NANOFABRICATION RESEARCH INTHE RESEARCH CENTRE IN NANOSCIENCE AND NANOTECHNOLOGY (CIN2)

Prof. Dr. Clivia M. Sotomayor Torres

Catalan Institute of Nanotechnology & ICREA

CIN2
CENTRE D'INVESTIGACIÓ
EN NANOCIÈNCIA
I NANOTECNOLOGIA
CAMPUS UAB, BELLATERRA, BARCELONA

CSIC

ICN
Institut
Català
de Nanotecnologia

Presentation to the NANOLITO Workshop 26th May 2009

OUTLINE

- Facilities
- Examples of research work
- Perspectives

ICN FACT SHEET

PEOPLE

Total 60

Including 13 non-researchers

PROJECTS

11 National	1.2 M€
12 European	5.2 M€
4 SME's	0.2 M€
Total	6.6 M€

PUBLICATIONS 2007 (08)

Nr of publications:

59 (84)

Average Impact Factor:
3.76 (3.96)

INDUSTRIAL ACTIVITIES

1 Spin-off
5 Patents

ICN Work with industrial partners

With NANÒNICA incorporating nanoparticles in wools (2007)

With ENDOR on synthesis and medical applications of advanced nanomaterials. (2007)

With BIOINGENIUM in a feasibility study to produce hormones for veterinary use. (2007)

With NANOINK on a NDA-covered agreement concerning patterning and ink applications (2007)

With LEITAT – ACONDICIONAMIENTO TARRASSENSE on textiles suitable for UV protection (2007)

ICN PATENTS (2008)

Catalysis

-Surface-supported Au nanoparticles for catalytic applications

Self-assembly and Nanofabrication (joint with VTT)

-Capillary-directed sedimentation on topologically patterned substrates

Drug and chemical compounds delivery

-Compounds encapsulation in Metal-Organic nanospheres

Nanobiomedicine

-Cell identification with Au nanoparticles by means of H ion reduction

-Au nanoparticles functionalized with peptide molecules

CIN2 COMMON EQUIPMENT

- **E-beam Metal Evaporators**
  - For non-magnetic materials
  - For magnetic materials (e-beam and sputtering)
- **SEM**
  - Environmental, 150 mm wafer – undergoing purchasing process
  - High resolution - undergoing purchasing process
- **TEM (200kV)** - undergoing purchasing process
- **X-ray Diffraction**
  - Powder XRD (for Co, Fe, Ni, … NPs)
  - Thin films XRD (High resolution, SAXS, reflectometry,texture, etc.)
- **XPS/UPS System**
- **SQUID**
- **Mid-far IR spectrometer**
- **AFM**
- **Nanoimprinter 50 mm wafer**
- **Focused ion beam (crossed-beam)**

Also

- **wide range of specialist eqyuipment in each research group**

Research strands in CIN2

- Theory and Atoms on Surfaces
- Nanoparticles, NPs in matrices and energy research
- **Nanofabrication and Nanometrology**
- Physical Properties of Nanostructures
- Nanobiosensors

THEORY AND NANOSTRUCTURES MANIPULATION

P Ordejon, P Gambardella and J Fraxedas

- **Atomistic simulations**
- **Magnetic atoms/molecules on surfaces**
- **Metal-organic nanostructures**
- **Small molecules**

V Puntes, D Ruiz-Molina, P Gomez-Romero, M Lira-Cantu

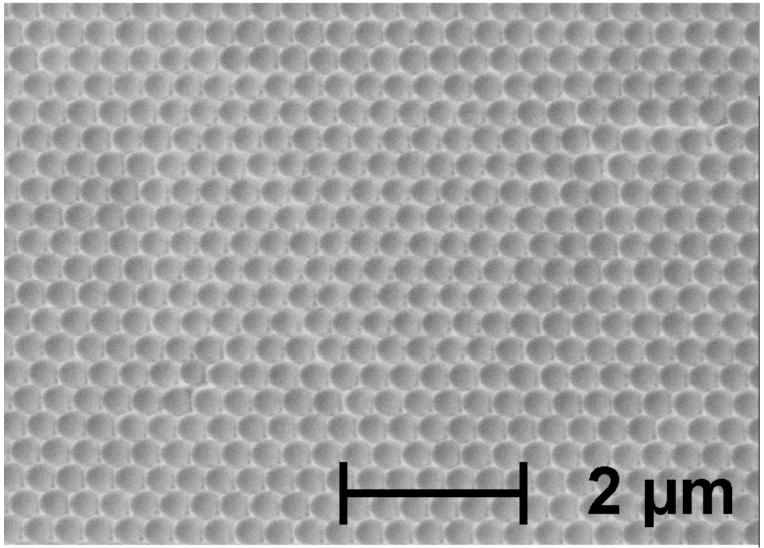
- **Inorganic nanoparticles**
- **Core-shell NPs**
- **Molecular electronics**
- **Metal-organic materials**
- **Energy storage and conversion**
- **Solar cells**

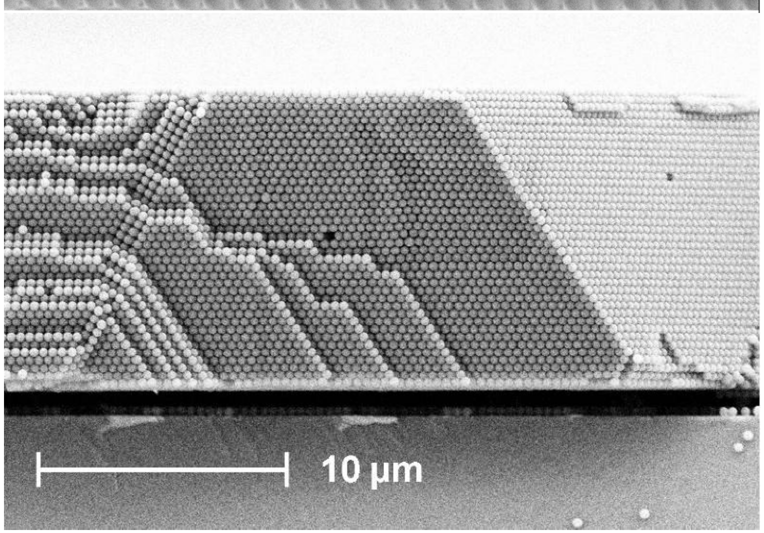
C M Sotomayor Torres, D Ruiz-Molina, S Valenzuela and A Bachtold

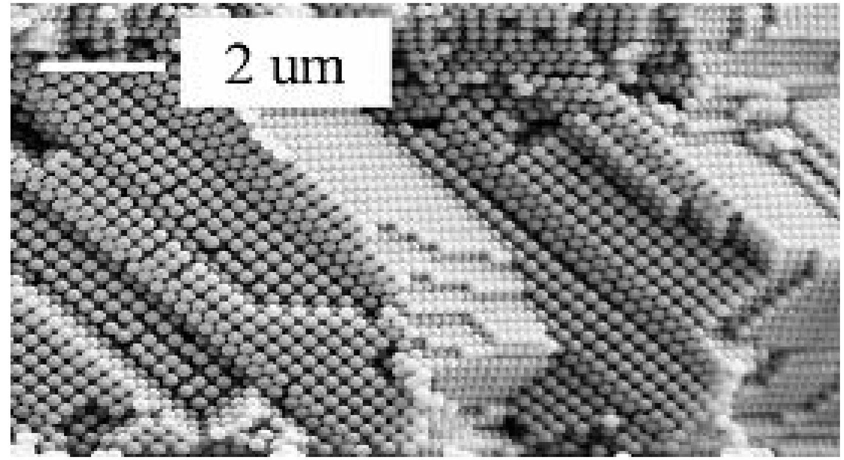
- **Self-assembly**
- **Focused ion and electron beam lithography**
- **Dip pen Lithography**
- **Nanoimprint lithography**
- **Nanometrology**

Other teams using nanfabrication facilities are those of L Lechuga (plasmonics for biosensors) and J Fraxedas (synchrotorn-based approaches)

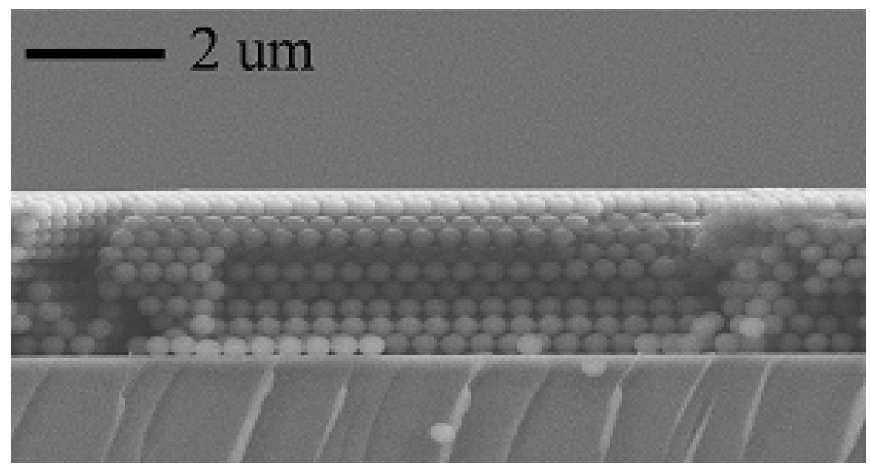
Self-assembly of 3D colloidal crystals







W Khunsin, G Kocher et al, to be published

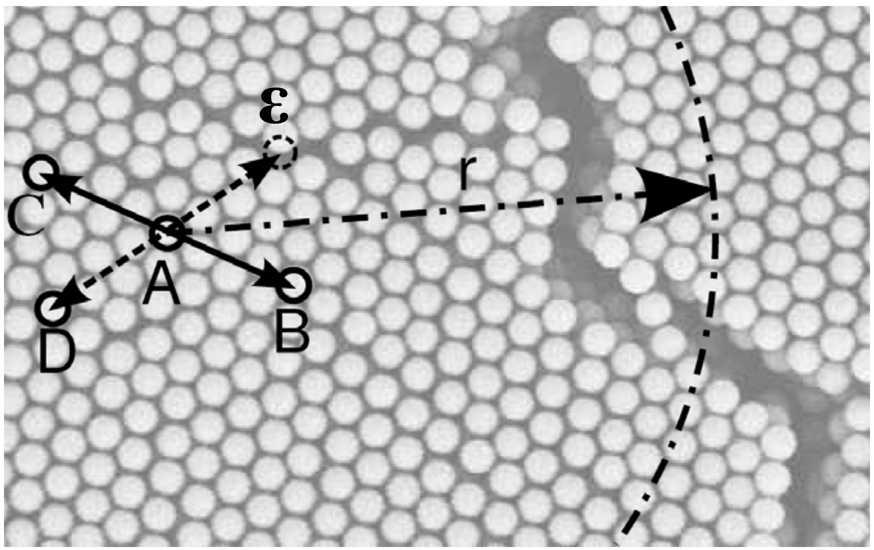


Quality improvement using acoustic noise

Concept of "*opposite beads*"

p(r) – probability of finding an opposite beads within a radius **r**, for a given tolerance parameter **ε** for the exact location of the spheres

At sphere 'A'



$$p(r) = \frac{\sum_{A \neq B,C} \chi_r(\overrightarrow{AB})\chi_\varepsilon(\overrightarrow{AB} + \overrightarrow{AC})}{\sum_{A \neq B} \chi_r(\overrightarrow{AB})}$$

$$\chi_y(\vec{R}) = \begin{cases} 1 & if \quad \left|\vec{R}\right| < y \\ 0 & else \end{cases}$$

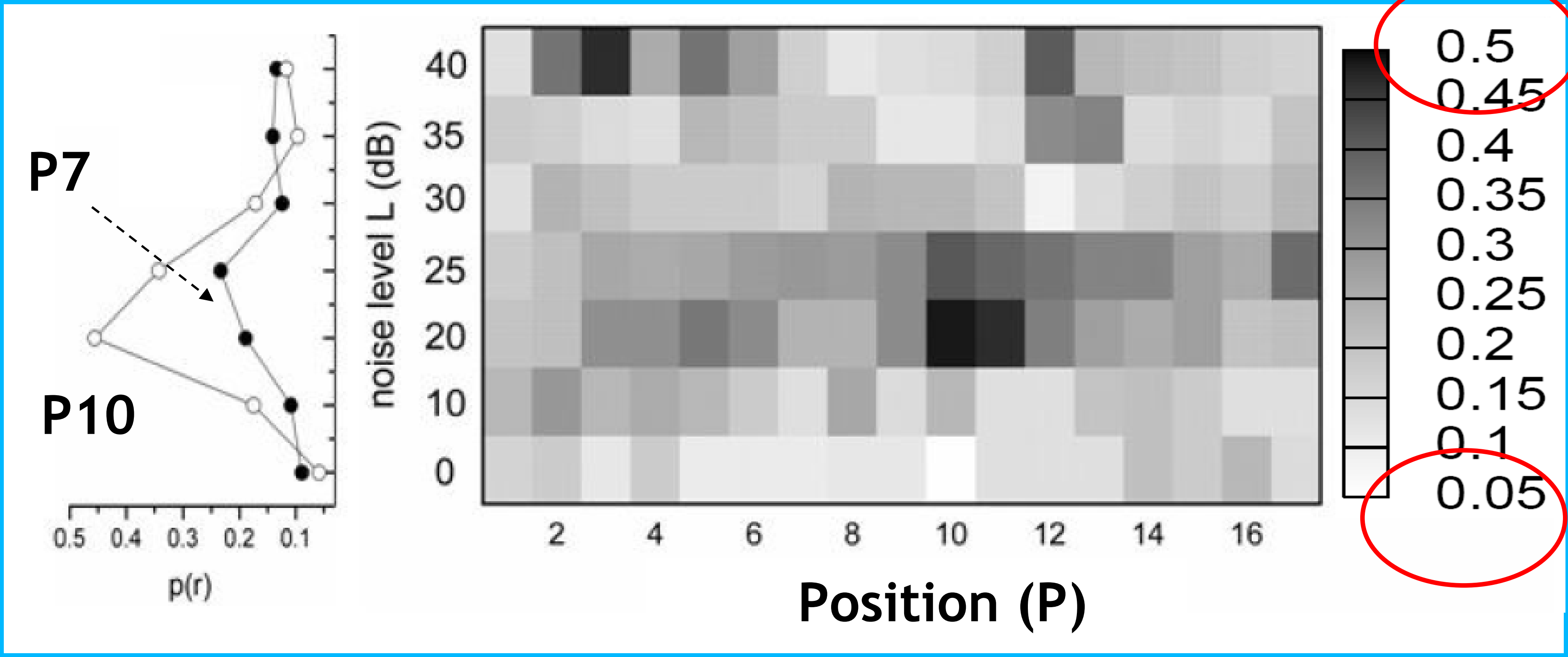
Global sum: weighted average

$$p(r) = \frac{\sum_A N_A(r) p_A(r)}{\sum_A N_A(r)}$$

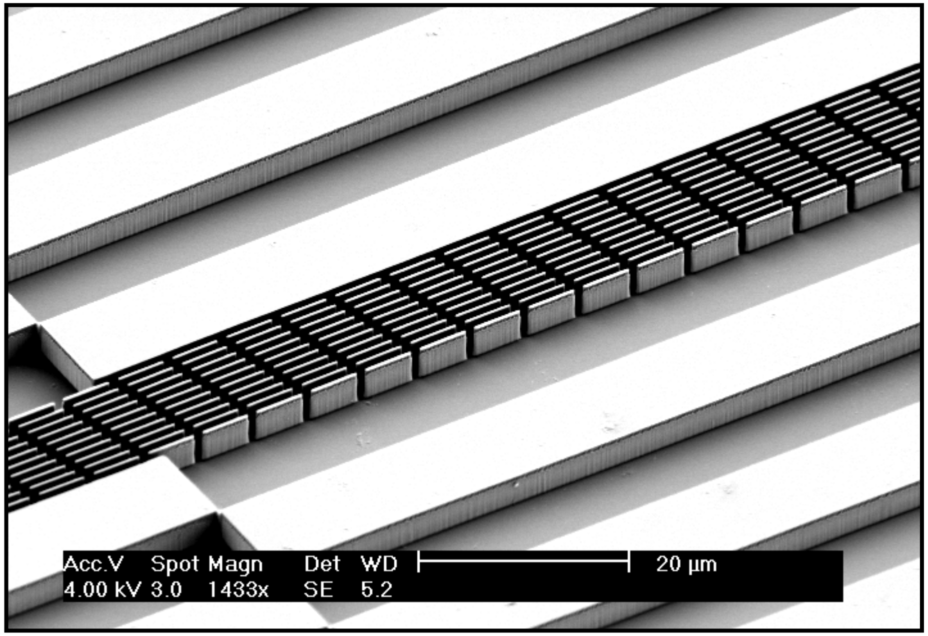
Stochastic-resonance in photonic crystal growth

D = 368 nm

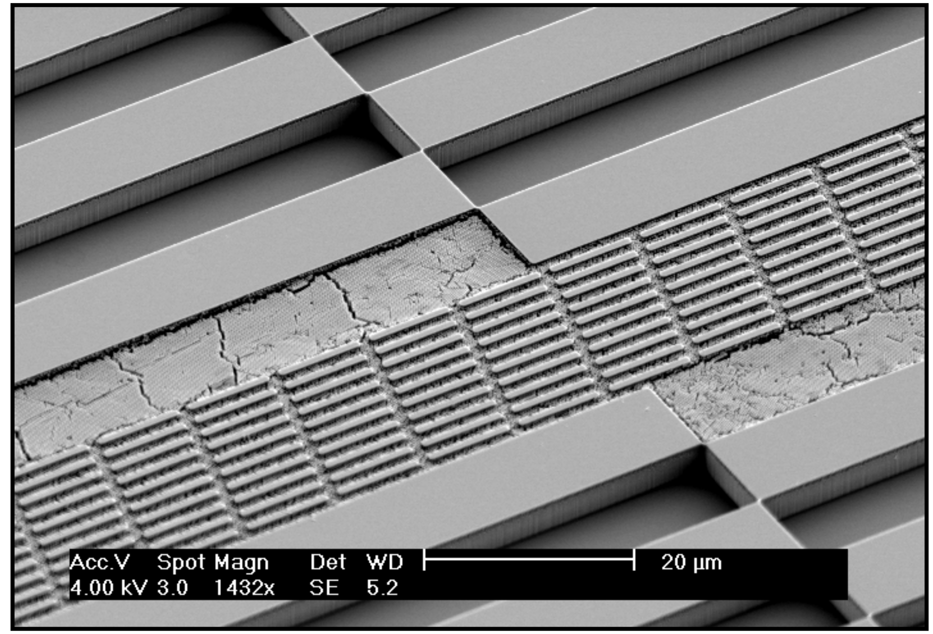
r = 5.5 μm ≈ 15D, and ε = 43 nm ≈ 0.12D



Particles self-assembled on patterned Silicon and SOI



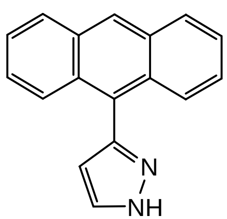
Etched silicon substrate



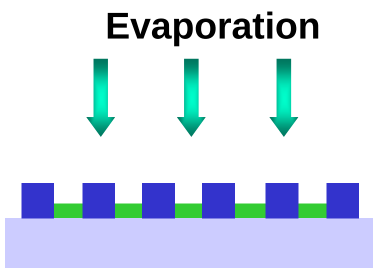
PMMA opal self-assembled in basins in etched silicon substrate

Joint patent 2007, S Arpianen, J Ahopelto, F Jonsson and C M Sotomayor Torres.

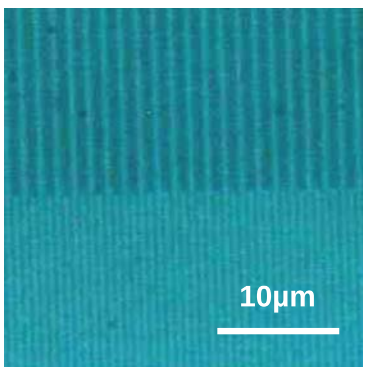
Molecular self-assembly assisted by nanoimprinting

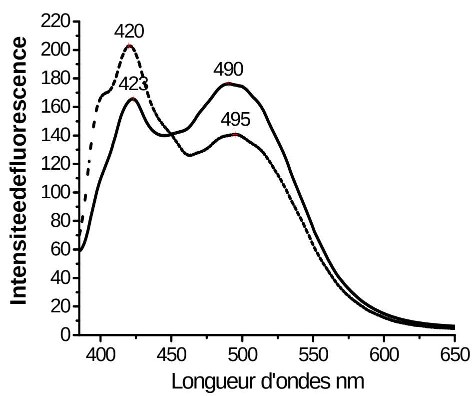


3-(9-anthryl) pyrazole
(ANP)

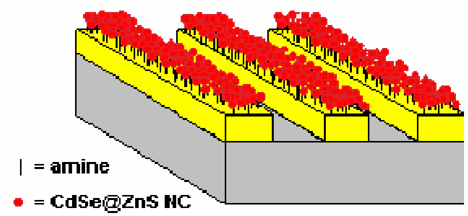


Microscopie de fluorescence

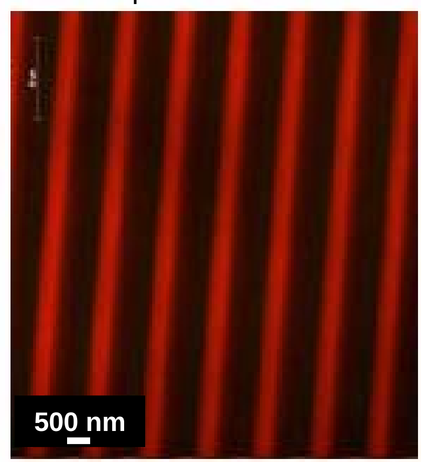




W. Hu,…, V. Reboud *et al.*, Adv. Materials, 19, 2119, 2007



Microscopie de fluorescence



V. Reboud *et al.*, en préparation

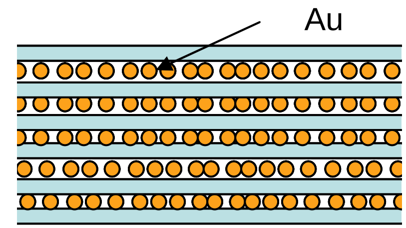
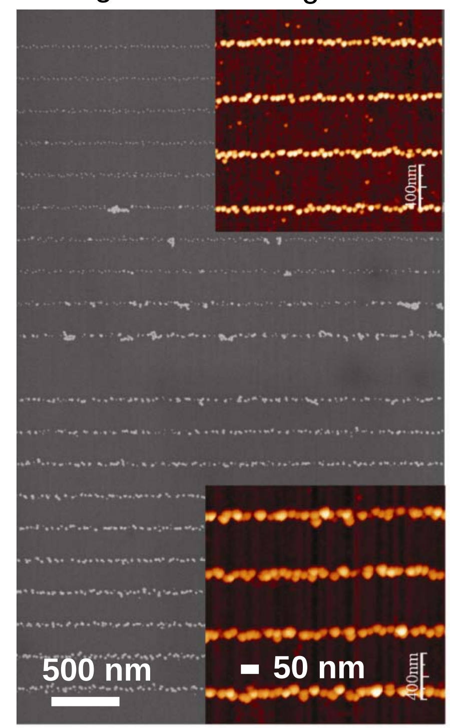
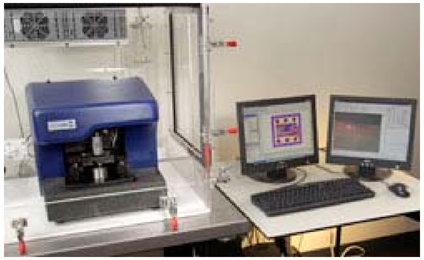
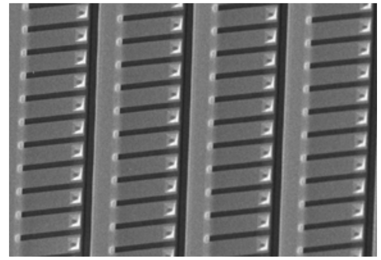


Image SEM Image AFM

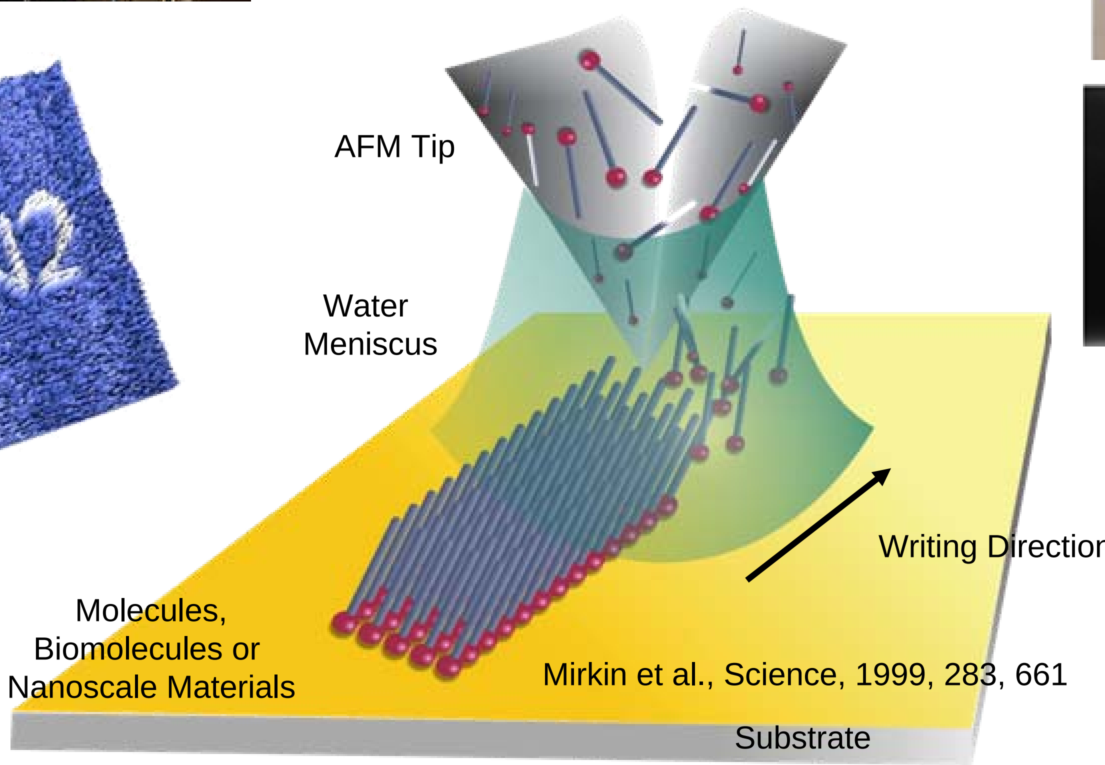


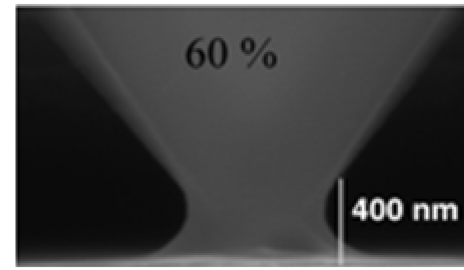
Surface functionalisation

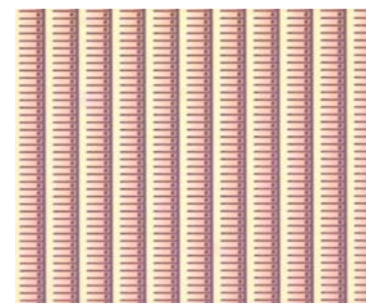


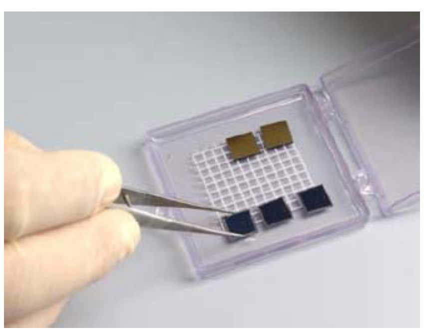



CIN2


AFM Tip
Water
Meniscus
Molecules,
Biomolecules or
Nanoscale Materials
Writing Direction
Mirkin et al., Science, 1999, 283, 661
Substrate


60 %
400 nm



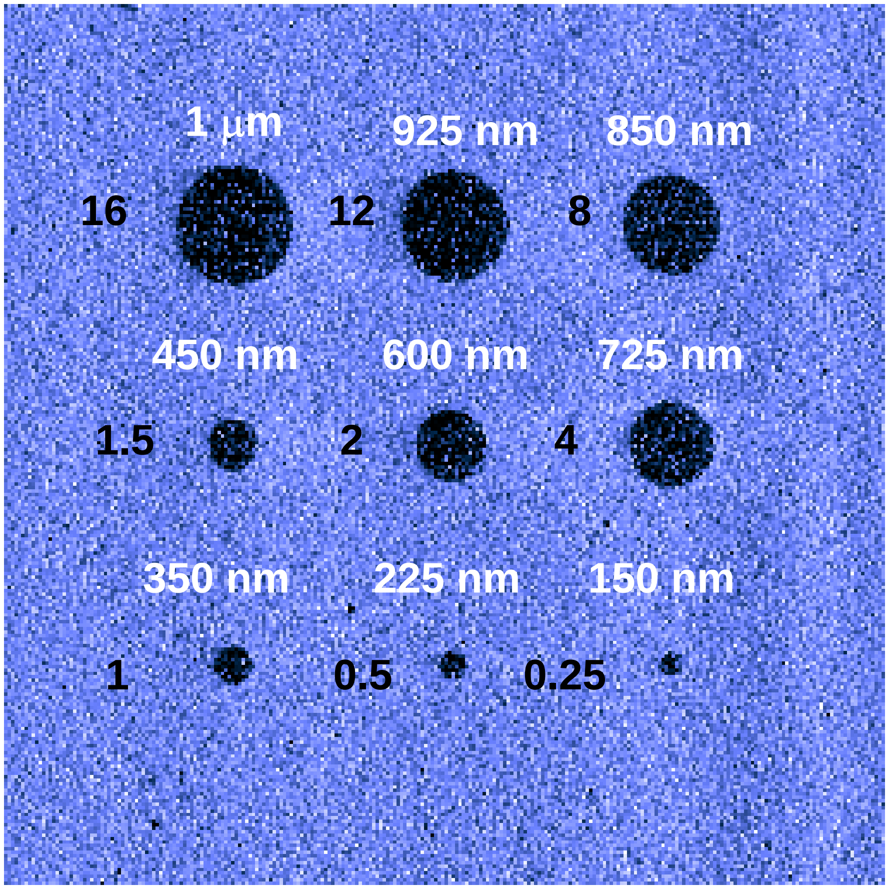



ICN

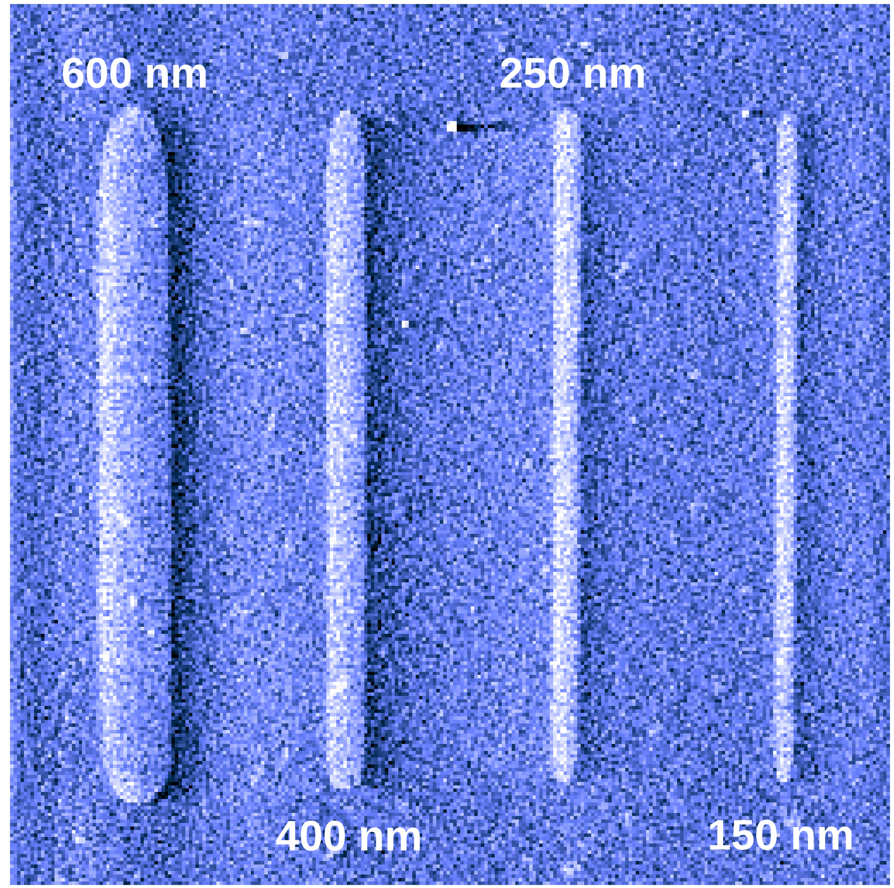
D Ruiz group

DPL Different writing modes

Static Writing

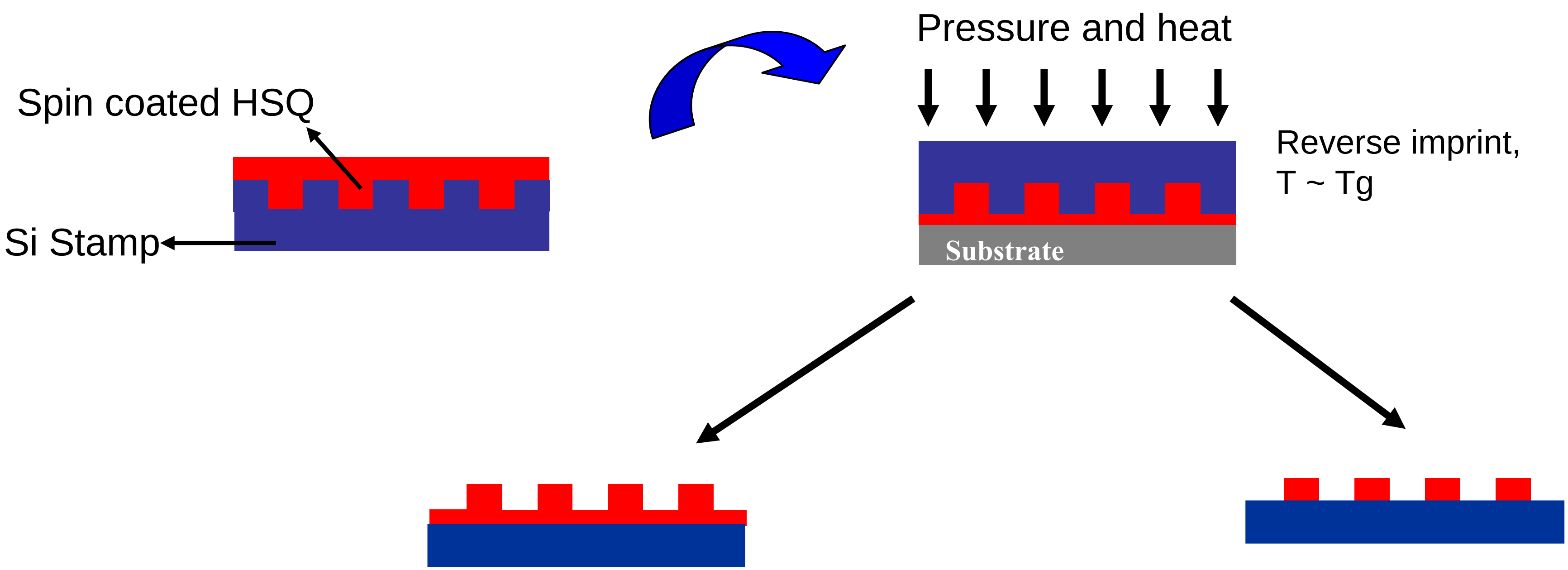


Dynamic Writing



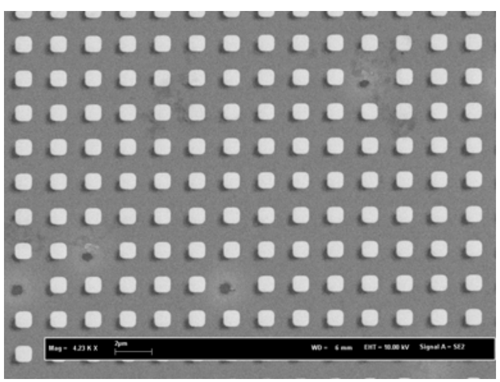
D Ruiz et al

Reverse Nanoimprint Lithography



Whole layer transfer mode

Inking mode

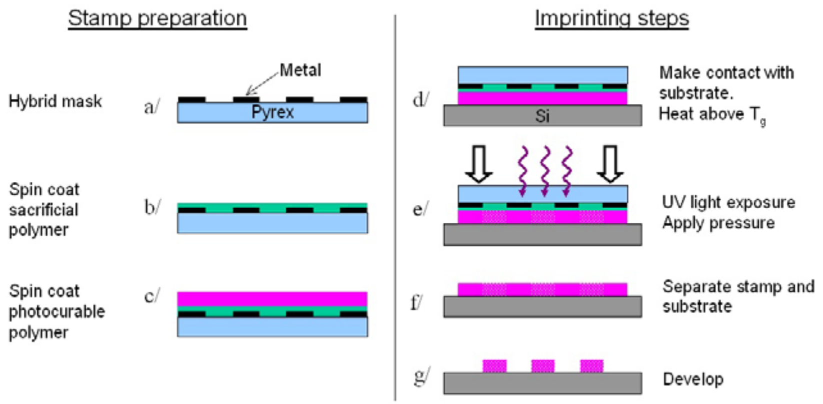


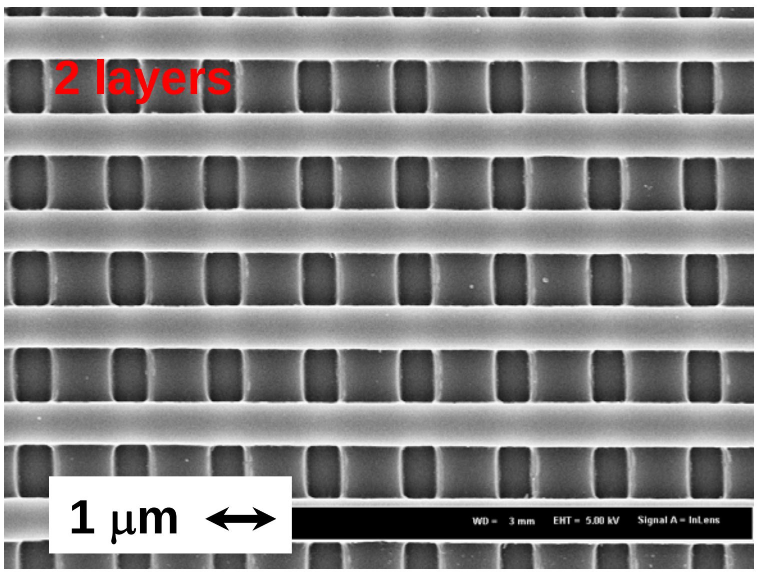
N Kehagias et al J Vac Sci Technol B **24**, 3002 (2006)

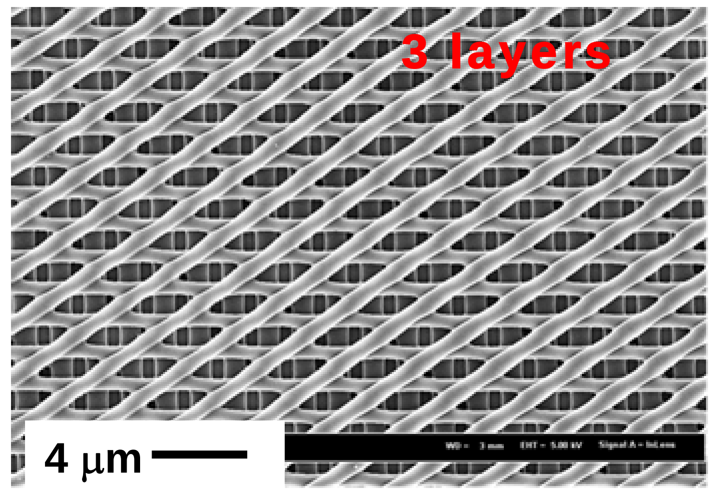
NaPa
Emerging Nanopatterning Methods

Reverse UV Nanoimprinting technique

- No residual layer
- No need for anti-adhesive treatment of the stamp
- The same photocurable polymer is used
- High resolution (stamp dependent)
- High throughput (<2 min)





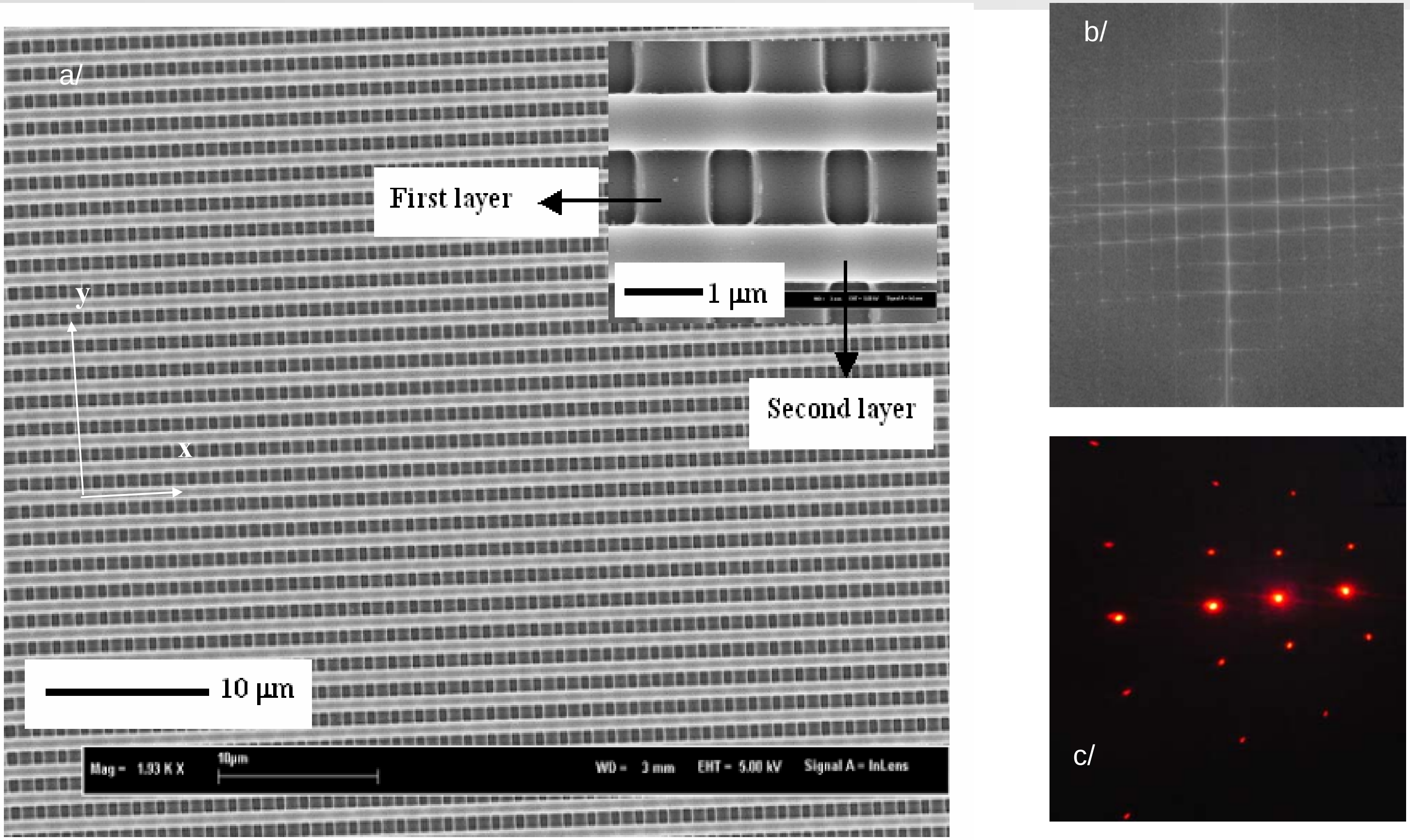


N. Kehagias *et. al*, *J. Vac. Sci. Technol. B* ***24****, 3002, (2006)*

N. Kehagias *et. al*, Nanotechnology, 18, 175303, (2007)

Patterned area 5 x 5 mm2

Polymer double layer grating by RUV NIL



a/ SEM image of a large (>50µm) double layer grating. b/ Fourier transform of a/ showing good homogeneity of lines over the whole surface with limited dispersion in size and position c/ Far -field optical image of diffracted light by the 3D grating.

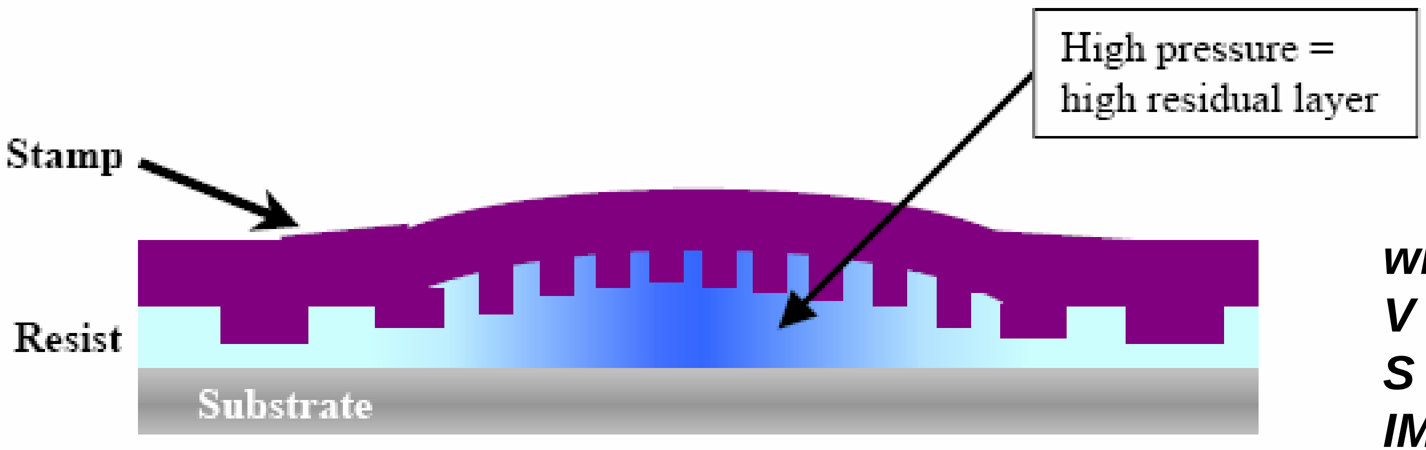
N Kehagias *et al., J. Vac. Sci. Technol. B **24**, 3002, 2006*

Modelling of the NIL process

Assume resist is an incompressible viscous fluid → non-stationary Navier-Stokes equations in velocity-pressure

$$\mathrm{Re}\left[\frac{\partial \mathbf{V}}{\partial t} + (\mathbf{V}\cdot\nabla)\mathbf{V}\right] = -\nabla P + \Delta \mathbf{V}, \qquad \begin{array}{c} \nabla \cdot \mathbf{V} = 0, \\ \mathbf{V} = (v^x, v^y, v^z), \end{array}$$

Re is the Reynolds number, V is the stamp velocity, P is the pressure. Also includes characteristic lateral size of the stamp and the density and the dynamic viscosity of the resist.



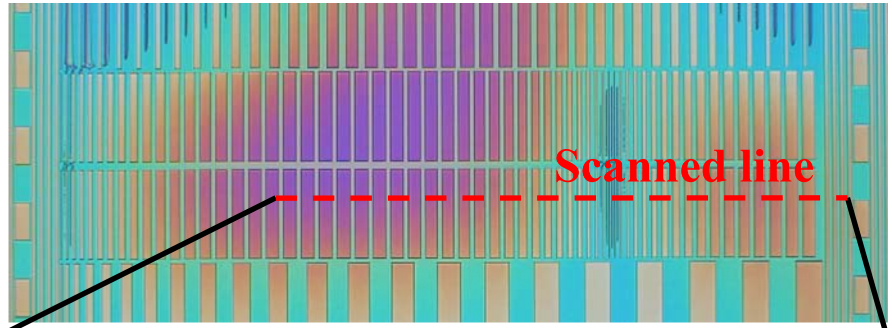
with V Sirotkin, S Zaitsev. IMT

Stamp bending due to non-homogeneous stamp design.

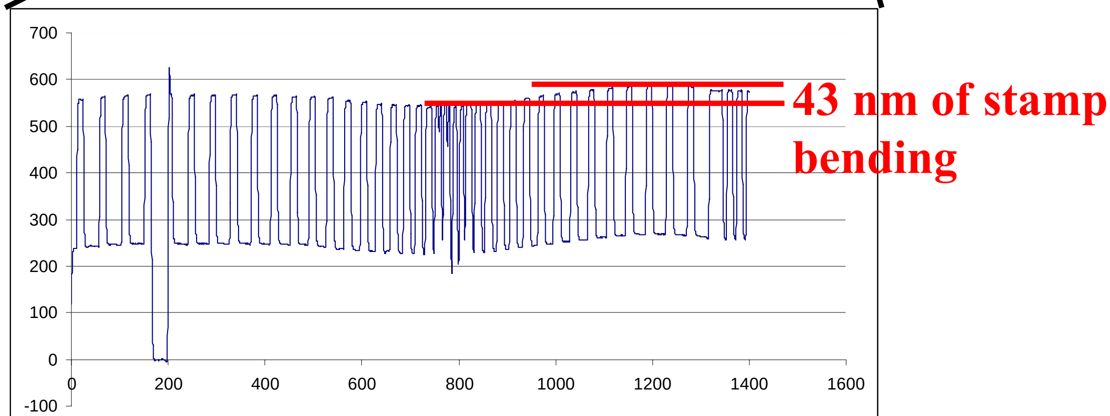
Areas with high resist pressure result in a higher residual layer thickness.

Modelling of the NIL process

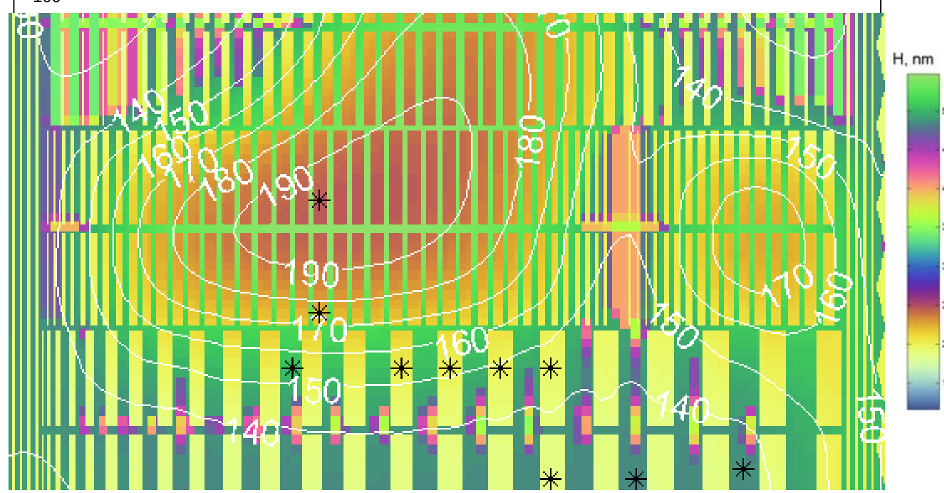
Optical microscope image.



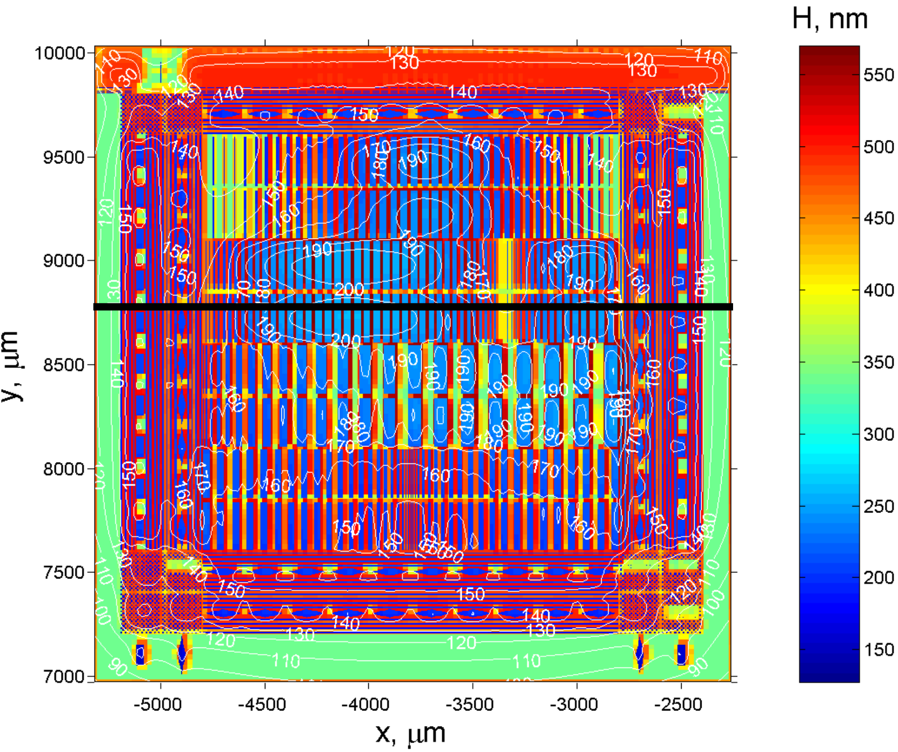
Profilometer measurement,
Showing stamp bending
during the NIL process



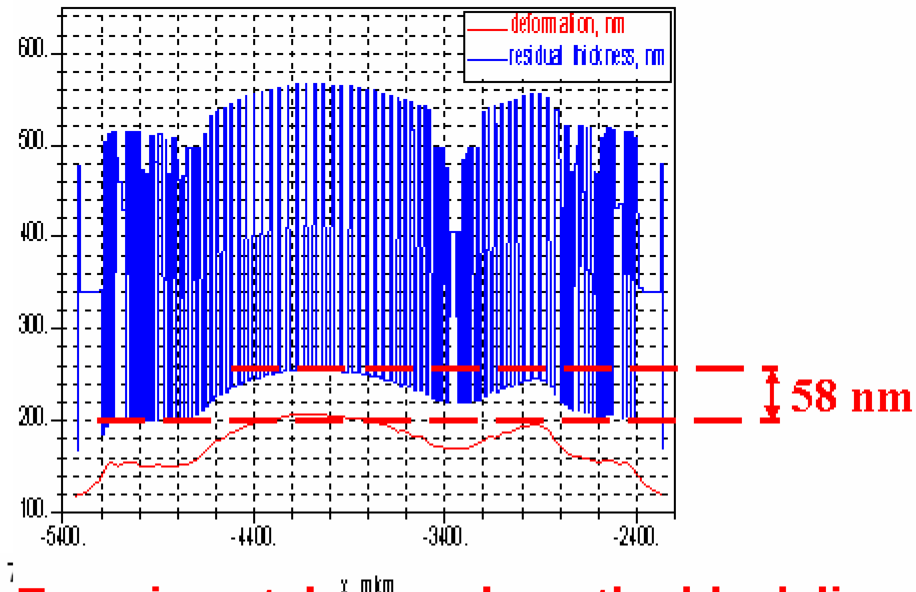
Simulated “RGB” images of residual layer height distribution. White iso-lines indicate the stamp bending in nm (190nm-150 nm= 40nm of stamp bending)



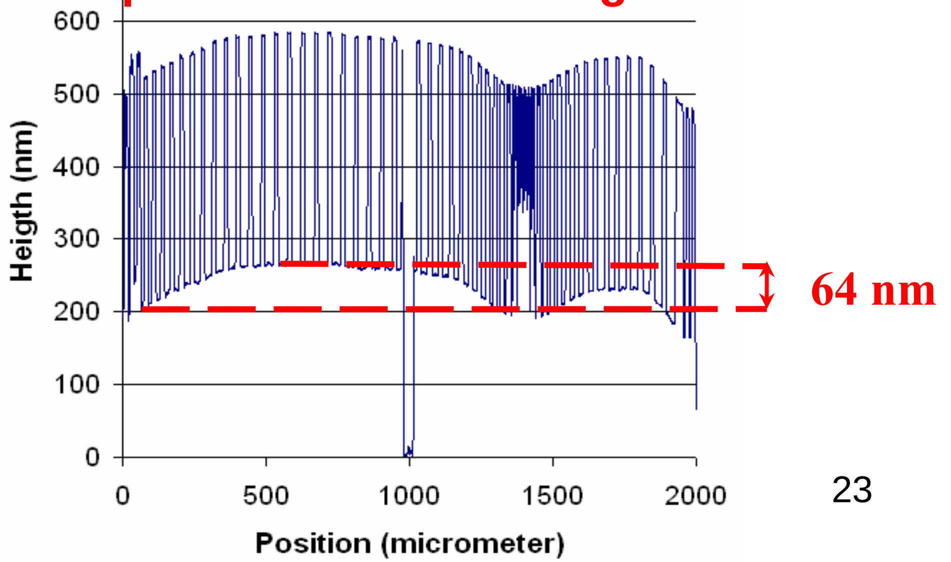
Modelling of the NIL process



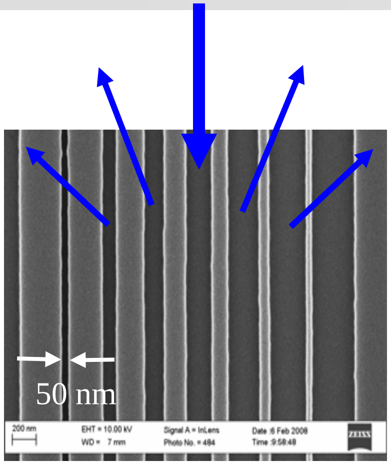
Simulated scan along the black line



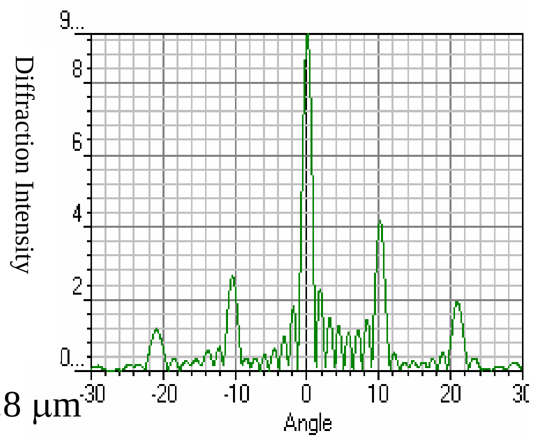
Experimental scan along the black line



Subwavelength diffraction

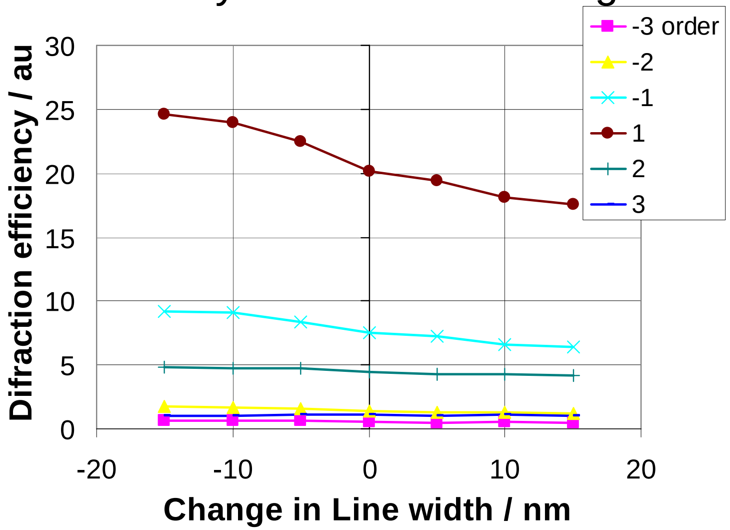


One period 2.8 µm

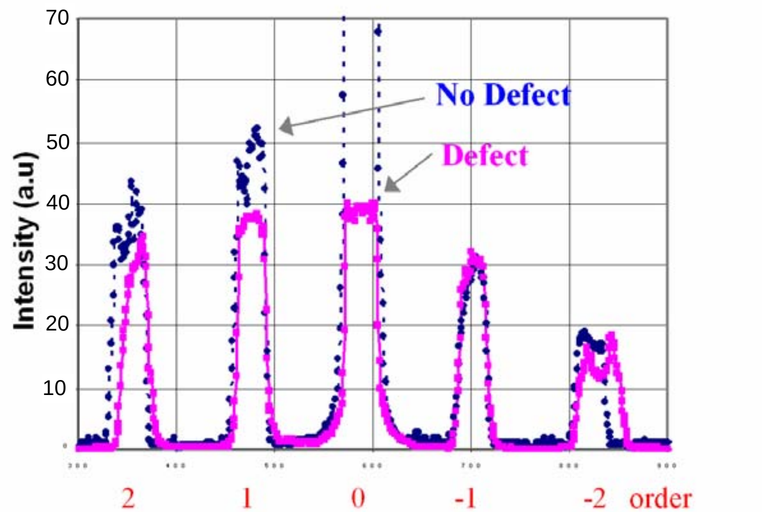


Sub-wavelength features within periodic test structure Line-width, height, defects affect the relative efficiency of orders in far-field diffraction.

- Models (FDTD and Rigorous Coupled Wave Analysis) show sensitivity to dimension changes of <10nm



- Shows presence of defect – missing 50nm lines



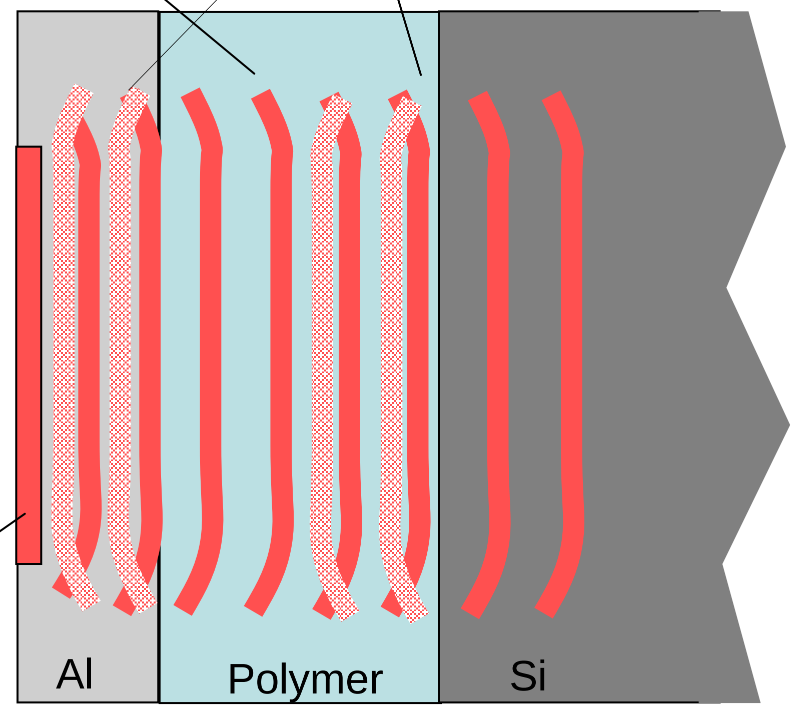
T. Kehoe et al, Sub-wavelength optical diffraction and photoacoustic metrologies for the characterisation of nanoimprinted structures, Proc. SPIE 6922 (2008) 69210F

Metrology with Photoacoustic spectroscopy

Physical parameters – Young’s modulus, Poisson’s number – calculated from acoustic speed

Propagating acoustic waves

Partial Reflection from interfaces



Pump/ probe measurement

Pump: 70fs laser pulse

Probe: Optical reflectivity change at surface

Laser absorption / generation of thermal stress – acoustic wave

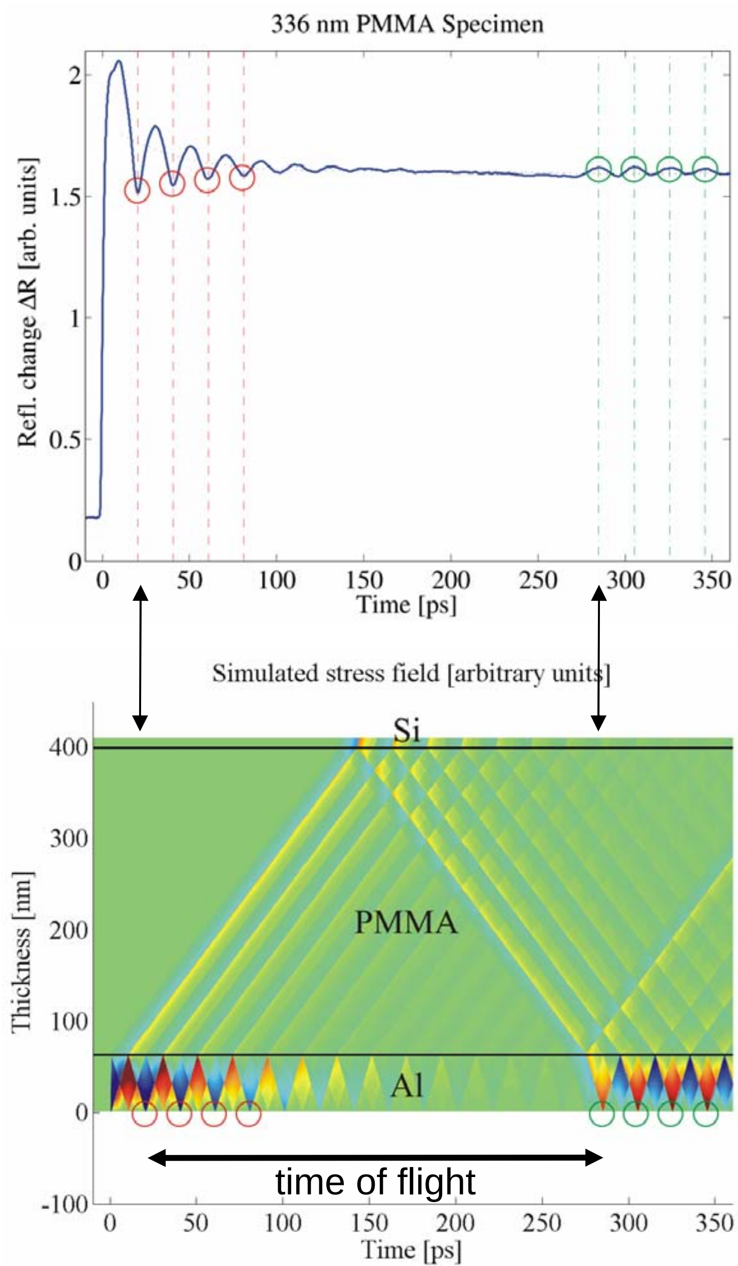
Collaboration with Juerg Bryner & Prof Dr Juerg Dual, Centre of Mechanics, ETH Zurich

Photoacoustic Metrology of Nanoimprint Polymers

- Good acoustic impedance difference
- Damping in polymer not excessive
- Strong signal from both interfaces

  Top interface: Al/polymer

  Bottom interface: polymer/Si



Physical parameters calculated from speed and thickness – Young's modulus (E) and Poisson's ratio (n)

$$c_p = \sqrt{\frac{E(1-v)}{\rho(1+v)(1-2v)}}$$

T. Kehoe et al, Proc. Acoustics08 Paris 2517, 2008

PHYSICAL PROPERTIES OF NANOSTRUCTURES

J Nogues, A Bachtold, S Valenzuela, J Santiso, C M Sotomayor Torres

Carbon nanotubes & **Graphene**

Spin transport

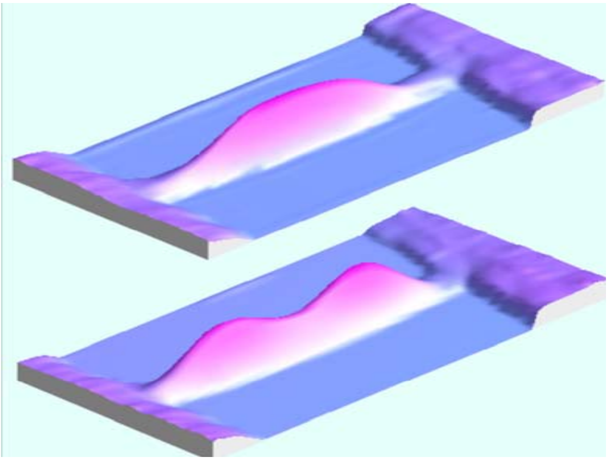
Nanoionics

Nanoscale thermal conduction

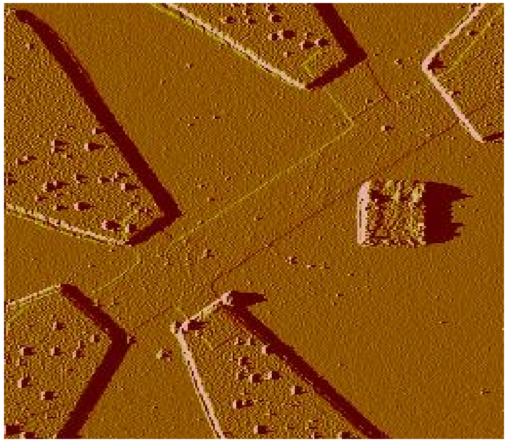
Nanophotonics

Phonons in Nanostructures

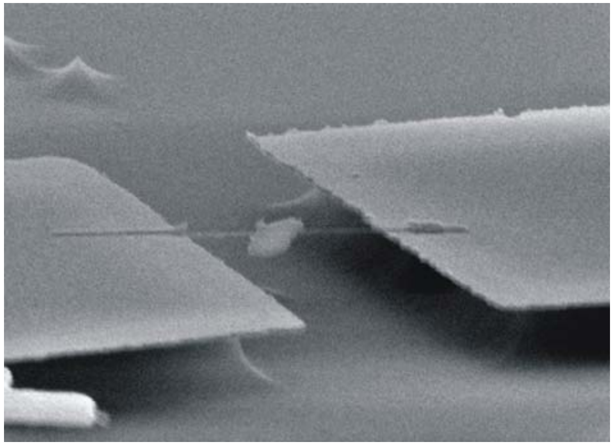
Carbon nanotubes and graphene



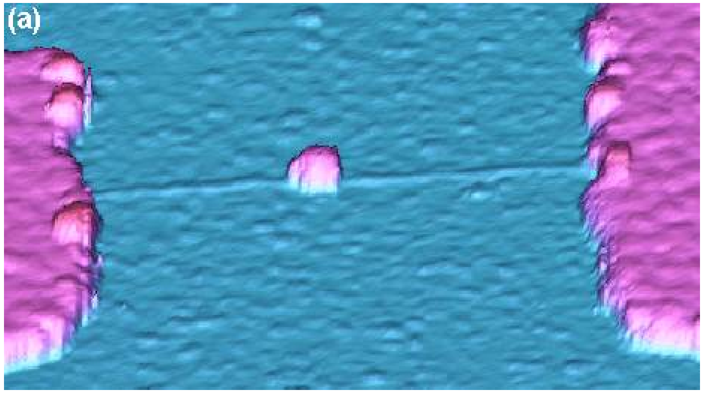
Electro-Mechanics



graphene



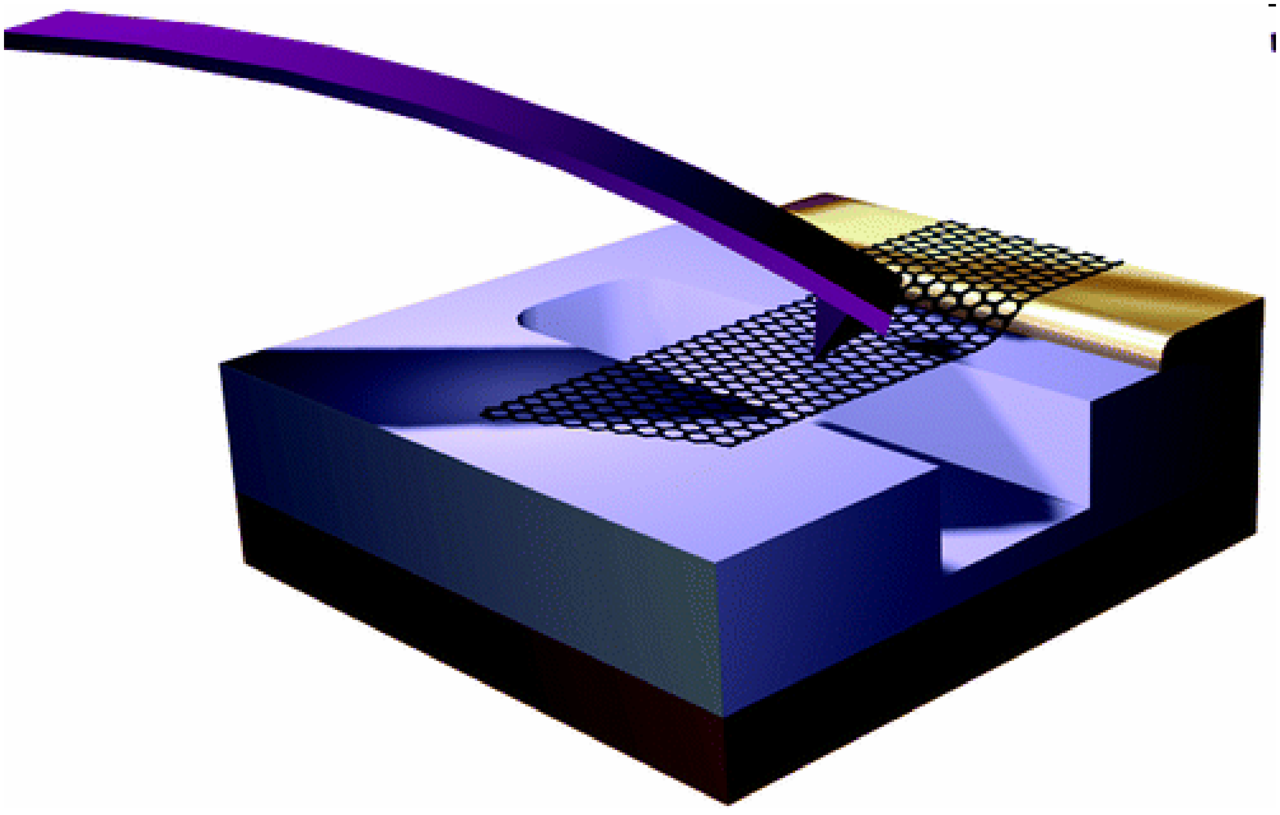
nanotube motor



single-electron spectroscopy

Bachtold et al

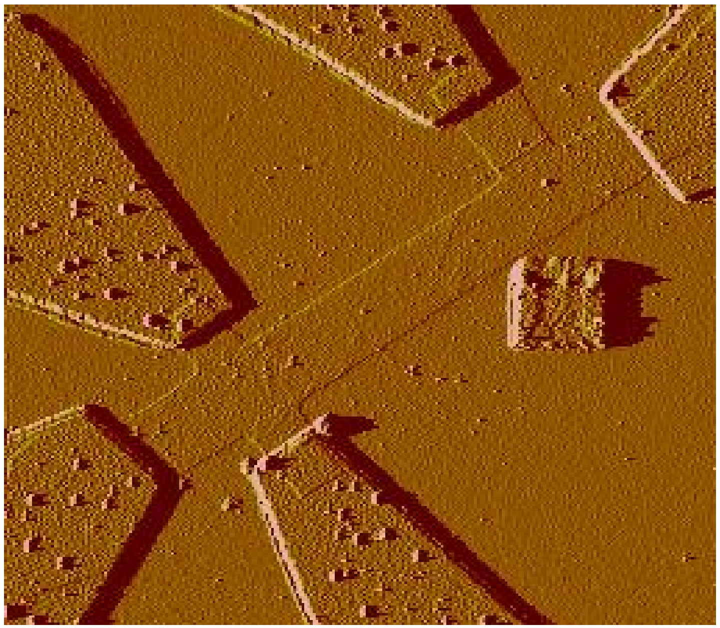
mechanical properties of graphene

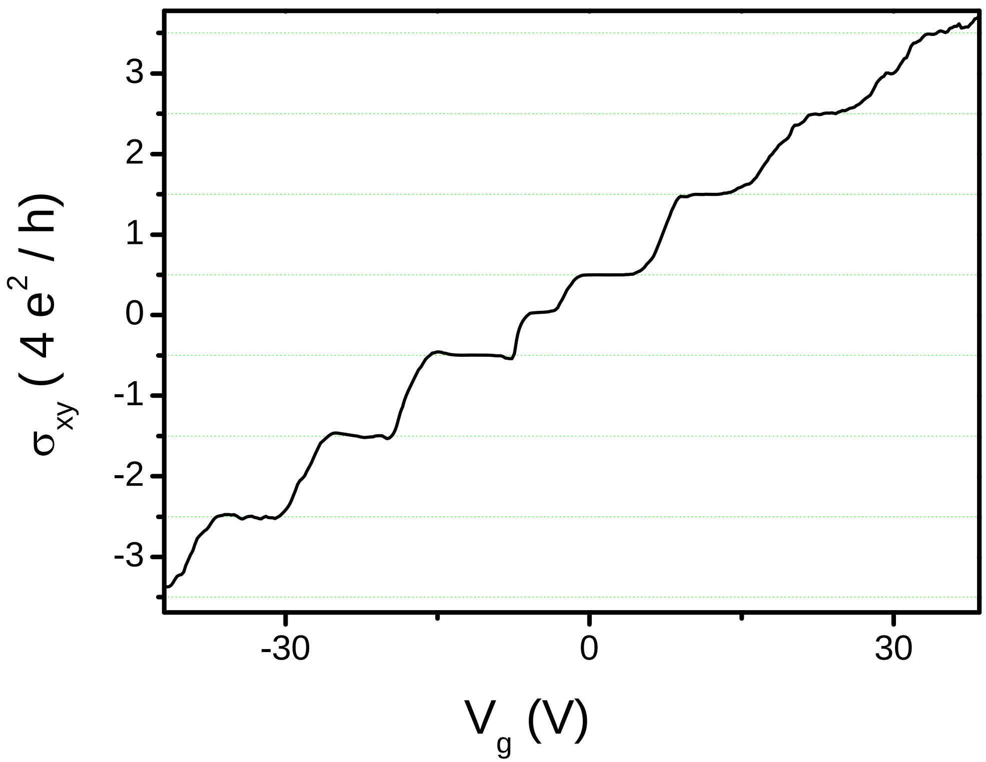


Garcia-Sanchez, van der Zande, San Paulo, Lassagne, McEuen, Bachtold
Nano Letters 8, 1399 (2008)

Transport properties of graphene

9 Tesla, 4 K





mobility ~ 15´000 to 25´000 cm^2/Vs

Moser, Barreiro, Bachtold, APL 2007

Si membrane

phys. stat. sol. (c) **1**, No. 11, 2609–2612 (2004) / **DOI** 10.1002/pssc.200405313

Observations of confined acoustic phonons in silicon membranes

C. M. Sotomayor Torres*[1,2], A. Zwick[2], F. Poinsotte[2], J. Groenen[2], M. Prunilla[3], J. Ahopelto[3], A. Mlayah[2], and V. Paillard[2]

[1] National Microelectronics Research Centre, University College Cork, Lee Maltings, Prospect Row, Cork, Ireland
[2] Laboratory of Solid State Physics (LPST), UMR 5477, Paul Sabatier University, 118 route de Narbonne, 31062 Toulouse Cedex 04, France
[3] VTT Centre for Microelectronics, Tietotie 3, 02150 Espoo, Finland

PHYSICAL REVIEW B 77, 045420 (2008)

Inelastic light scattering by longitudinal acoustic phonons in thin silicon layers: From membranes to silicon-on-insulator structures

J. Groenen,* F. Poinsotte, and A. Zwick
Centre d'Elaboration des Matériaux et d'Etudes Structurales UPR 8011, CNRS-Université Paul Sabatier, 29 Rue Jeanne Marvig, F 31055 Toulouse Cedex 4, France

C. M. Sotomayor Torres
University College Cork, Tyndall National Institute, Lee Maltings, Cork, Ireland;
Catalan Institute of Nanotechnology, Campus de Bellaterra, Edifici CM7, ES 08193 Bellaterra (Barcelona), Spain;
and ICREA-Catalan Institute for Research and Advanced Studies, 08010 Barcelona, Spain

M. Prunnila and J. Ahopelto
VTT Micro and Nanoelectronics, P.O. Box 1000, FI-02044 VTT, Espoo, Finland
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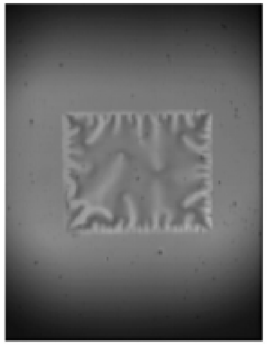
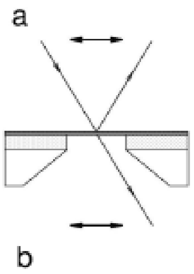
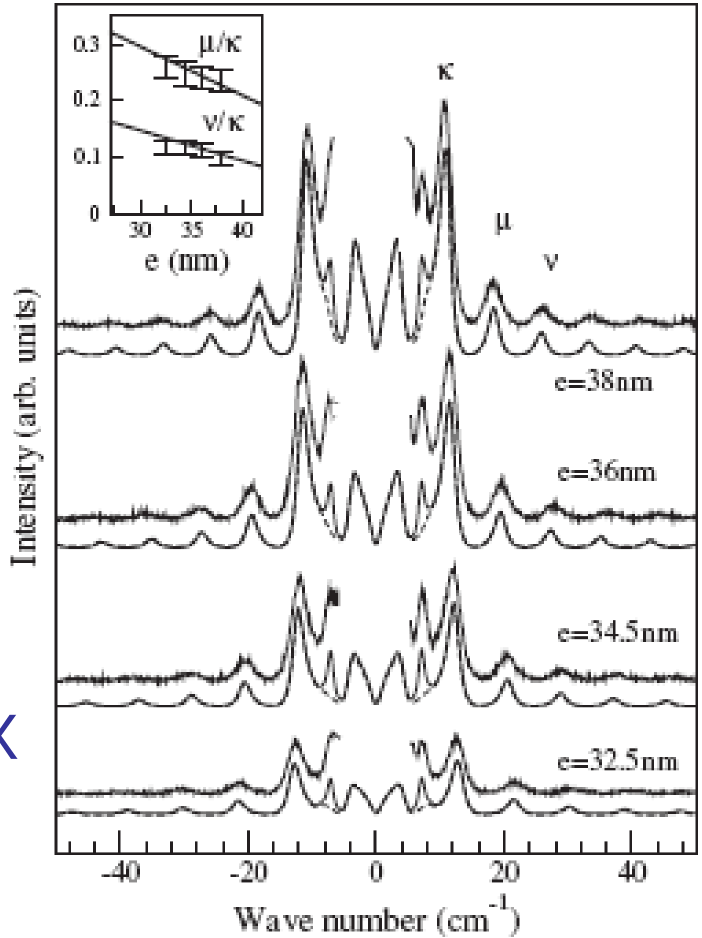


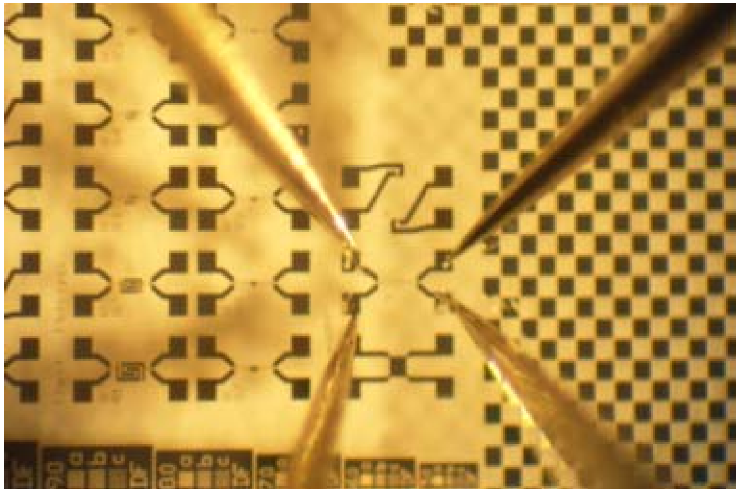




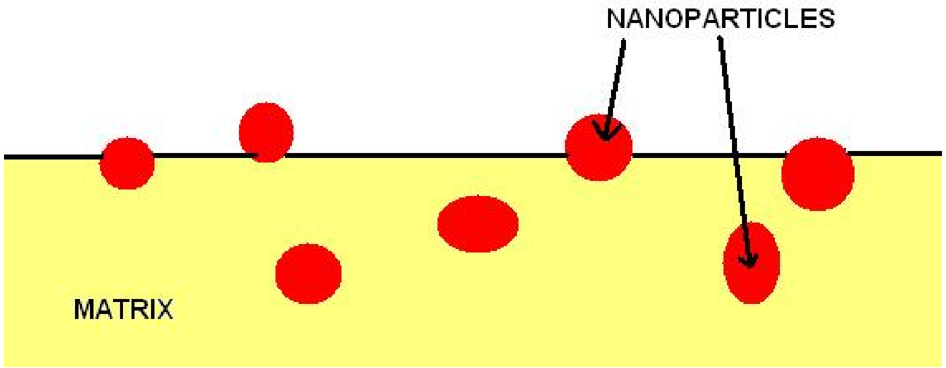
30 nm SOI + 400 nm BOX

3ω method and samples for nanoscale thermal measurements

- **Principle:** Temperature of the device lower if the substrate is more thermally conductive
- **Method:** Link the device temperature to the substrate thermal conductivity



Probes in contact with the pads of the chip fabricated at VTT

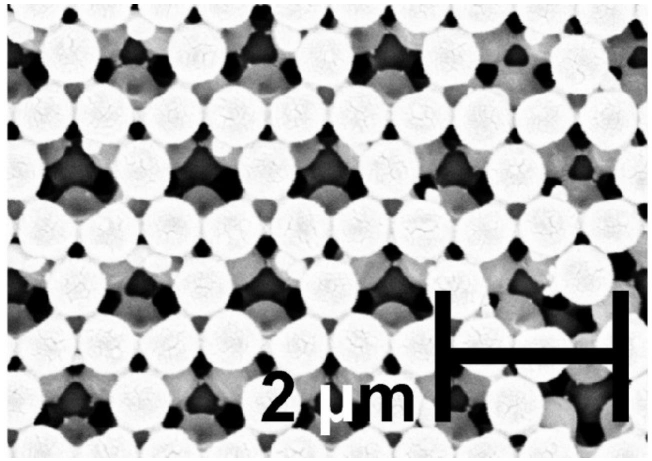


Schematics of a grease with nanoparticles and its nonplanar surface

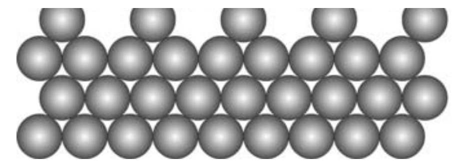
Diffraction Measurements

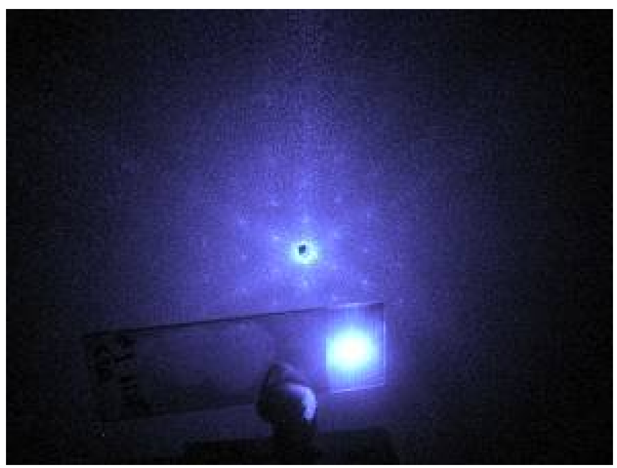
Patterns from triangular 2D defect layers inscribed on top of 3D PMMA opals with different periodicity

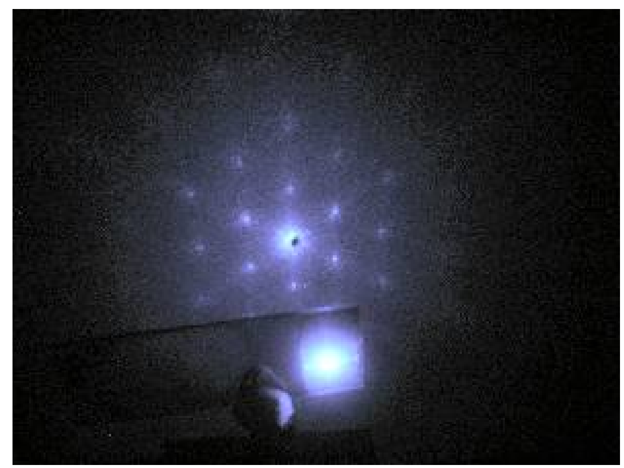
For these lattice constant and laser wavelength, unpatterned parts show no pattern



Side view

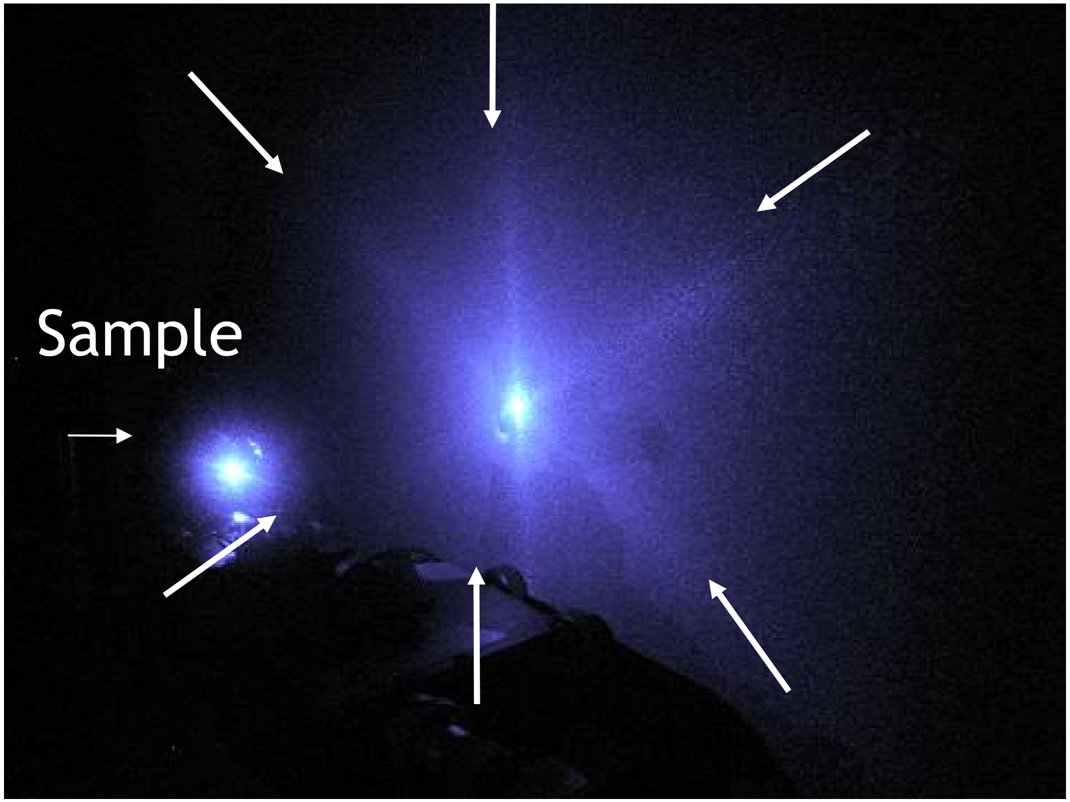


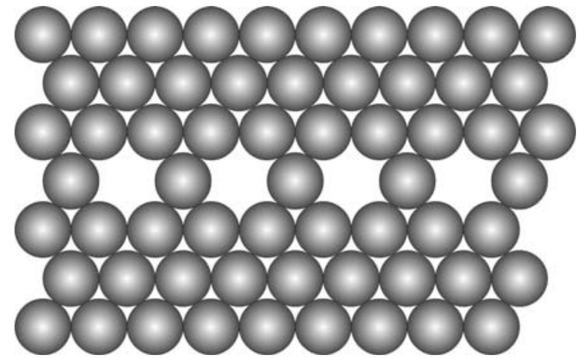




G Kocher, C M Sotomayor Torres et al to be published

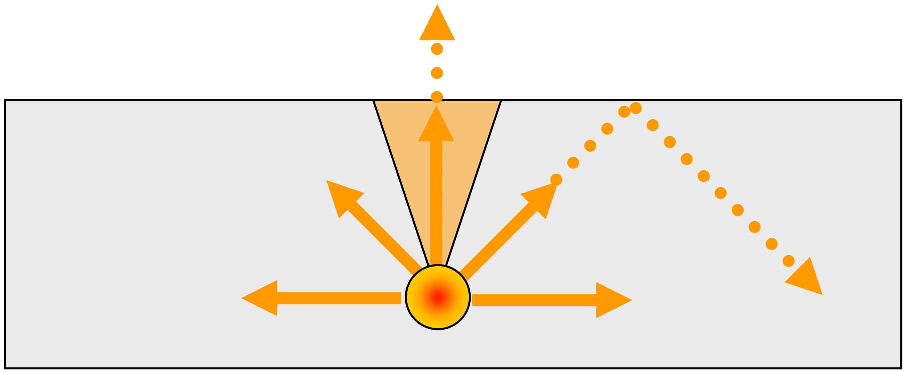
Buried 2D Defect Layer in a 3D photonic crystal





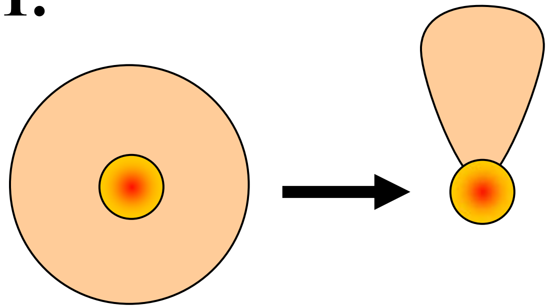
Diffraction patterns from buried 2D defect layer inscribed in PMMA opals

How to increase the light extraction of a polymer film?



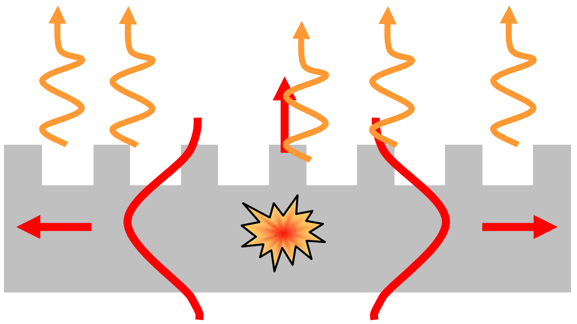
$1/4n^2 \approx 9.8\%$ of light extracted
(n=1.6)
~ 90.2 % trapped in the material

1.



Modification of emission pattern: **micro-cavity**

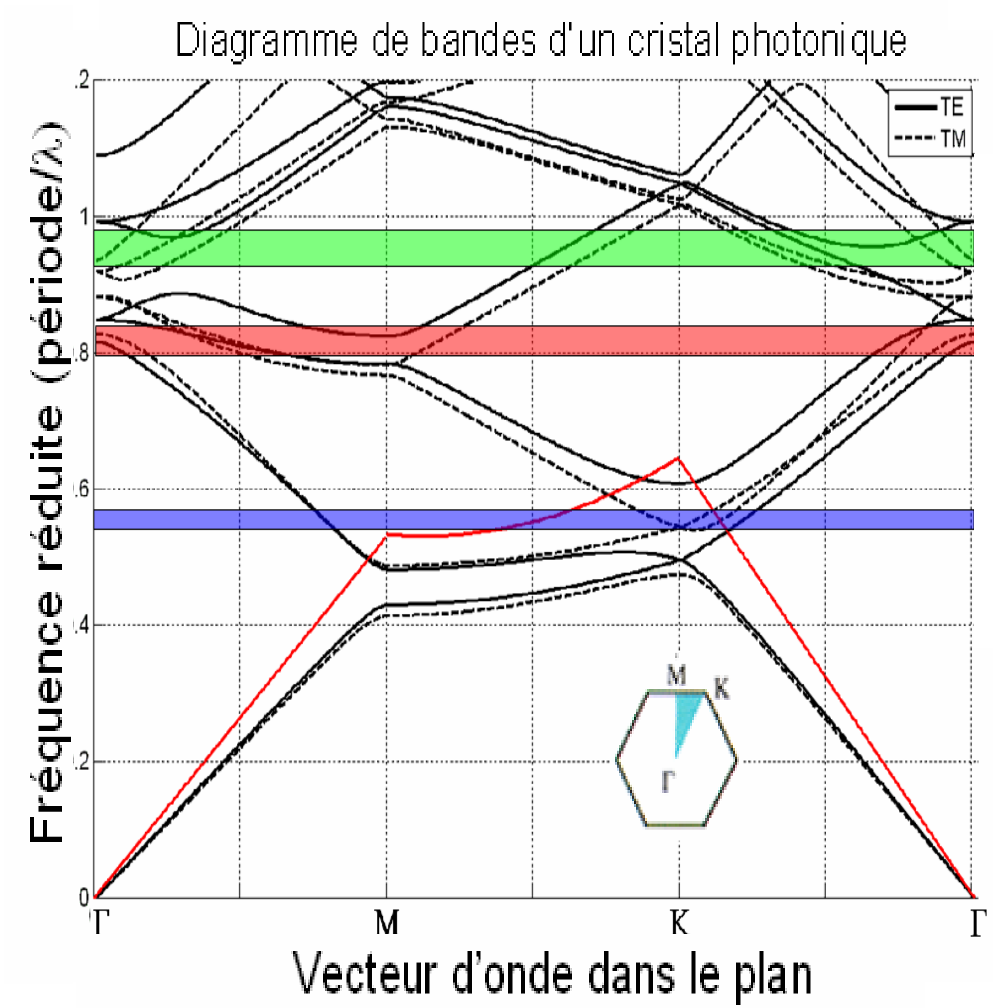
2.

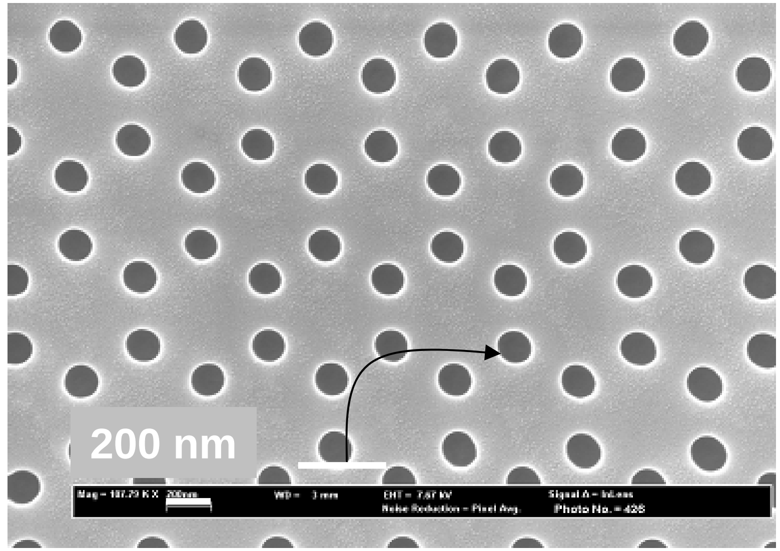


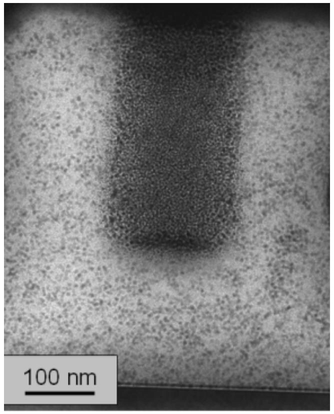
Diffraction of trapped light: **Photonic Crystals**

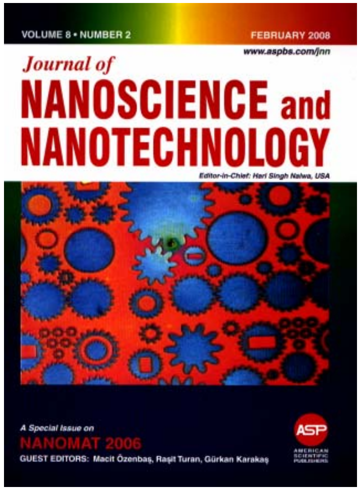
Potential application: OLEDs

Nanoimprinted polymer photonic components



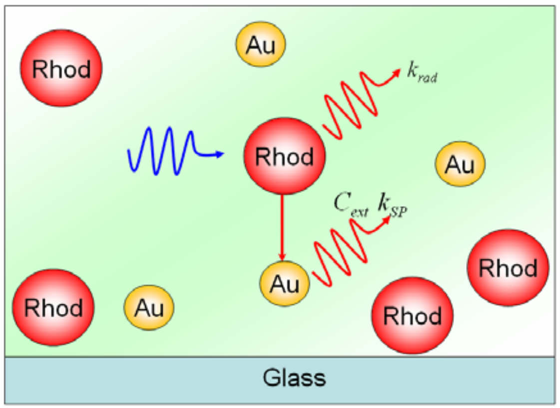


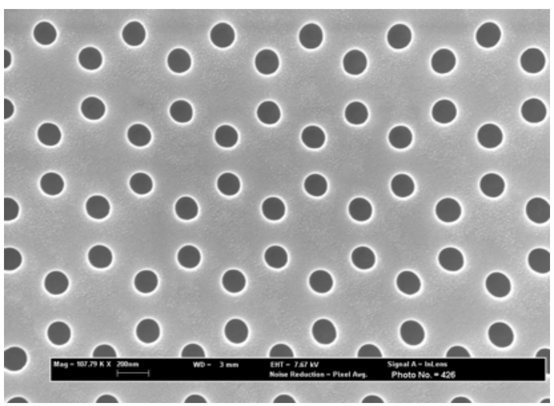


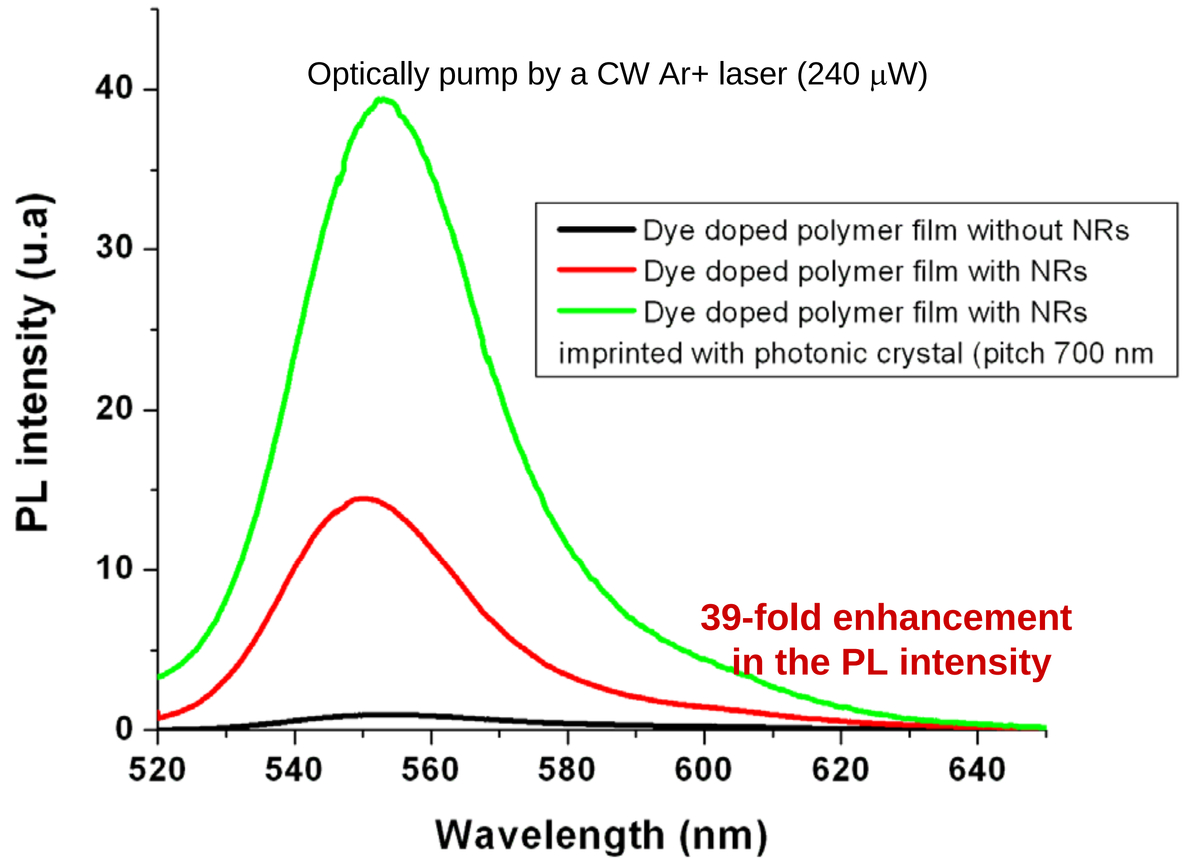


- ➢ Emission of (CdSe)ZnS nanocrystals unaffected ny NIL
- ➢ Homogeneous distribution of nanocrystal in matrix essential
- ➢ Improvement of light emission by factor of 2.4

Plasmon-exciton coupling in printed photonic crystals







PL spectra of the dye doped polymer film with (red) and without (black) Au nanorods,
PL spectra of dye doped polymer film with Au nanorods 2D imprinted with photonic crystal

V. Reboud, *et al.*, Optics Express, 15, 12, 7190, 2007.

Summary and Perspectives in Nanofabrication

- A sound starting base for nanofabrication work to underpin research in CIN2.
- An enormous know-how pool on nanofabrication available. Logistics is a problem. “Viscous medium” is the other. Eg: 24 x 7.
- Procedures for efficient and timely work are needed to use access potential of CNM-ICTS Nanolithography clean room.
- Central pooling of information? Access via web?
- So far incomplete processing line for non-CMOS compatible fabrication. Access to CNM-ICTS Nanolithography covers part of processing needs. Many processes must be developed anew.
- Much work is carried out in collaboration with external partners through joint projects.
- Future looks much better with the new CIN2 building closer to completion.