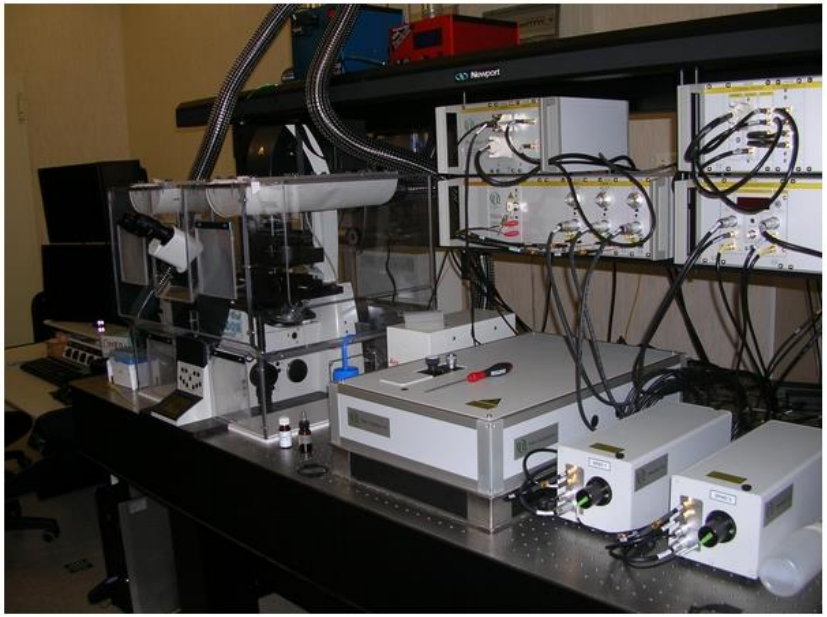
Facilities @ NEST



1.1 Clean Room Facility

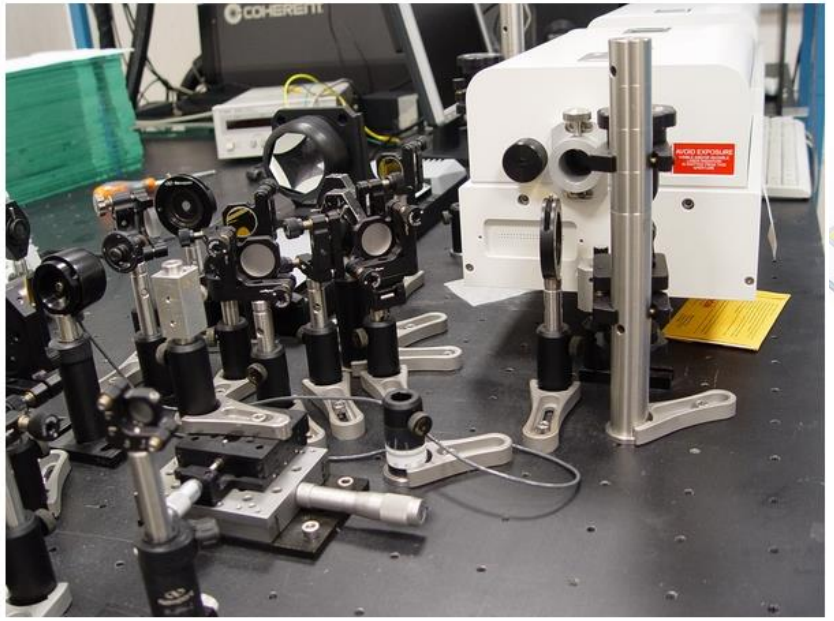
AFM

Facilities @ NEST



1.5 Single-molecule Confocal Microscopy

Facilities @ NEST

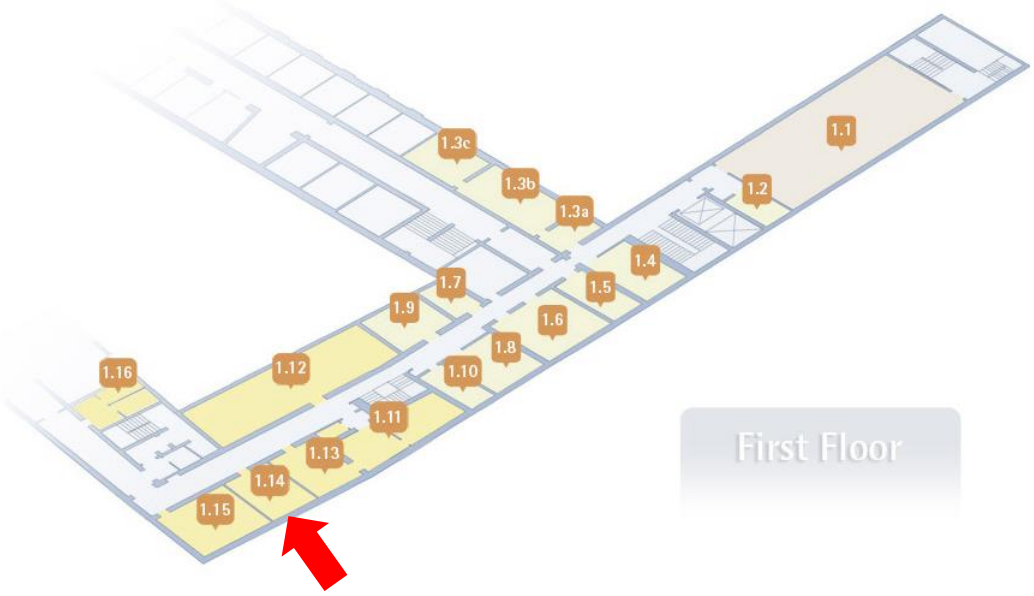


1.6 THZ Quantum Cascade Lasers and DNSOM

Facilities @ NEST

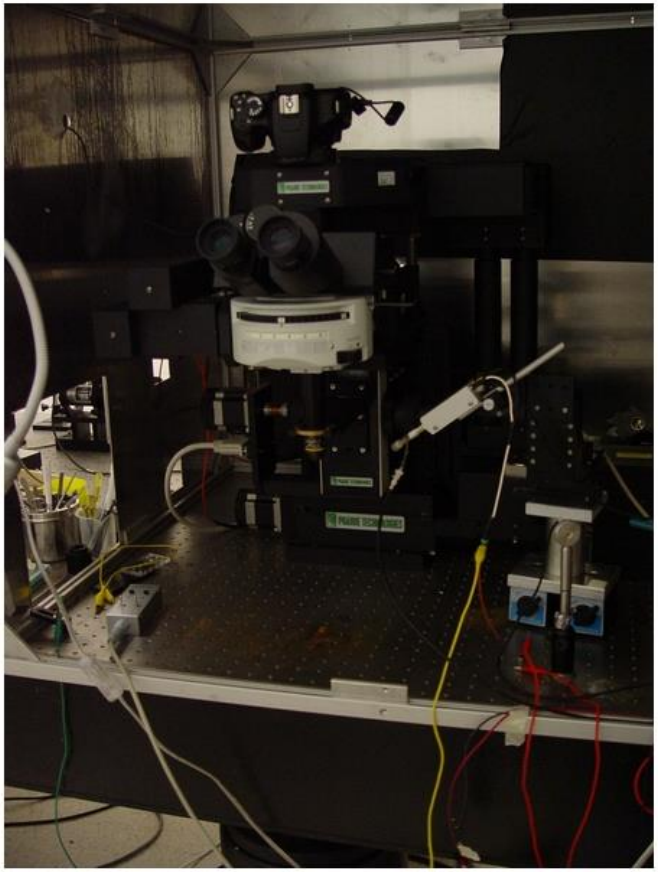
1.12 Bio Chemistry and Molecular Biology

Facilities @ NEST

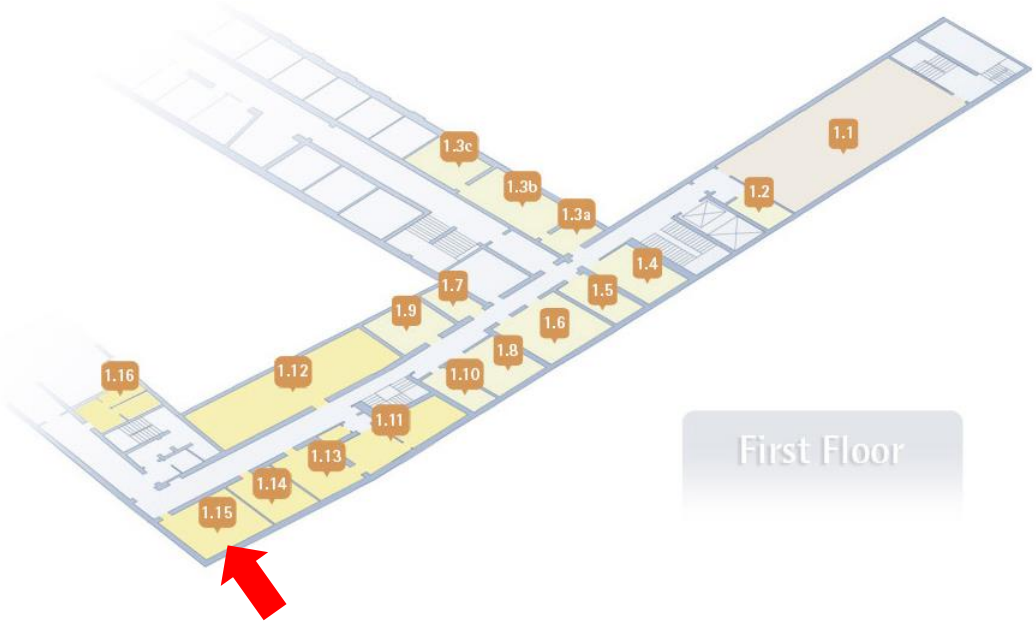


1.14 Lab-on-a-Chip Tecnologies

Facilities @ NEST



1.15 In vivo Two-Photon Imaging



Outline

- CNR Nano
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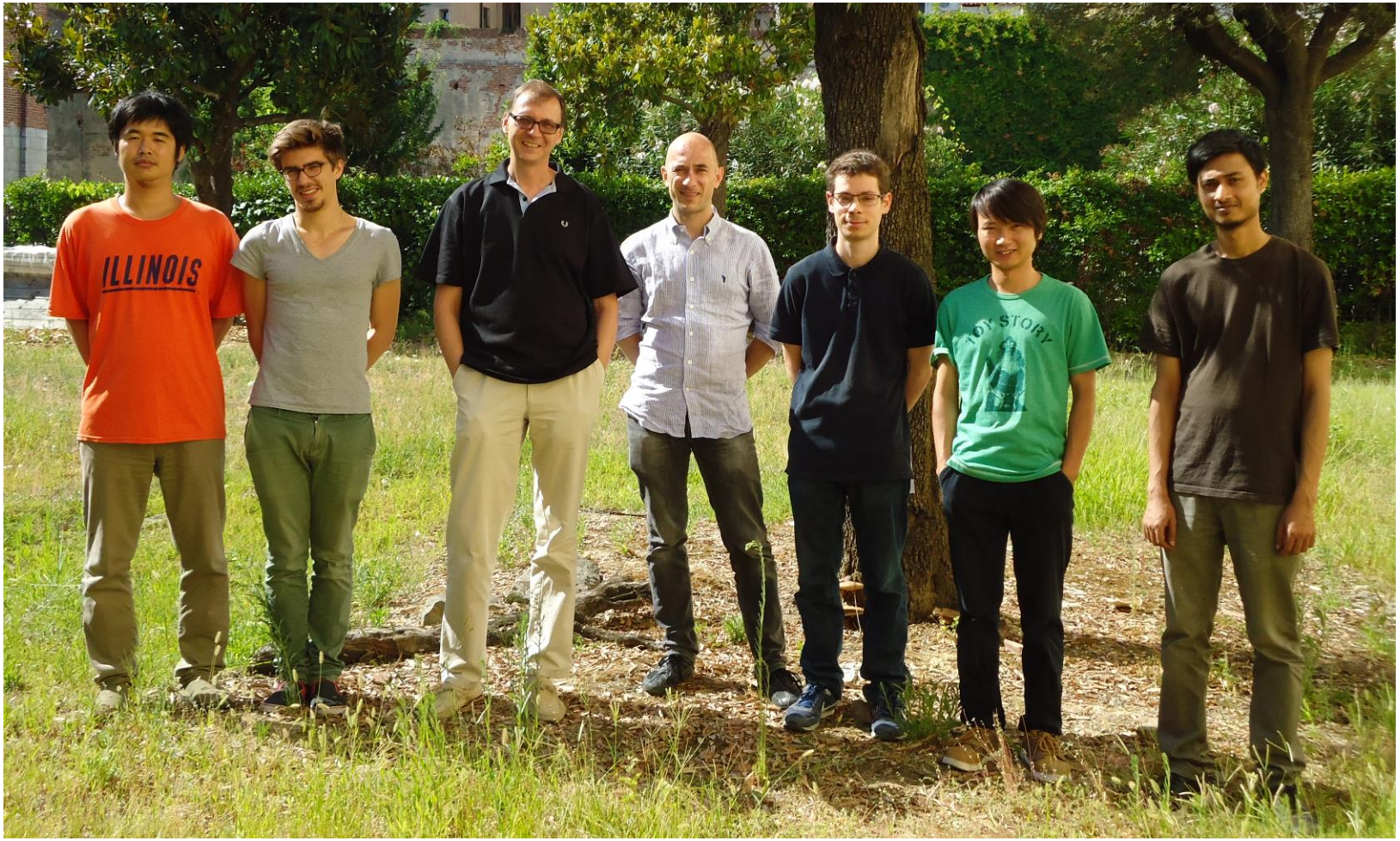
- My Research Activities



Yuya Murata Stefan Heun Stefano Guiducci Abhishek Kumar

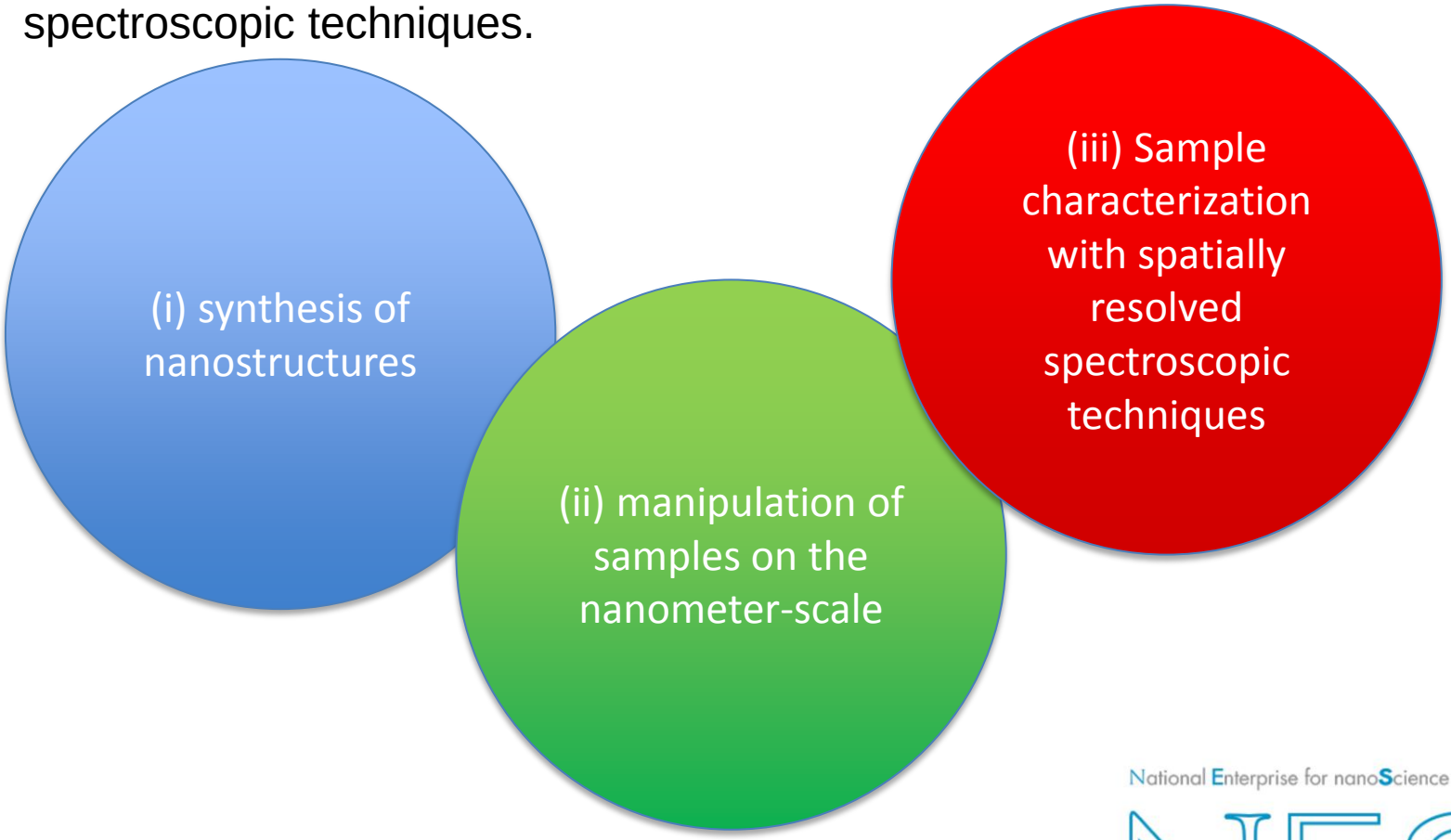
Luca Planat Stefano Roddaro Shaohua Xiang

National Enterprise for nanoScience and nanoTechnology

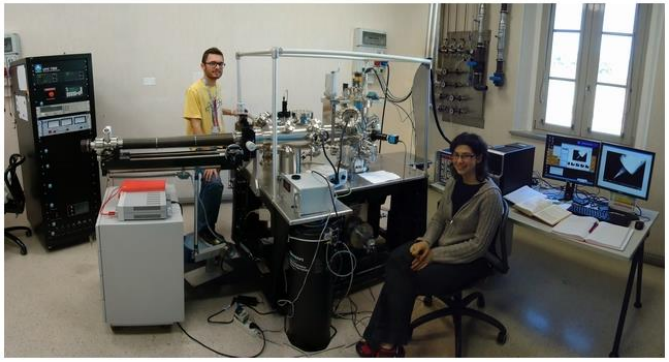
NEST

Research Activities

The physics of low-dimensional systems. This includes three aspects: (i) the synthesis of nanostructures, (ii) the manipulation of samples on the nanometer-scale, and (iii) their characterization with spatially resolved spectroscopic techniques.



Surface Science & Magneto-Transport



UHV-VT-STM

UHV-LT-STM

Scanning Gate Microscopy
300 mK, 9 T

Projects

GRAPHENE FLAGSHIP

Graphene for Hydrogen Storage

erc

Phosphorene

Ministero degli Affari Esteri
e della Cooperazione Internazionale

G. Gervais, Mc Gill University,
Montreal, Canada
2D Materials

Consiglio Nazionale delle Ricerche

JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE
日本学術振興会

S. Suzuki, NTT
High-mobility Graphene

National Enterprise for nanoScience and nanoTechnology
NEST

Recent Activities

- SGM on QPCs in III-V 2DEGS
- Magneto-transport in Graphene
- Hydrogenated Graphene
- Hydrogen Storage in Graphene
- Phosphorene

Nano Research 2015, 8(3): 948–956
DOI 10.1007/s12274-014-0576-y
Research Article

ISSN 1998-0124
CN 11-5974/O4

Scanning gate imaging of quantum point contacts and the origin of the 0.7 anomaly

Andrea Iagallo[1], Nicola Paradiso[1], Stefano Roddaro[1,2], Christian Reichl[3], Werner Wegscheider[3], Giorgio Biasiol[2], Lucia Sorba[1], Fabio Beltram[1], and Stefan Heun[1] (✉)

[1] *National Enterprise for Nanoscience and Nanotechnology (NEST), Istituto Nanoscienze-CNR and Scuola Normale Superiore, Piazza San Silvestro 12, 56127 Pisa, Italy*
[2] *Istituto Offcina dei Materiali CNR, Laboratorio TASC, 34149 Trieste, Italy*
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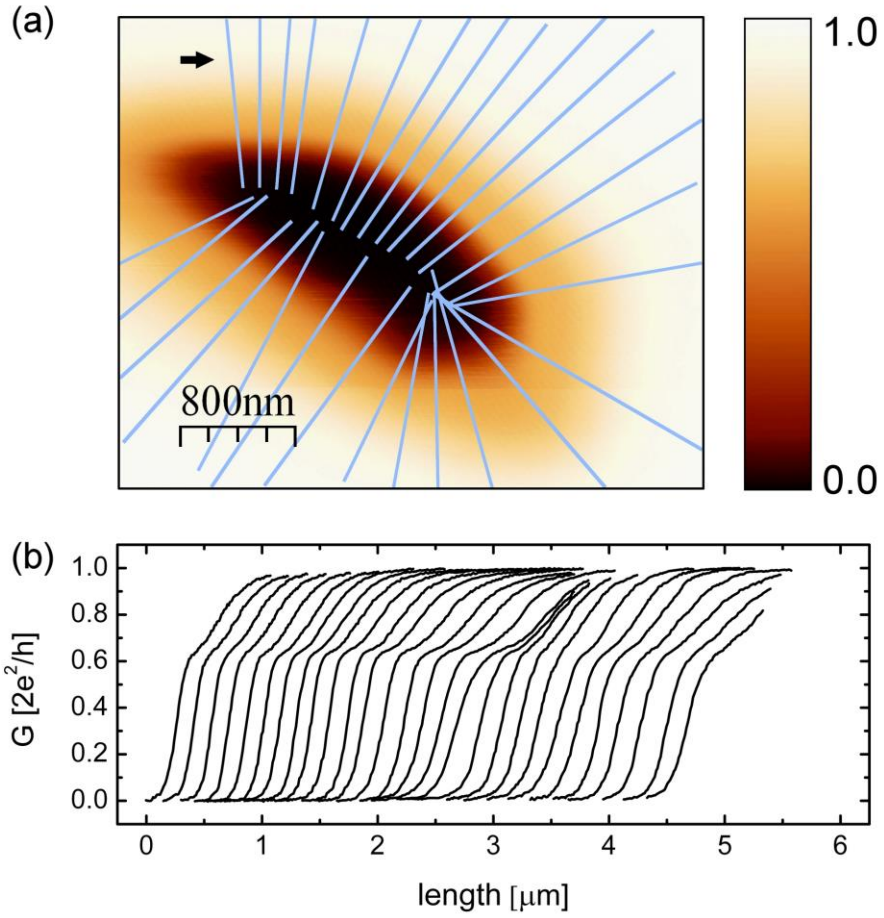
0.7 Anomaly



A. Iagallo et al., Nano Research 8 (2015) 948.

IOP Publishing

Semiconductor Science and Technology

Semicond. Sci. Technol. **30** (2015) 055007 (6pp)

doi:10.1088/0268-1242/30/5/055007

Bilayer-induced asymmetric quantum Hall effect in epitaxial graphene

Andrea Iagallo[1], Shinichi Tanabe[2,4], Stefano Roddaro[1], Makoto Takamura[2], Yoshiaki Sekine[2], Hiroki Hibino[2], Vaidotas Miseikis[3], Camilla Coletti[3], Vincenzo Piazza[3], Fabio Beltram[1,3] and Stefan Heun[1]

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[2] NTT Basic Research Laboratories, NTT Corporation, 3–1 Morinosato Wakamiya, Atsugi, Kanagawa, 243–0198, Japan

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Published 7 April 2015

CrossMark

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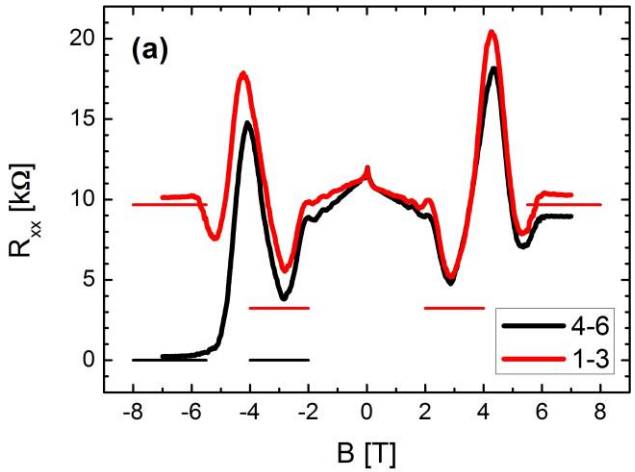
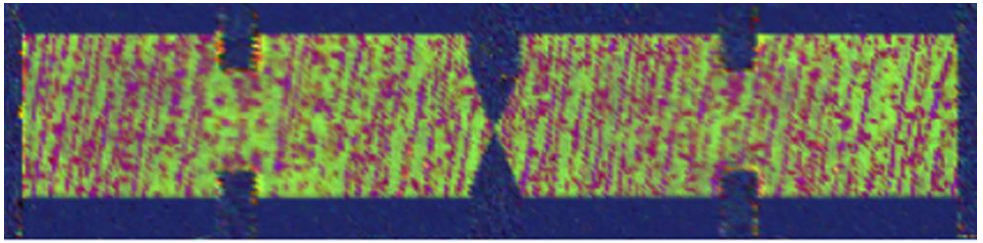
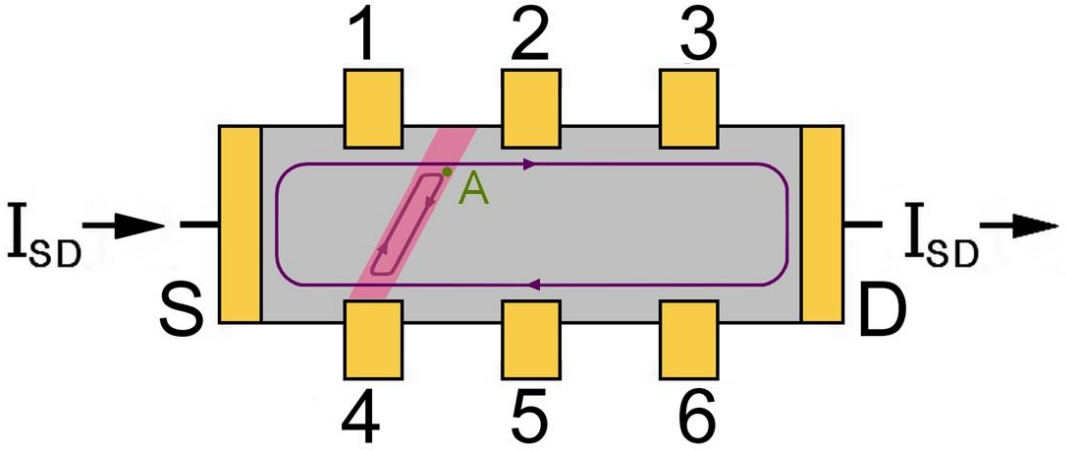
Bilayer-induced asymmetric quantum Hall effect







A. Iagallo et al., Semicond. Sci. Technol. 30 (2015) 055007.

IOP Publishing 2D Mater. 2 (2015) 014006 doi:10.1088/2053-1583/2/1/014006

2D Materials

PAPER

Rapid CVD growth of millimetre-sized single crystal graphene using a cold-wall reactor

RECEIVED
30 July 2014

ACCEPTED FOR PUBLICATION
19 December 2014

PUBLISHED
20 January 2015

V Miseikis[1], D Convertino[1,2], N Mishra[1], M Gemmi[1], T Mashoff[1], S Heun[3], N Haghighian[4], F Bisio[5], M Canepa[4], V Piazza[1] and C Coletti[1,2]

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[3] NEST, Istituto Nanoscienze—CNR and Scuola Normale Superiore, Piazza San Silvestro 12, I-56127 Pisa, Italy
[4] Dipartimento di Fisica, Università di Genova, Via Dodecaneso 33, I-16146 Genova, Italy
[5] CNR-SPIN, Corso Perrone 24, I-16152 Genova, Italy

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Keywords: graphene, chemical vapour deposition, single crystal

Supplementary material for this article is available online

National Enterprise for nanoScience and nanoTechnology
NEST

Single-crystal CVD graphene

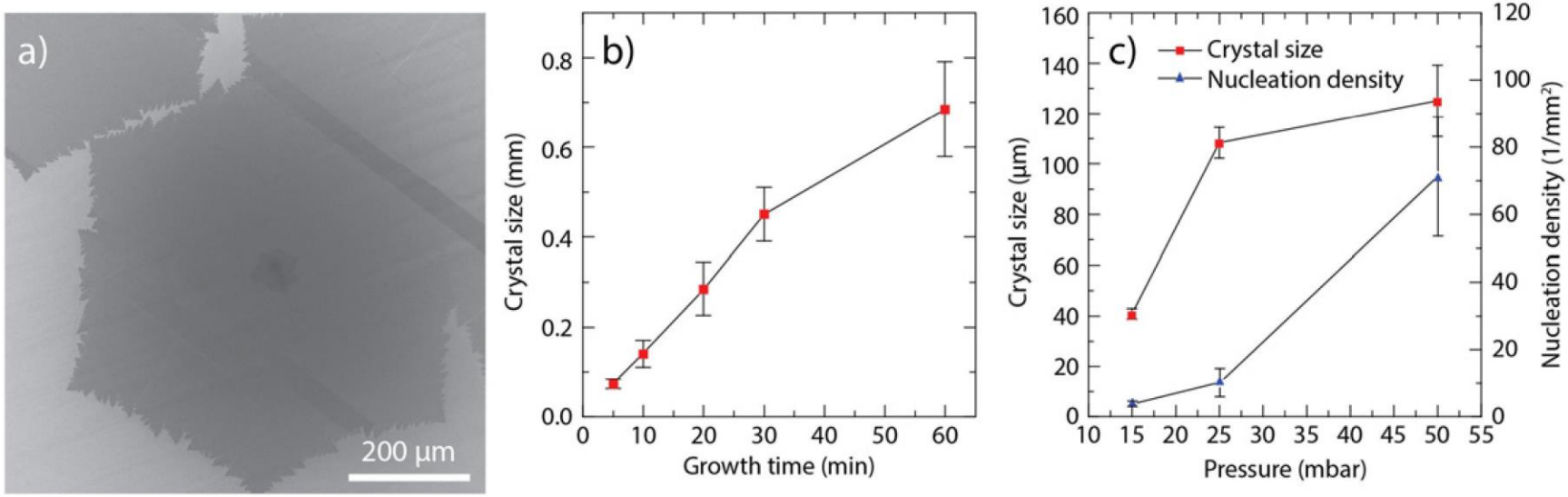

Figure 3. (a) SEM image of an isolated graphene crystal with a diagonal dimension of nearly 750 μm. (b) The size of graphene crystals as a function of growth time. (c) Crystal size and nucleation density obtained after 10 min of growth as a function of process pressure.

V. Miseikis et al., 2D Mater. 2 (2015) 014006.

Measurement of Topological Berry Phase in Highly Disordered Graphene

K. Bennaceur,[1] J. Guillemette,[1,2] P. L. Lévesque,[3] N. Cottenye,[3] F. Mahvash,[2,4] N. Hemsworth,[1] Abhishek Kumar,[5] Y. Murara,[5] S. Heun,[5] M. O. Goerbig,[6] C. Proust,[7] M. Siaj,[4] R. Martel,[3] G. Gervais,[1] and T. Szkopek[2,*]

[1] *Department of Physics, McGill University, Montréal, Québec, H3A 2T8, Canada*
[2] *Department of Electrical and Computer Engineering, McGill University, Montréal, Québec, H3A 2A7, Canada*
[3] *Department of Chemistry, Université de Montréal, Montréal, Québec, H3C 3J7, Canada*
[4] *Department of Chemistry, Université du Québec à Montréal, Montréal, Québec, H3C 3P8, Canada*
[5] *NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, Piazza San Silvestro 12, 56127 Pisa, Italy*
[6] *Laboratoire de Physique des Solides, Univ. Paris-Sud, CNRS UMR 8502, 91405 Orsay, France*
[7] *Laboratoire National des Champs Magnétiques Intenses, CNRS, INSA, UJF, UPS, Toulouse, 31400 France*

(Dated: June 2, 2015)

We have observed the quantum Hall effect (QHE) and Shubnikov-de Haas (SdH) oscillations in highly disordered graphene at magnetic fields up to 65 T. Disorder was introduced by hydrogenation of graphene up to a ratio H/C $\approx 0.1\%$. The analysis of SdH oscillations and QHE indicates that the topological part of the Berry phase, proportional to the pseudo-spin winding number, is preserved upon introduction of disorder by hydrogenation in large scale graphene.

PACS numbers: 72.80.Vp, 75.47.-m, 03.65.Vf

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NEST

Berry Phase in Graphene

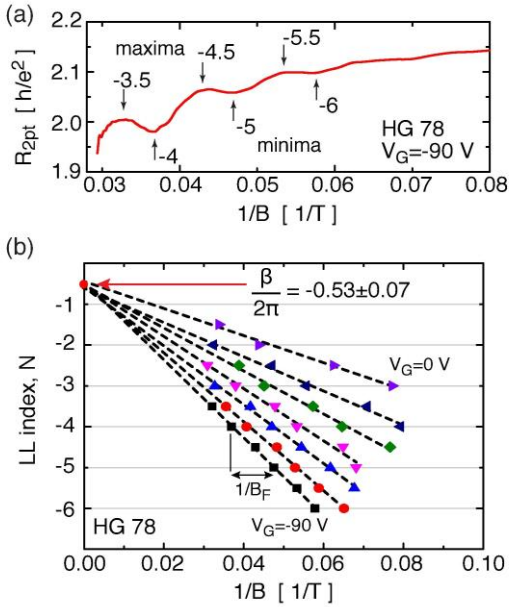

FIG. 4. (a) The measured R_{2pt} versus $1/B$ of HG78 at a gate voltage $V_G = -90$ V. The local minima and maxima of R_{2pt} versus $1/B$ are identified. (b) A Landau fan diagram of LL index versus $1/B$ for sample HG78 at different gate voltages. The SdH frequency B_F at each gate voltage is extracted from the slope of the LL fan (linear fit indicated by dashed lines). The intercept $\beta/2\pi = -0.53 \pm 0.07$ is in good agreement with $\beta = \pi$.

K. Bennaceur et al., Phys. Rev. B, submitted.

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Increasing the active surface of titanium islands on graphene by nitrogen sputtering

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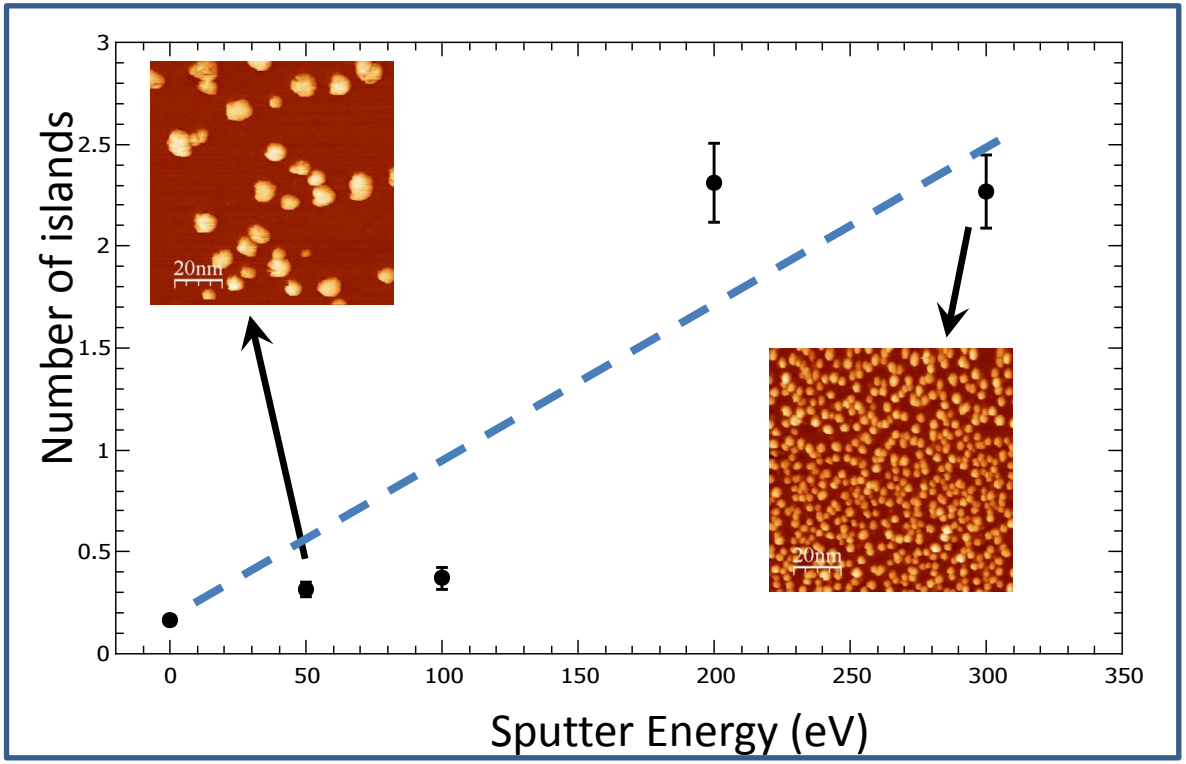
Titanium-island formation on graphene as a function of defect density is investigated. When depositing titanium on pristine graphene, titanium atoms cluster and form islands with an average diameter of about 10 nm and an average height of a few atomic layers. We show that if defects are introduced in the graphene by ion bombardment, the mobility of the deposited titanium atoms is reduced and the average diameter of the islands decreases to 5 nm with monoatomic height. This results in an optimized coverage for hydrogen storage applications, since the actual titanium surface available per unit graphene area is significantly increased. © *2015 AIP Publishing LLC.*
[http://dx.doi.org/10.1063/1.4913562]

Hydrogen storage in Ti-functionalized graphene

Average Number of Islands per 100 nm^2



T. Mashoff et al., Appl. Phys. Lett. 106 (2015) 083901.

The role of water in the preparation and stabilization of high quality phosphorene flakes

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This paper is dedicated to the 60th birthday of Prof. Dr. Manfred Scheer…..

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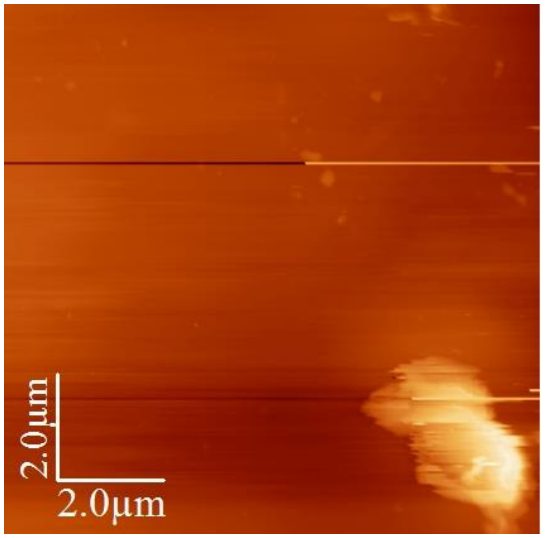
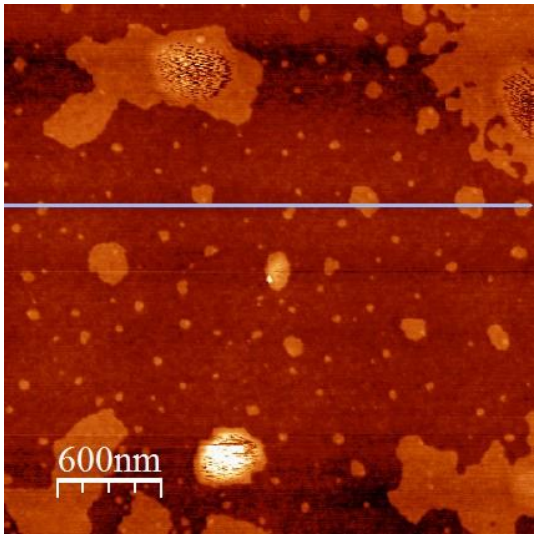
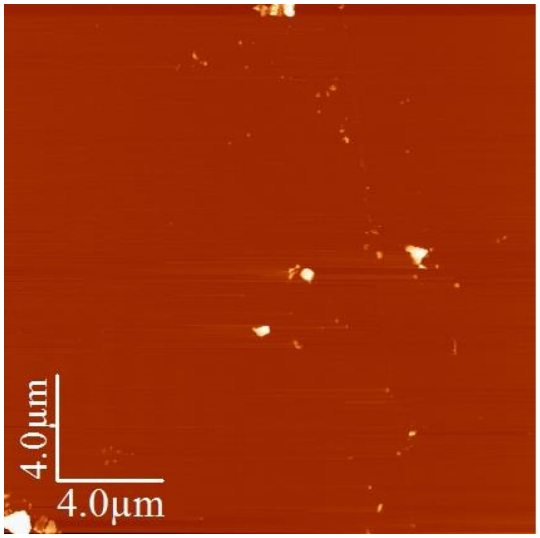
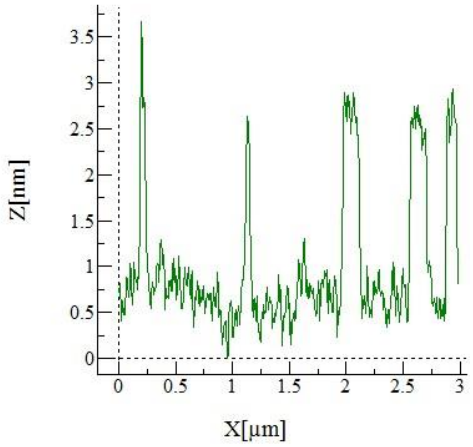
Phosphorene Flakes









M. Serrano-Ruiz et al.,
in preparation.

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