The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2037-22

Introduction to Optofluidics

1 - 5 June 2009

Fabrication of Optofluidic devices III

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PATTERN ORIGINATION

Techniques to produce devices, mask and stamps

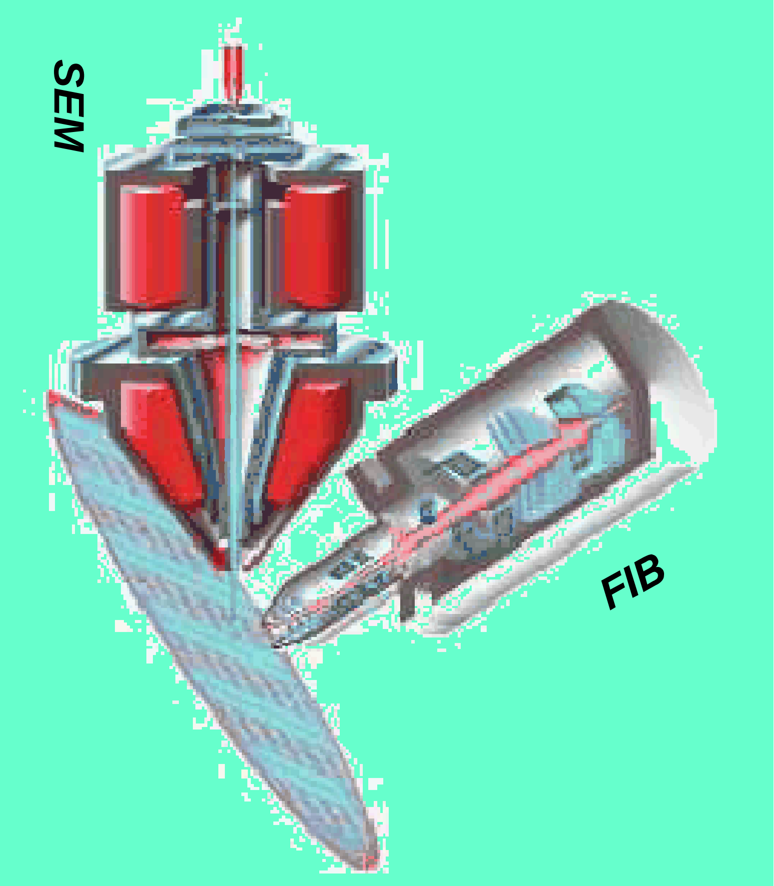
Massimo Tormen

PART III

FOCUSED ION BEAM LITHOGRAPHY

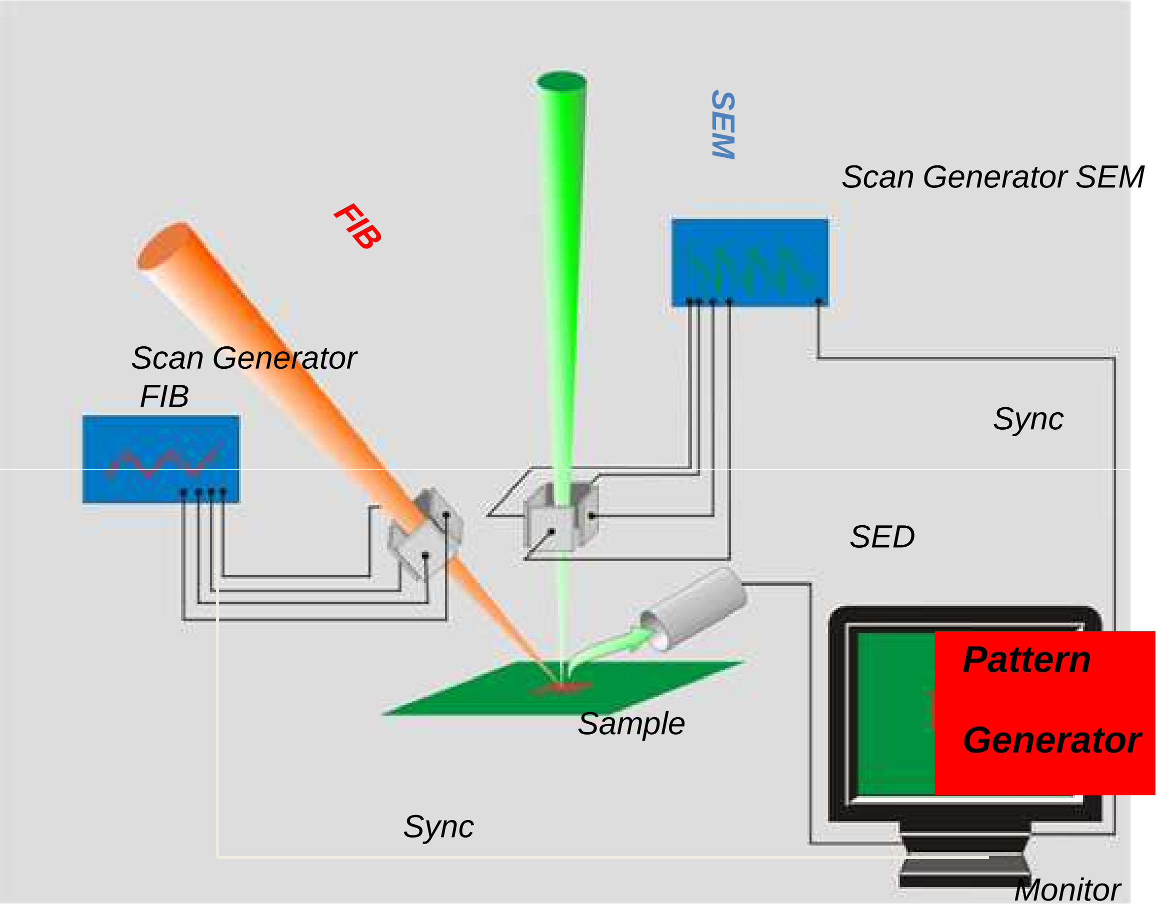
<u>Aknowledgements:</u> ***S. Cabrini, L. Businaro, F. Romanato,***
M. Prasciolu, A. Carpentiero, D. Cojoc, E. Di Fabrizio

Zeiss (LEO) 1540XB CrossBeam® Workstation: a complete laboratory



**SEM, EBL, FIB,
FIBGAE (Gas Assisted Etching),
FEBID FIBID (Electron and Ion Induced Deposition),
EDX (Microanalysis System)**

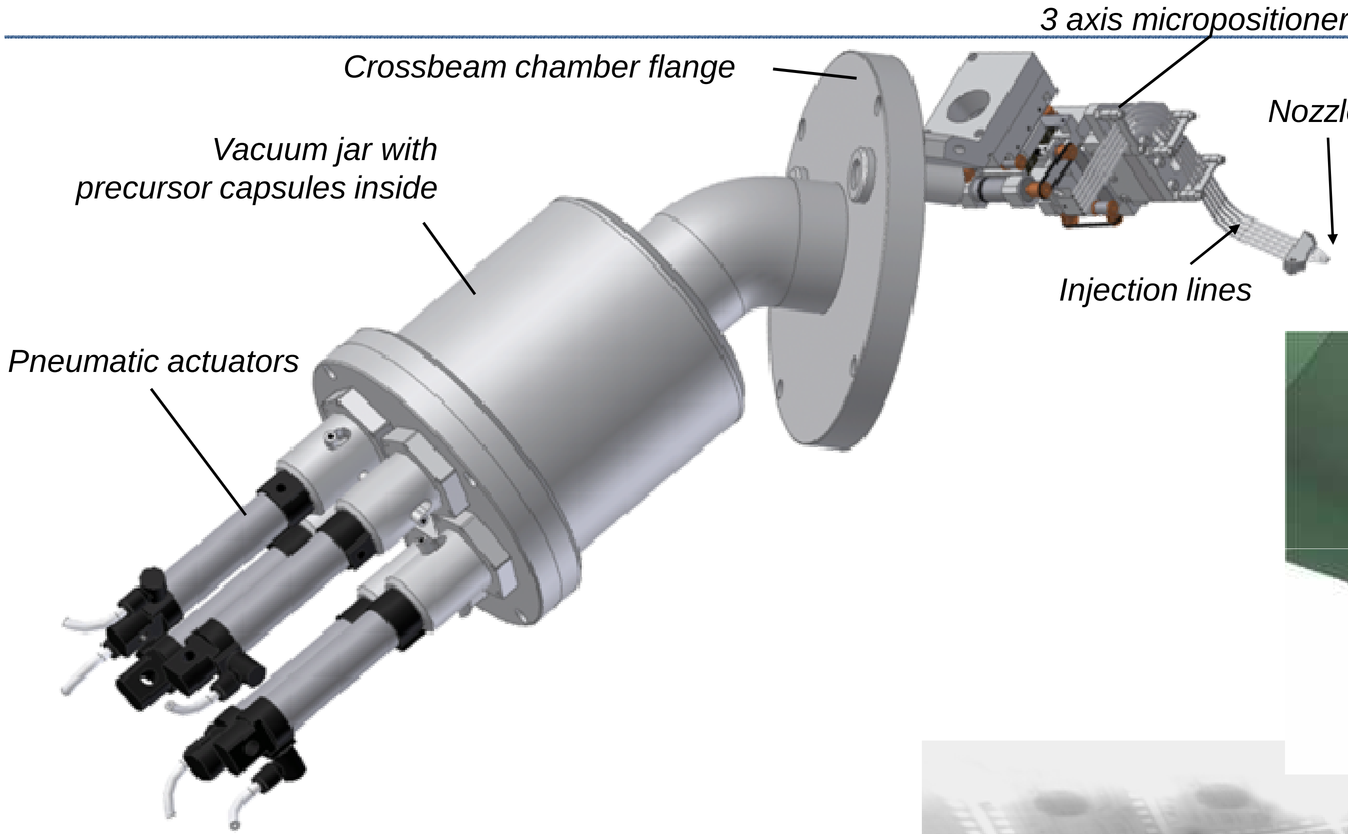
CrossBeam® Operation

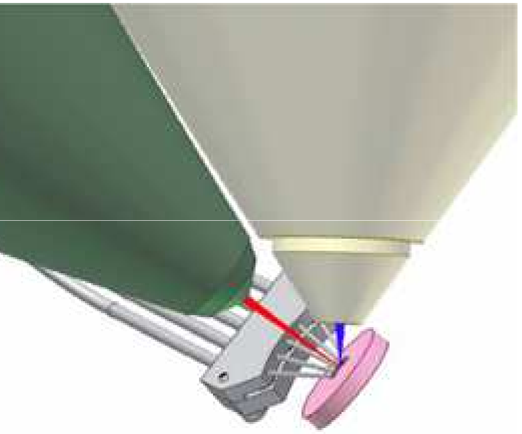


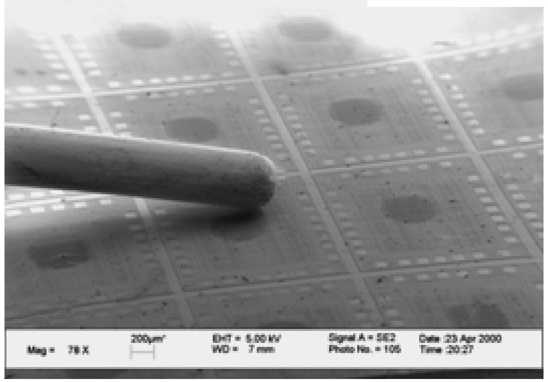
Both beams are scanned completely independent form each other and the Secondary Electron Detector (SED) signal is synchronized to the SEM scan. This results in the CrossBeam™ operation feature:
The ion milling process can be imaged using the SEM in real-time!

The Cross-Beam equipped by a good lithography pattern generator tool became an excellent instrument for the micro and nano fabrication

Gas Injection System







- **5 reservoirs for up to 5 different gases**
- **5 separate injection lines (one per gas)**
- **All reservoirs and injection lines can be heated separately**
- **Fully software controlled**

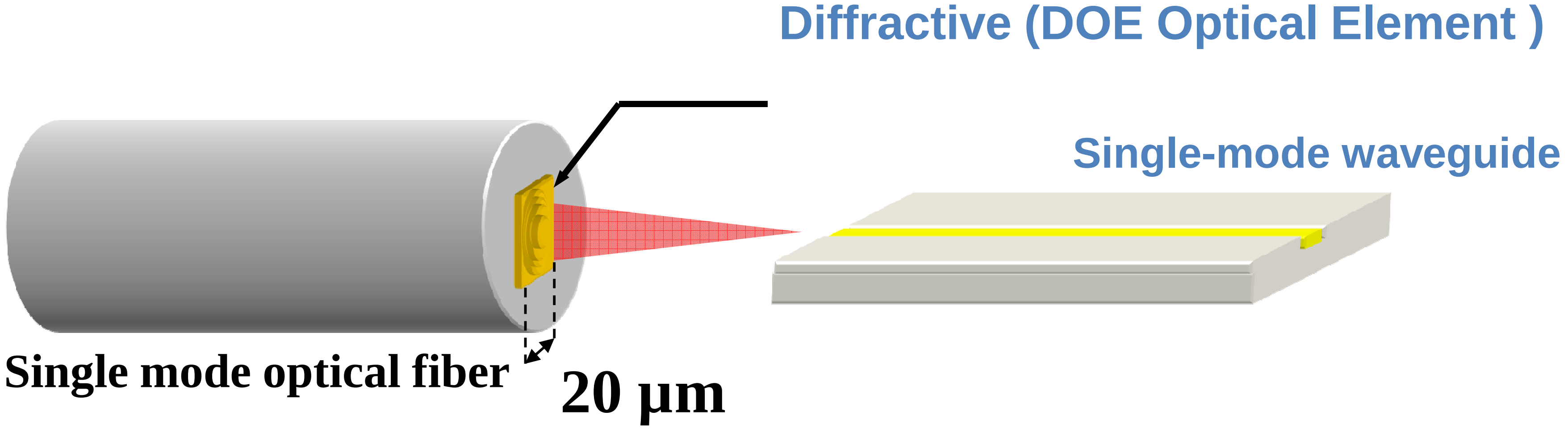
Cross beam system SEM + FIB

SEM images taken during the FIB milling process

LENS on the CROSS-SECTION of an OPTICAL FIBER

- Need to optimal in- and out- coupling of optical signal to waveguides (solid or liquid)
- Optical tweezers at the exit of an optical fiber made by FIB milling

DOE on silica made by Focused Ion Beam Assisted Etching (FIBGAE)

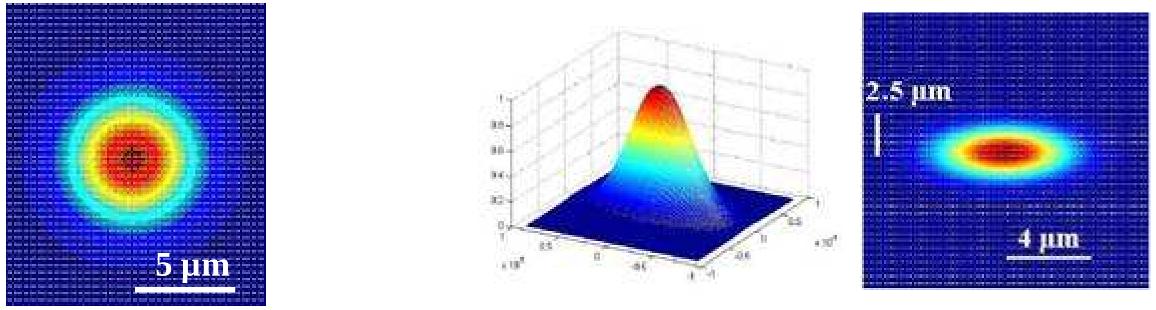


Diffractive (DOE Optical Element)

Single-mode waveguide

Single mode optical fiber

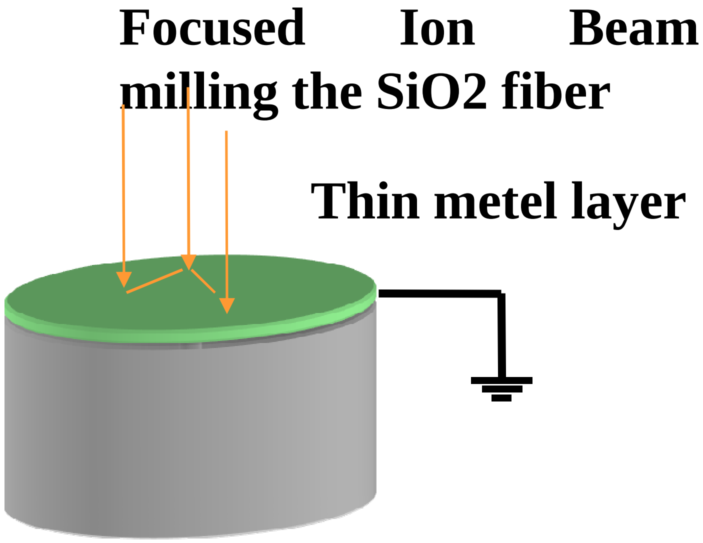
20 µm



We have used a Germanium doped SiO2 fibre of 8.3 µm core diameter, with a core refraction index of 1.485 @ λ = 1550 nm and 0.001 step index. The LiNbO3 waveguides were instead built by annealed proton exchange (APE).

Patterning dielectric substrates: avoiding charging effects

Test structures of the DOE-microlens milled on the surface by Focus Ion Beam



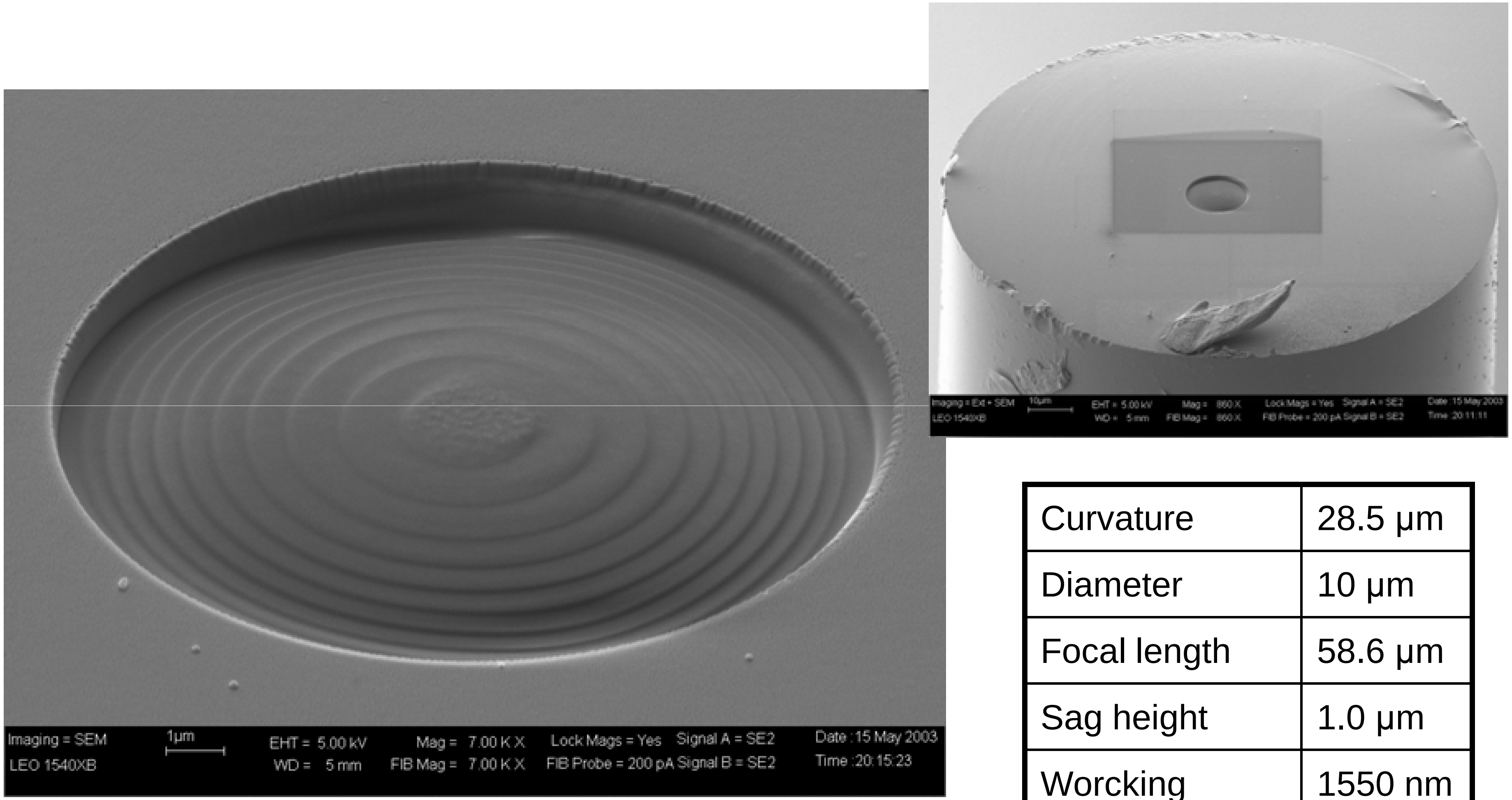
Focused Ion Beam milling the SiO2 fiber

Thin metel layer

Ion Beam Exposition

The head of the fiber before the tests, to avoid charged effect a thin film of metal is sputtered on it.

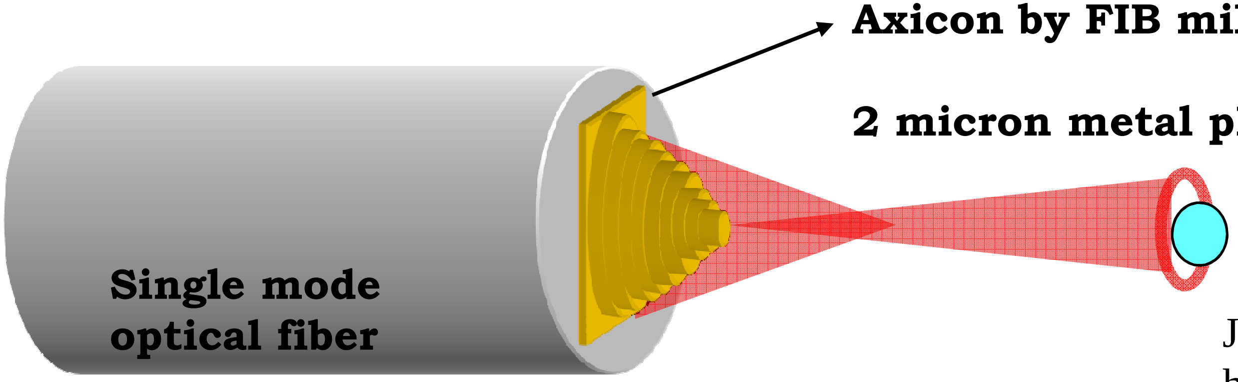
Microlenses for optimal in-coupling into waveguides



Curvature	28.5 µm
Diameter	10 µm
Focal length	58.6 µm
Sag height	1.0 µm
Worcking wavelength	1550 nm

Schiappelli F et al. JJAP Part 1- 43 (6B): (2004); Microelect. Eng. 73-74: (2004); Prasciolu M et al.; SPIE Vol 5227, 2003

DOE on silica made by Focused Ion Beam Assisted Etching (FIBGAE)

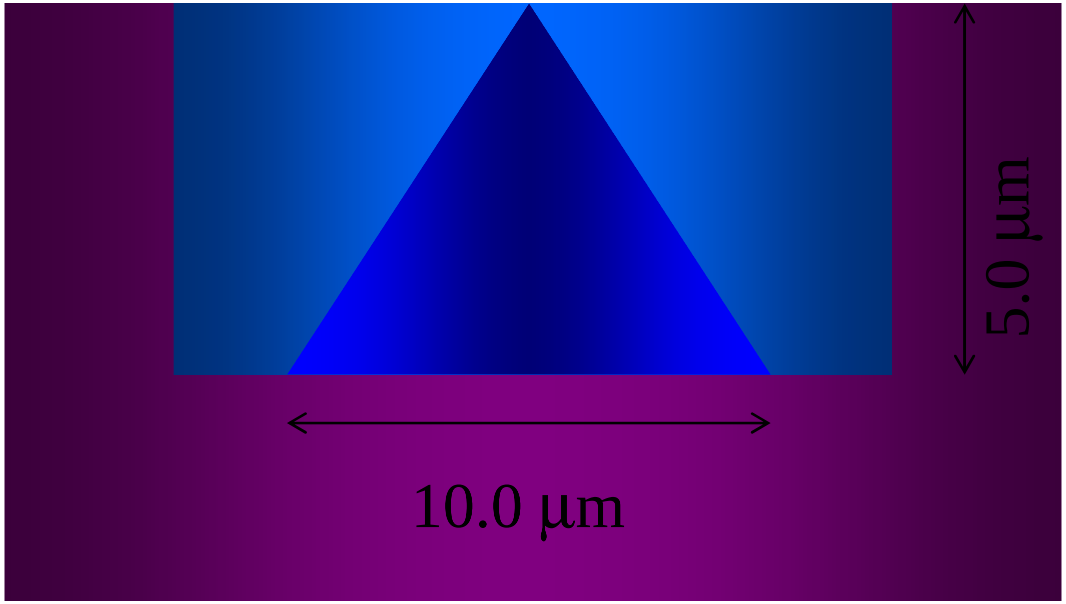


Axicon by FIB milling

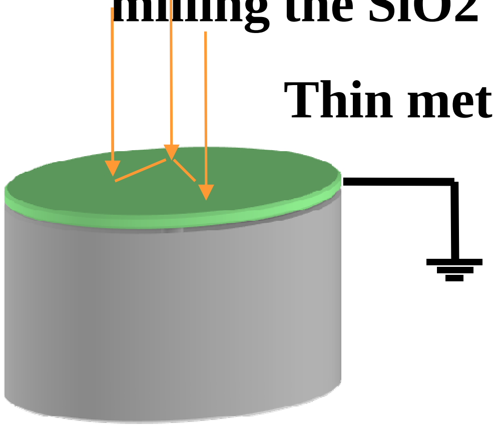
2 micron metal phere

Optical trapping

J.Arlt, K. Dholakia: “Generation of high order Bessel beams by use of an axicon”; Optic Communications 177 (2000) 297-301



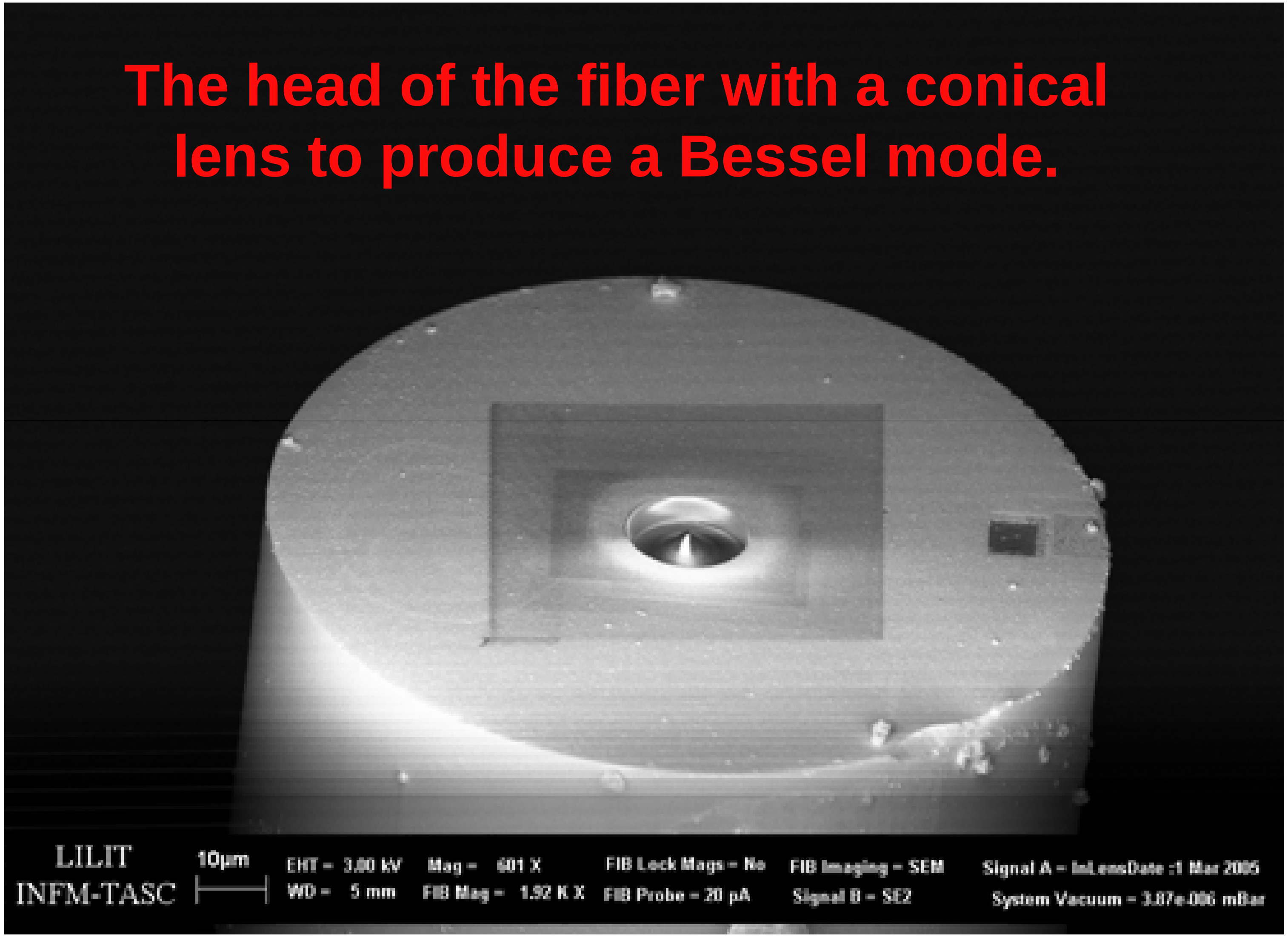
Focused Ion Beam milling the SiO2 fiber



Thin metel layer

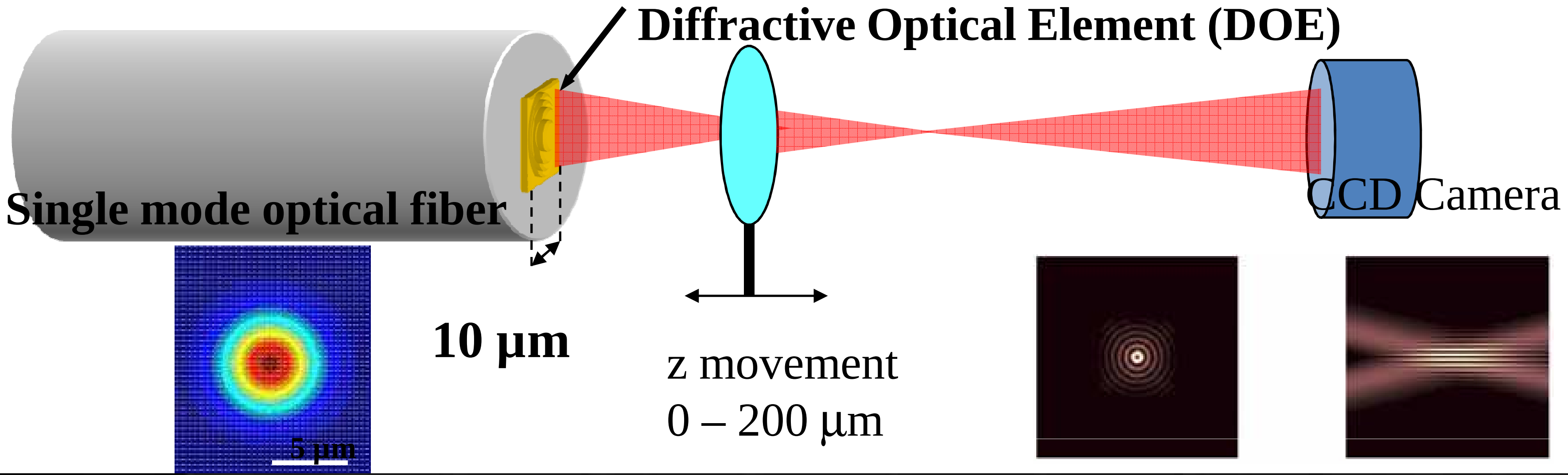
Ion Beam Exposition

DOE on silica made by Focused Ion Beam Assisted Etching (FIBGAE)



The head of the fiber with a conical lens to produce a Bessel mode.

Bessel mode from an optical fiber



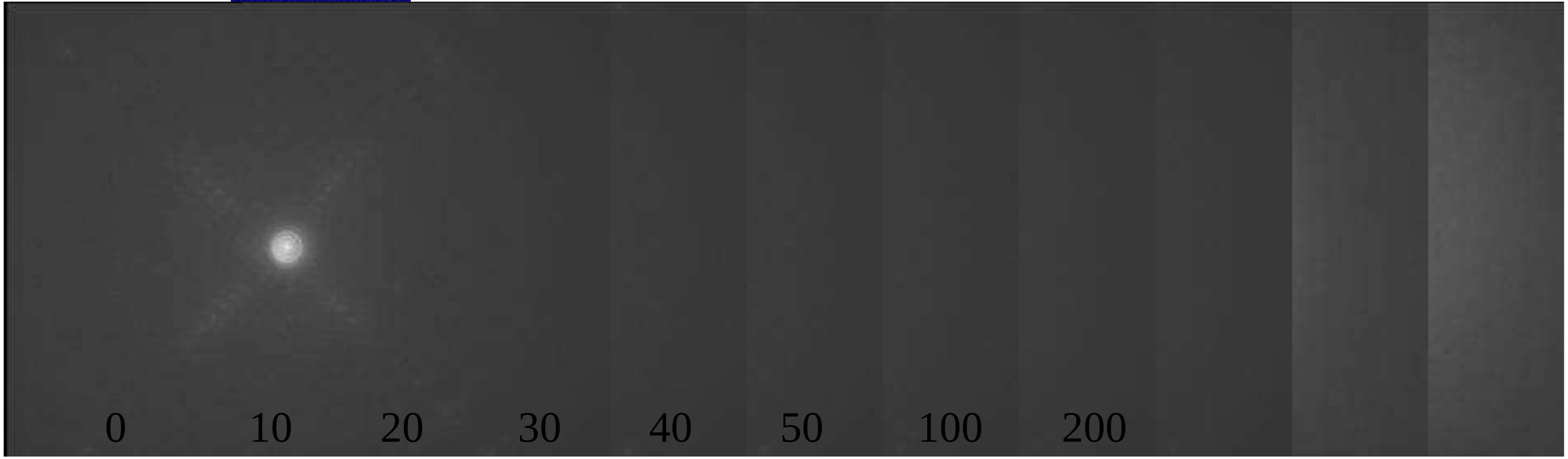
Diffractive Optical Element (DOE)

Single mode optical fiber

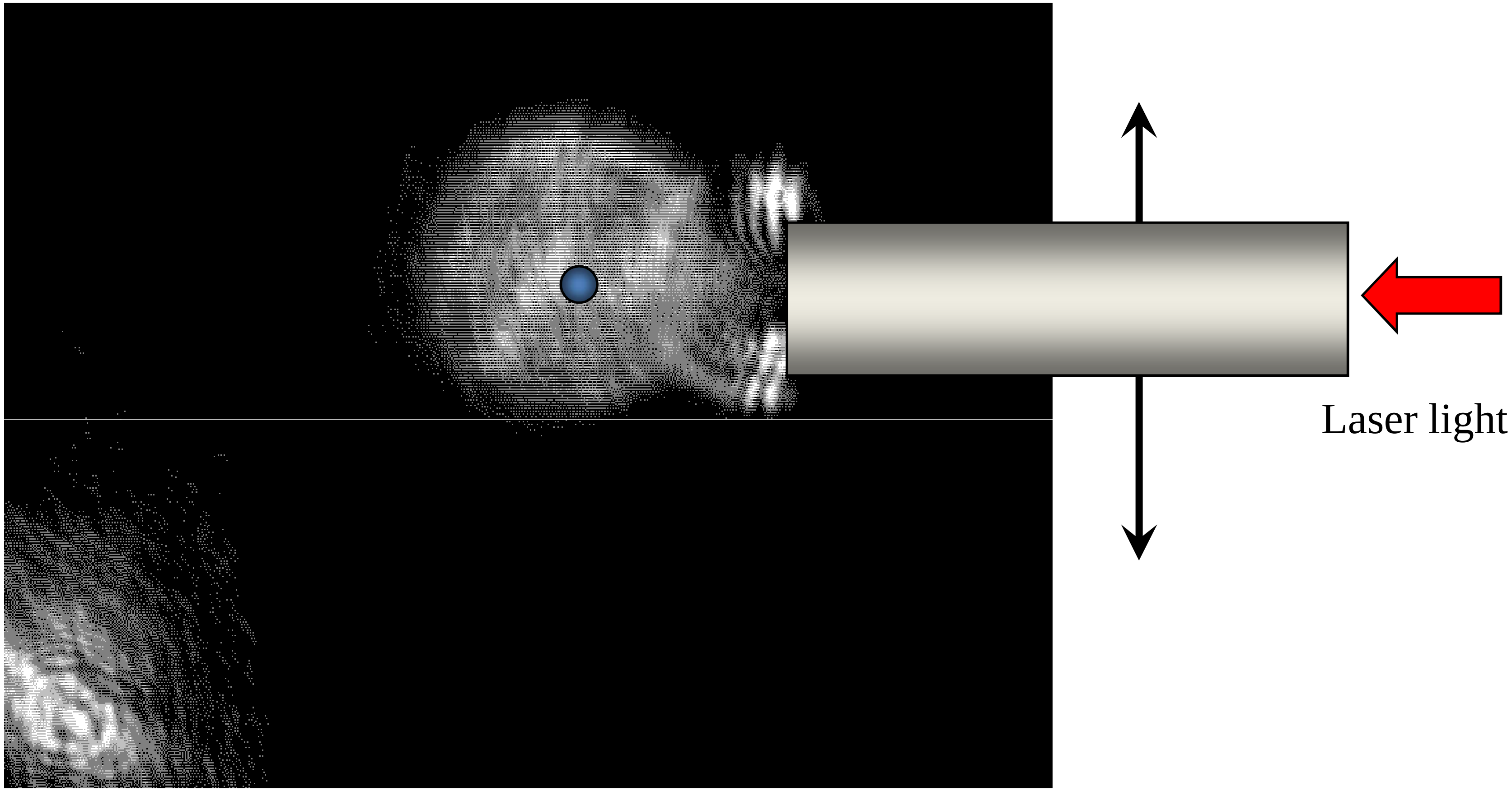
10 µm

z movement
0 – 200 µm

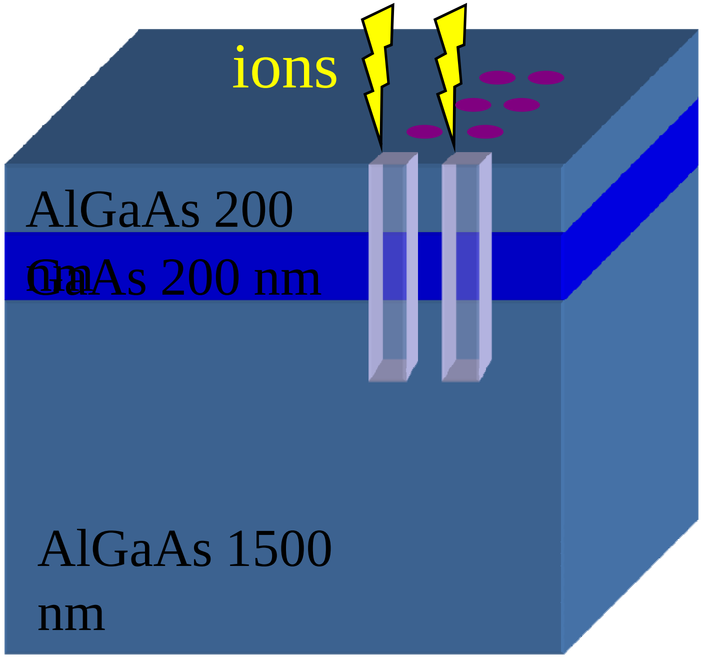
CCD Camera

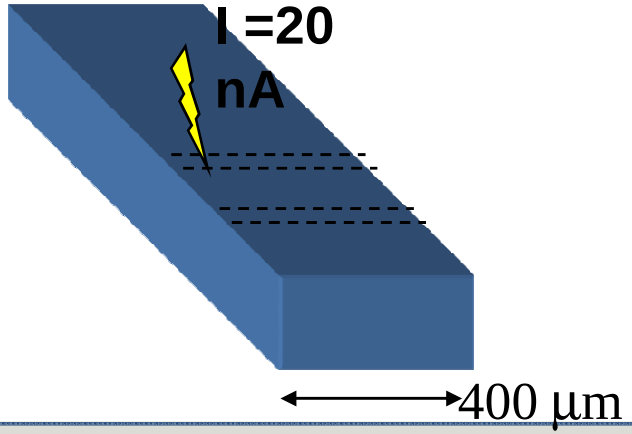


Bessel mode beam generated by an optical fiber

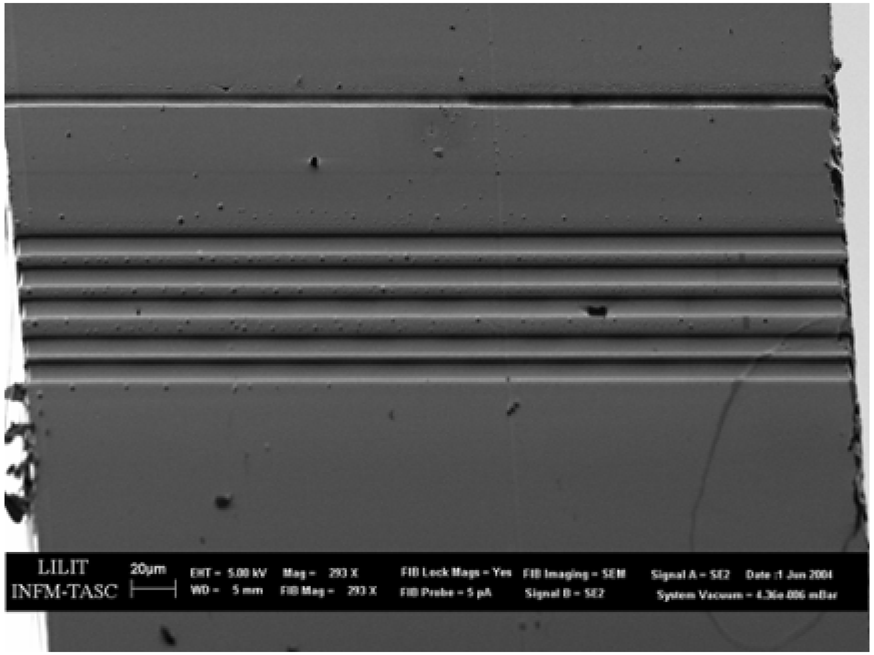


Holes pattern in GaAs/AlGaAs heterostructure



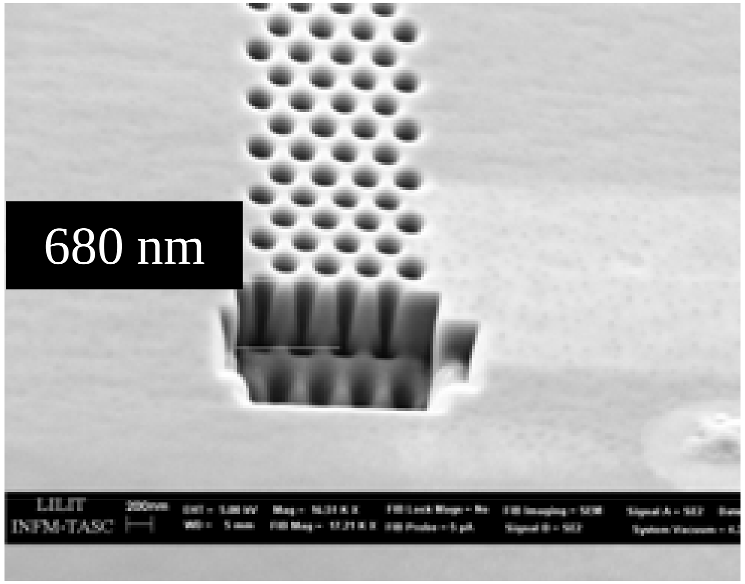


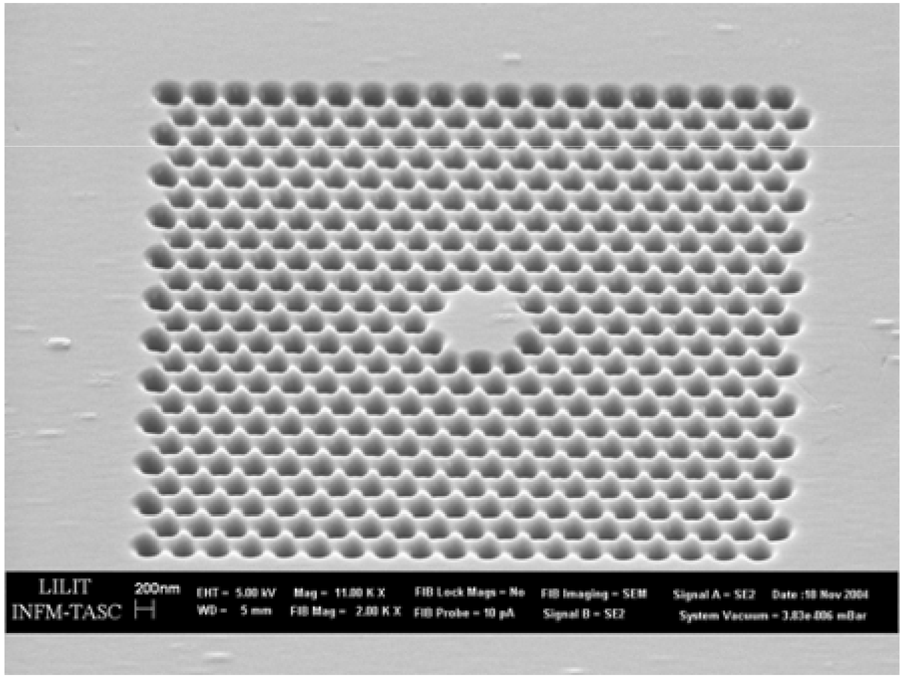
Optical wave guide and 2D photonic crystal pattern directly written on GaAs/AlGaAs substrate by 30 keV gallium FIB lithography (see Cabrini et al. Microelectronic Engineering 78–79 (2005), T. Stomeo et al. Microelectronic Engineering 78 (2005)).

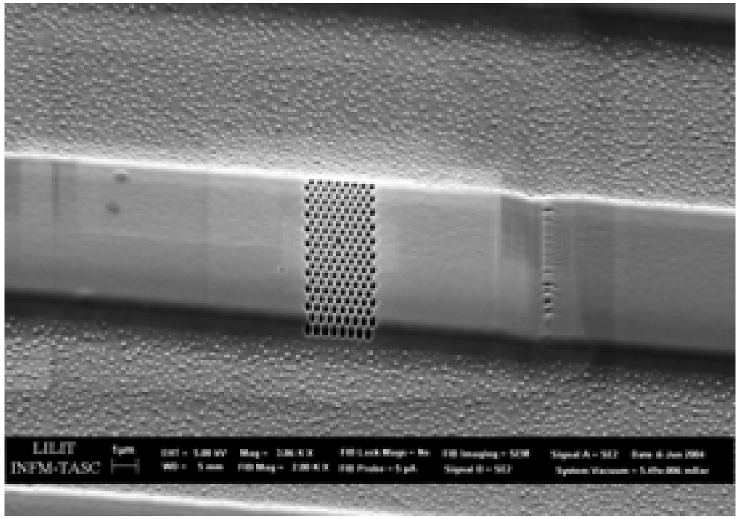


Pattern of periodic holes in GaAs/AlGaAs heterostructure

Optical wave guide and 2D photonic crystal pattern directly written on GaAs/AlGaAs substate by 30 KeV gallium FIB lithography (I= 10 pA)







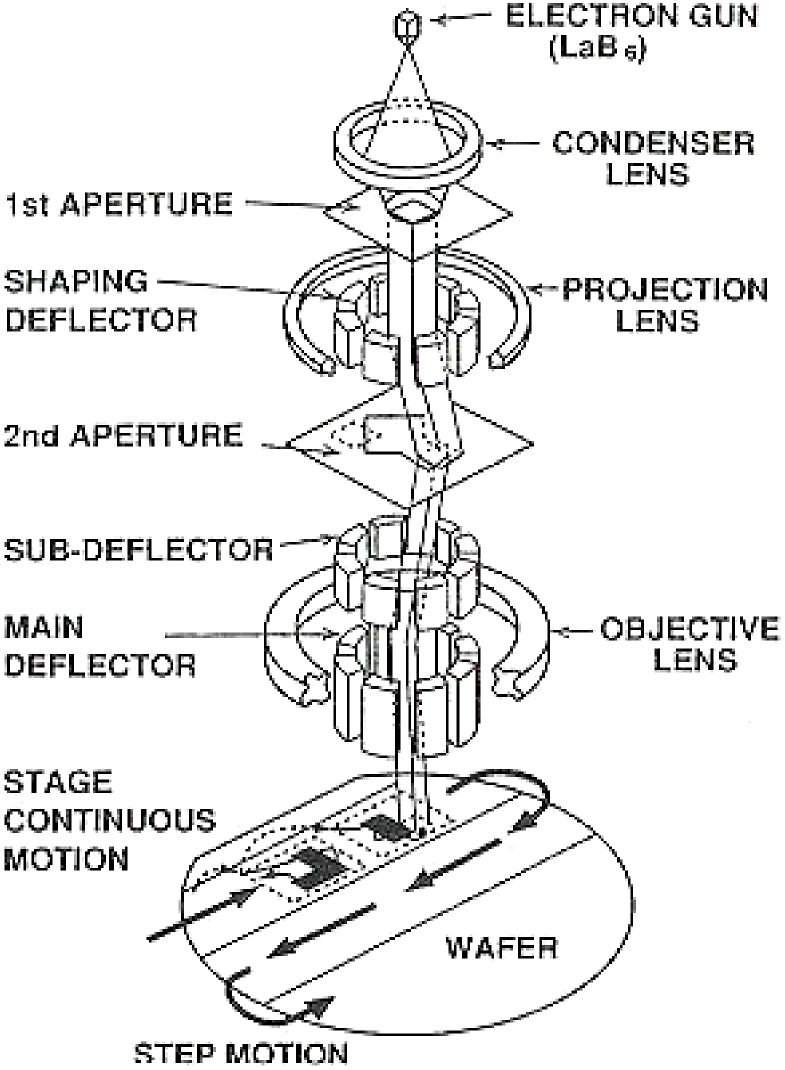
ELECTRON BEAM LITHOGRAPHY

Aknowledgements: ***S. Cabrini, L. Businaro, F. Romanato,***
M. Prasciolu, A. Carpentiero, D. Cojoc, E. Di Fabrizio

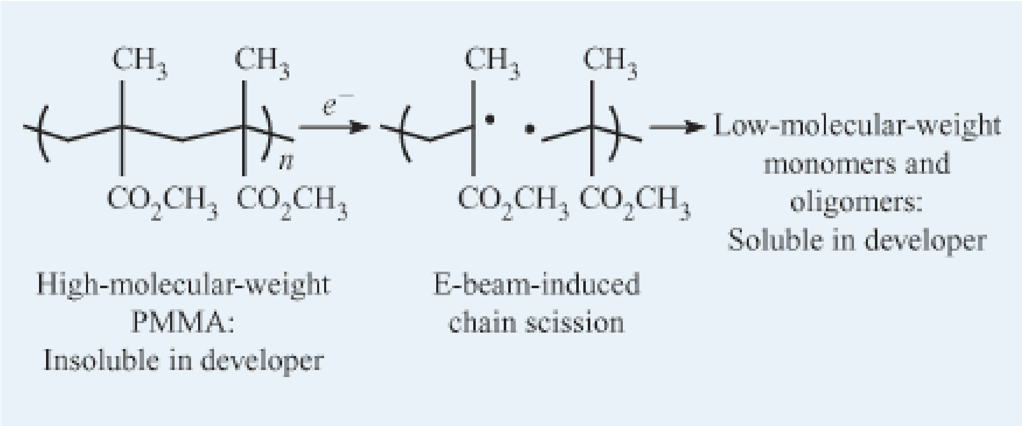
Electron Beam Lithography System

An electron beam system has the following main characteristics:

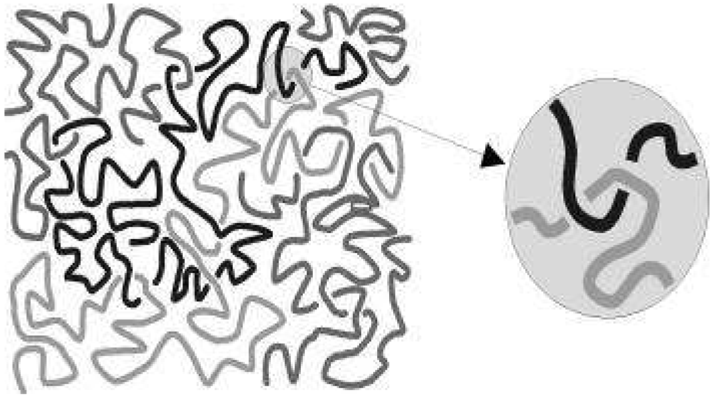
- Accelerated electron beam: 1-100 kV
- Beam size: 1-10 nm
- Field size: 50-1000 μm
- Clock: 1-50 MHz
- Substrate size (2” to 12”)
- The beam is deflected expose pixel by pixel a pattern defined by a CAD



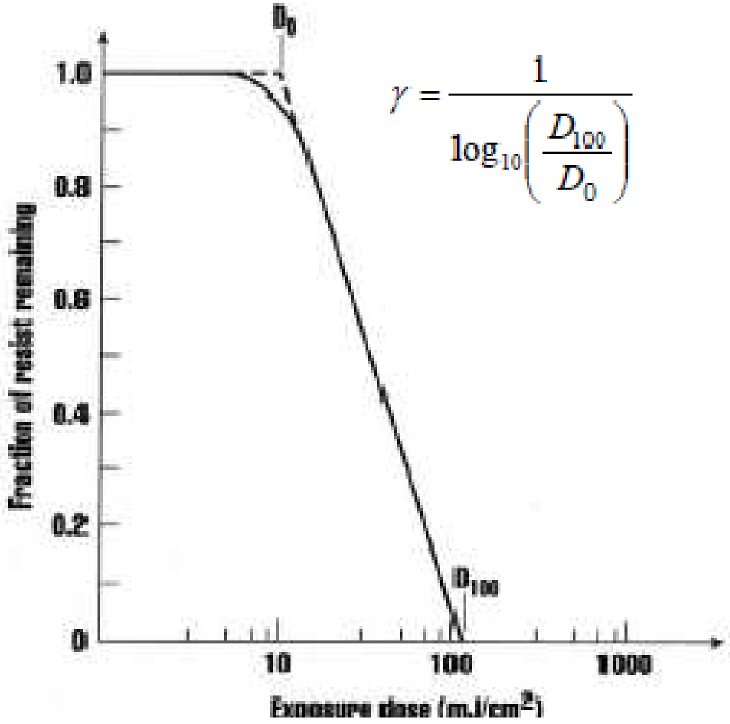
Resist under irradiation



Poly(methylmethacrylate)- the most common e-beam resist.



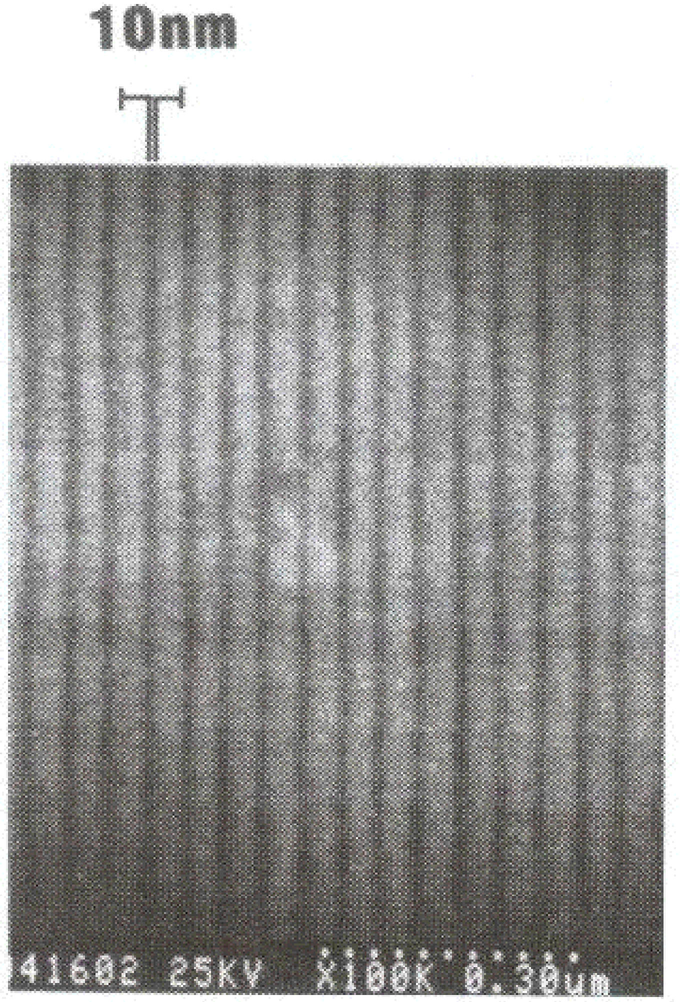
Definition of contrast γ of positive resists



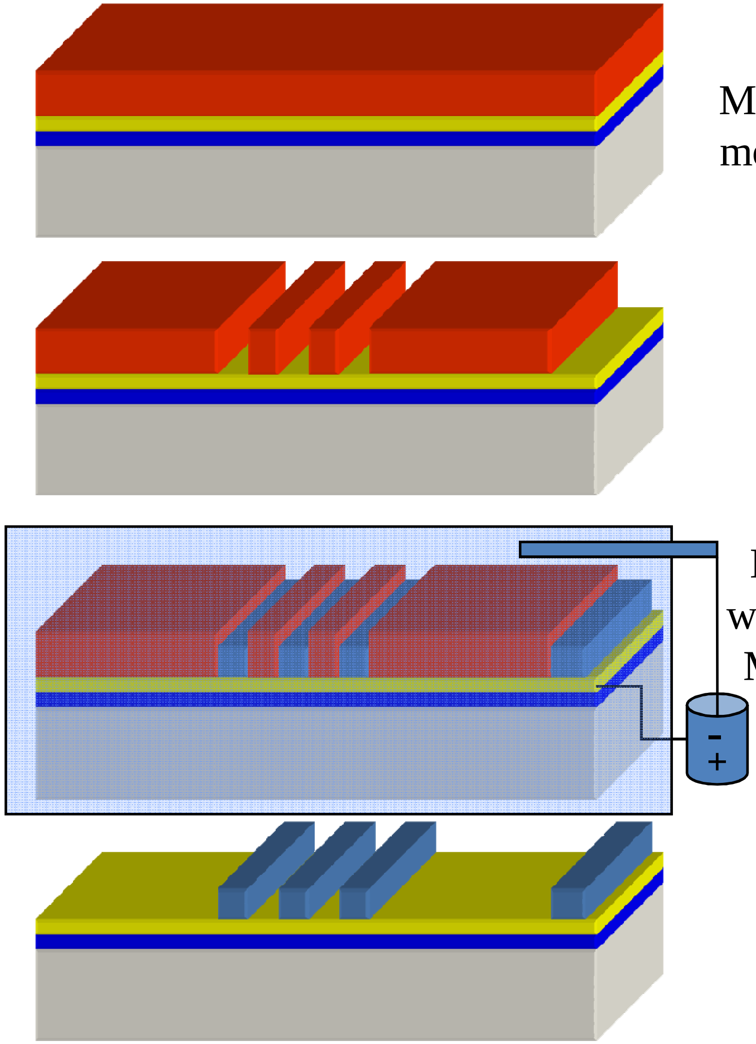
$$\gamma = \frac{1}{\log_{10}\left(\frac{D_{100}}{D_0}\right)}$$

Fabrication of nanostructures by EBL: a basic process

- 30-50 nm thick poly(methyl methacrylate) (PMMA) is spin-cast on Si substrate.
- Exposure to e-beam breaks polymer bonds and increases solubility.
- 10 nm lines are dissolved away by a solvent (MIBK:IPA).



Pattern Transfer- Addictive Process – (evaporation, sputter, electrolytic grown)

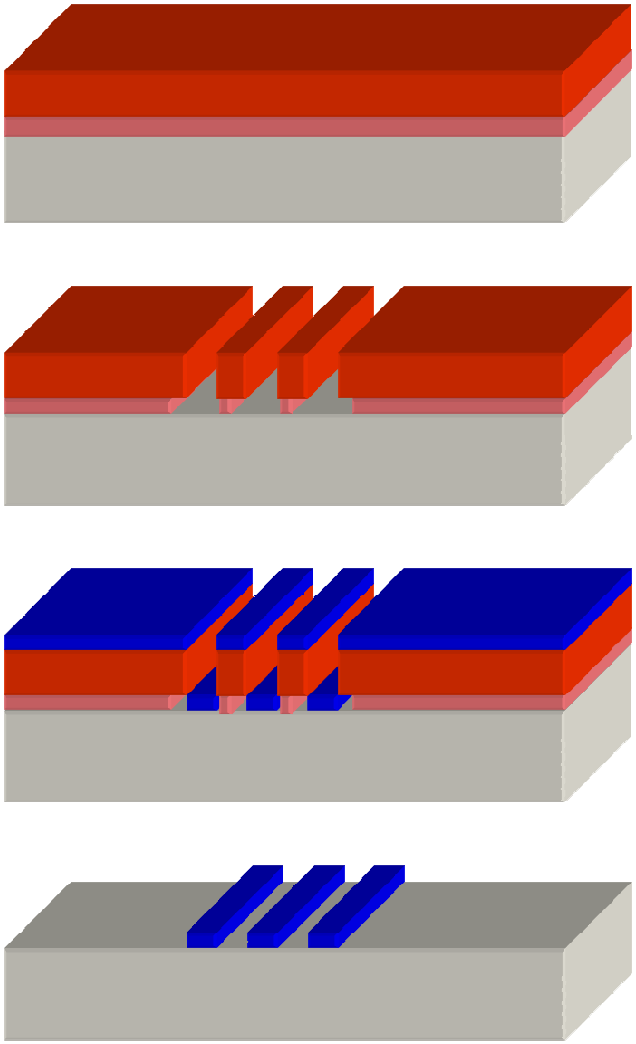


Photoresist
Metal base plating (right)
more sensible resist (left)
Si substrate

Photolithography or
other lithography
develop and rince

Electrolitic process in
wet solution (right side).
Material deposition by
sputter evaporation
etc.(left)

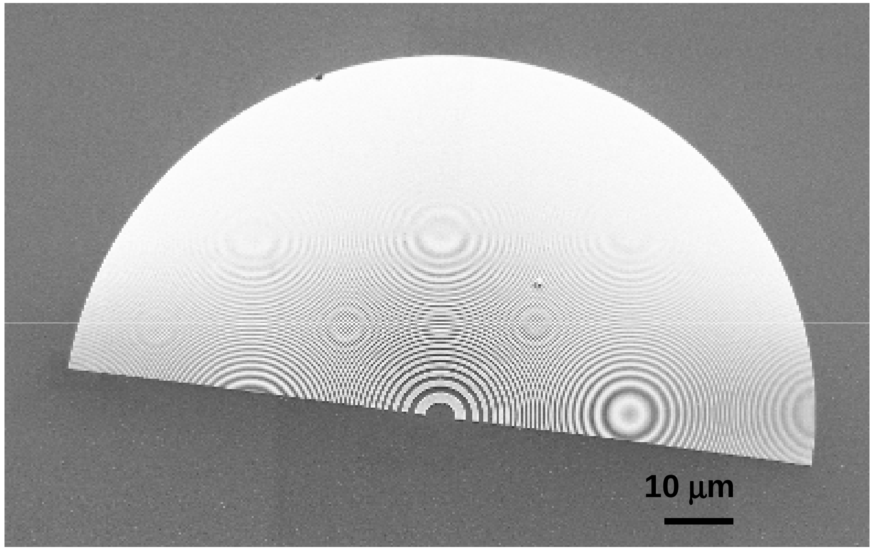
Photoresist stripping
and cleaning for the
final device

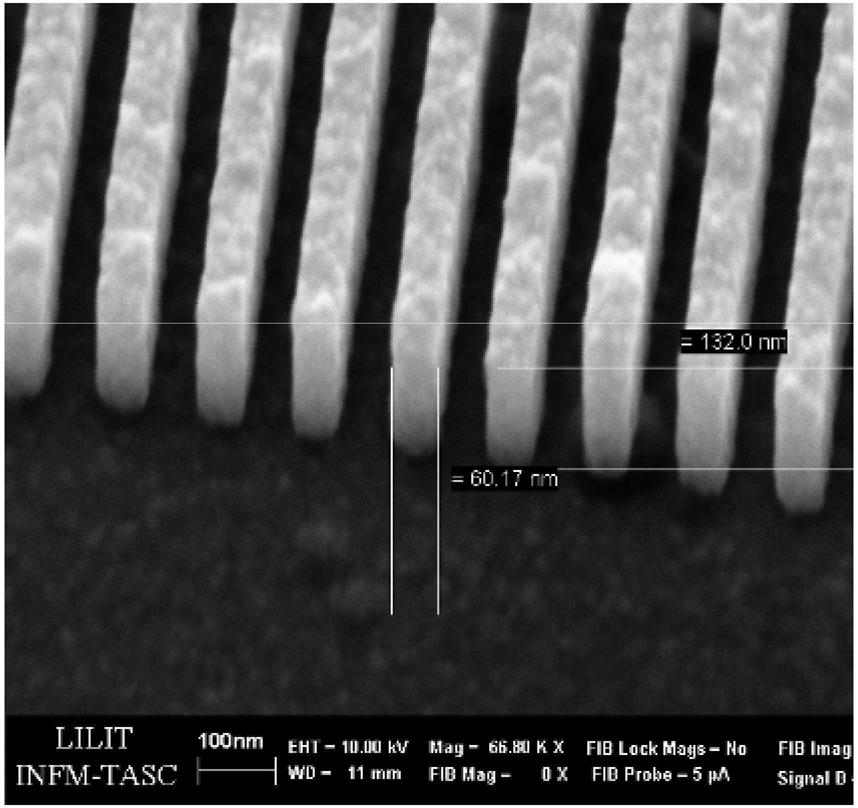


Electroplating

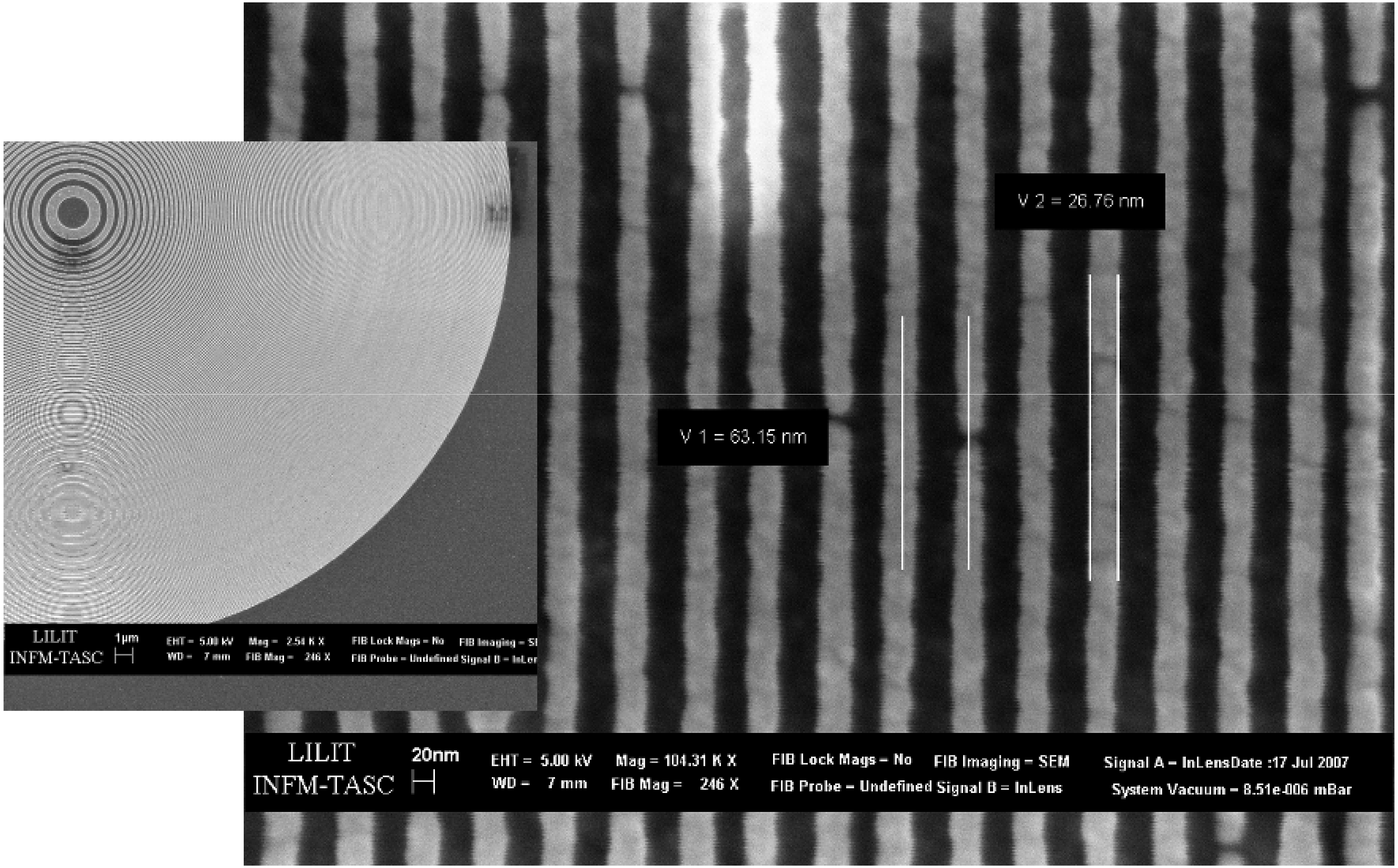
Lift-off

EBL + Au electroplating



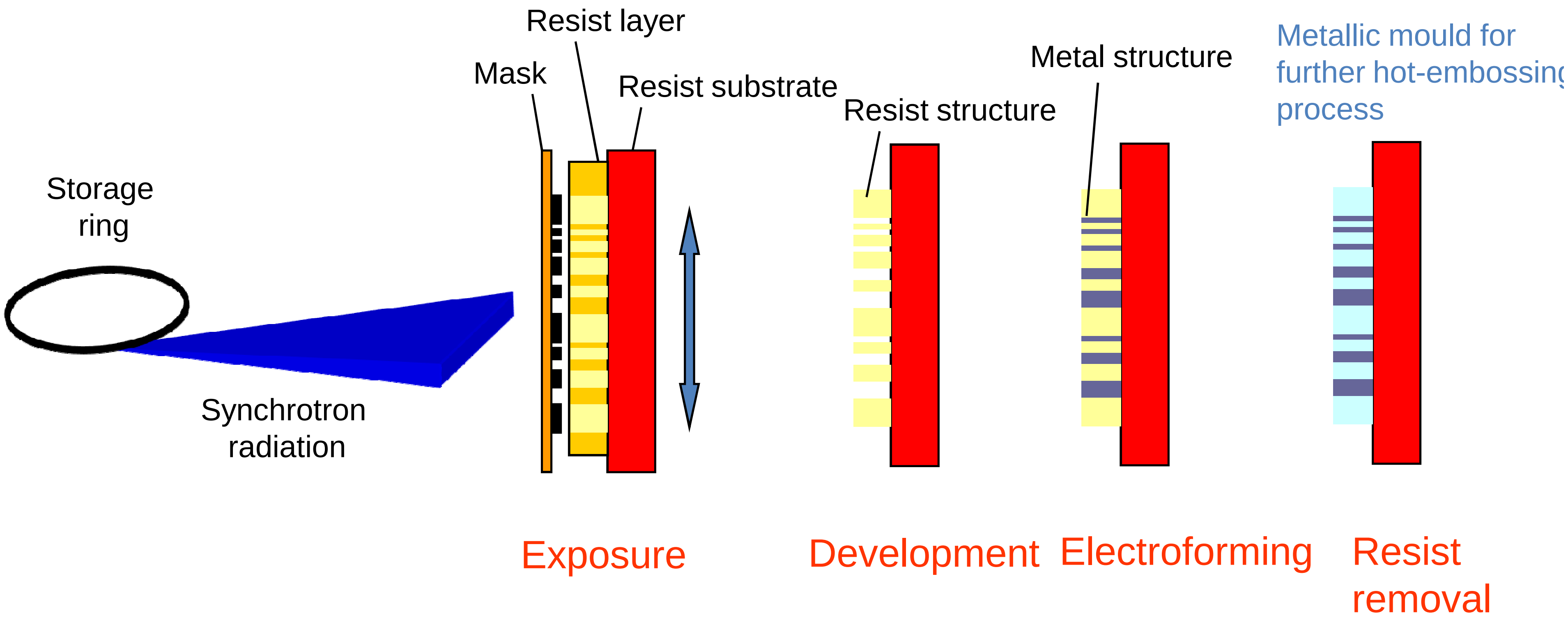


Very high resolution Zone Plates

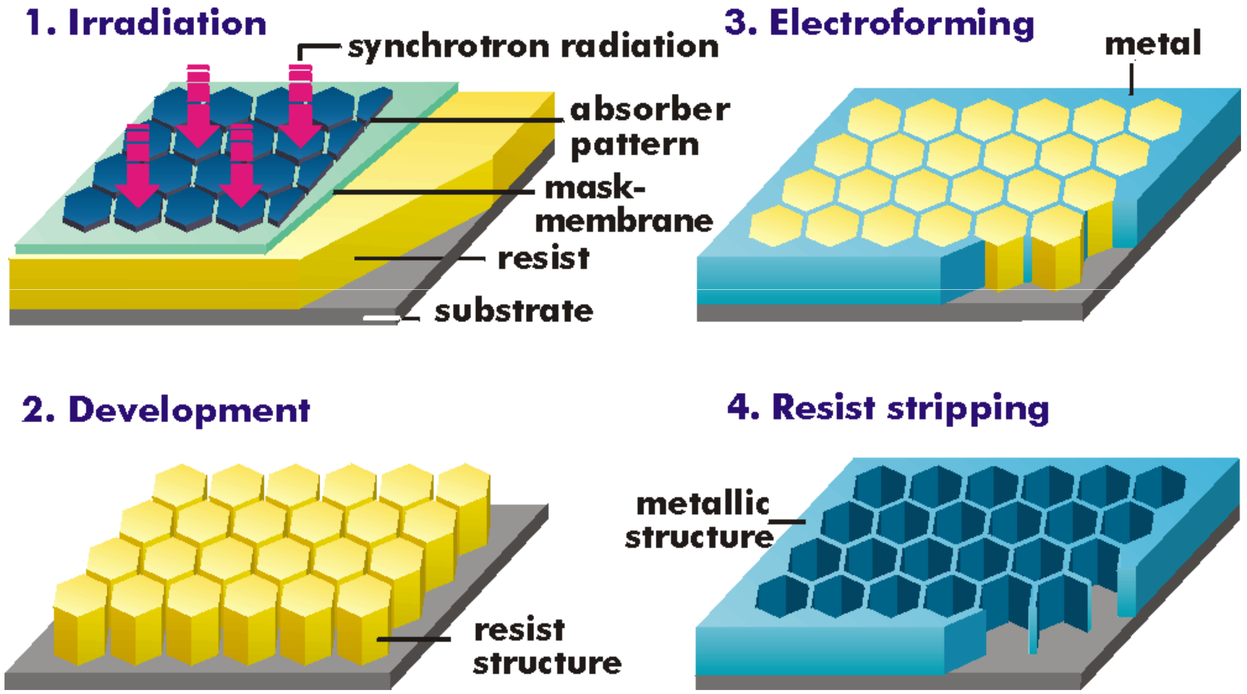


X-RAY LITHOGRAPHY

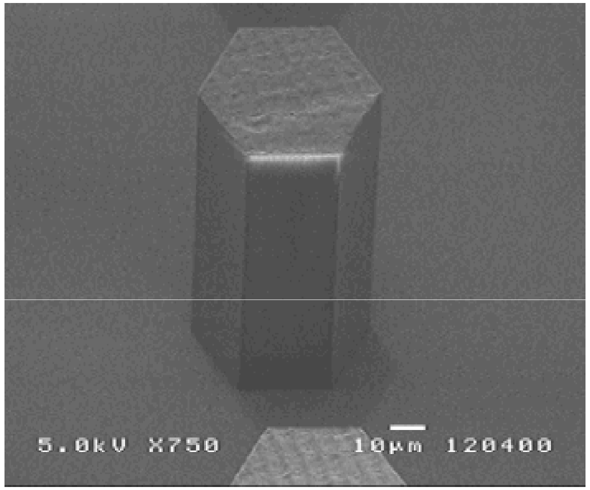
The LIGA process
(Lithography, Electroforming, Moulding)



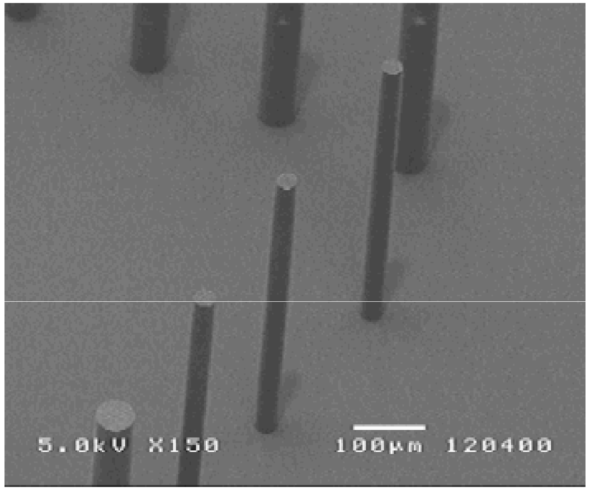
The LIGA process



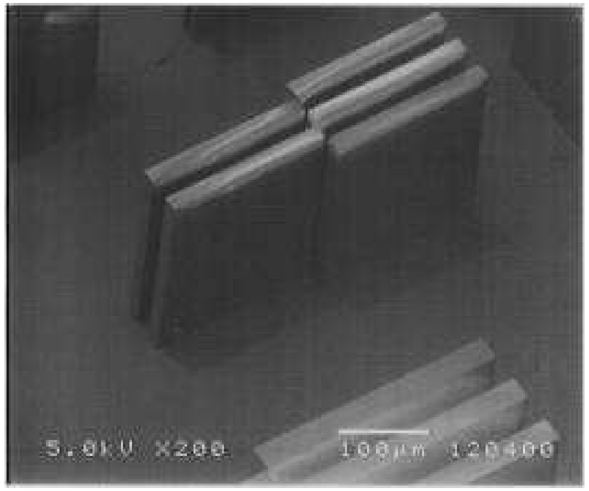
Example of PMMA microstructures produced at ELETTRA



Exposition parameter No. 3
Thickness 100 µm
Exposure time=26 mins
Development time= 4 hours;



Exposition parameter No. 4
Thickness 200 µm
Exposure time=40 mins
Development time= 17 hours;

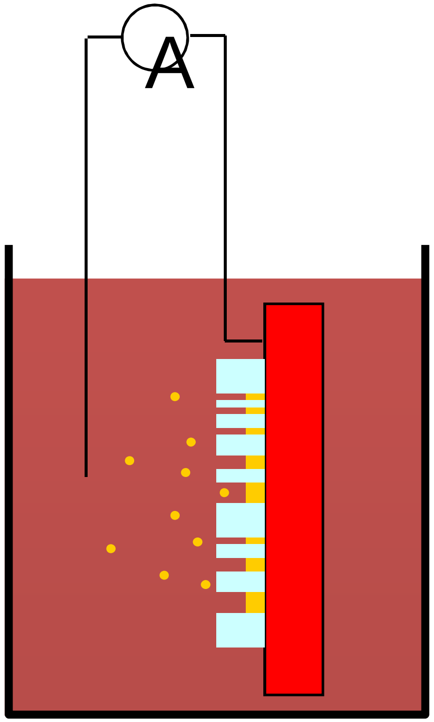


Exposition parameter No. 5
Thickness 500 µm
Exposure time=1h30 mins
Development time= 15.5 hours

Electrodeposition

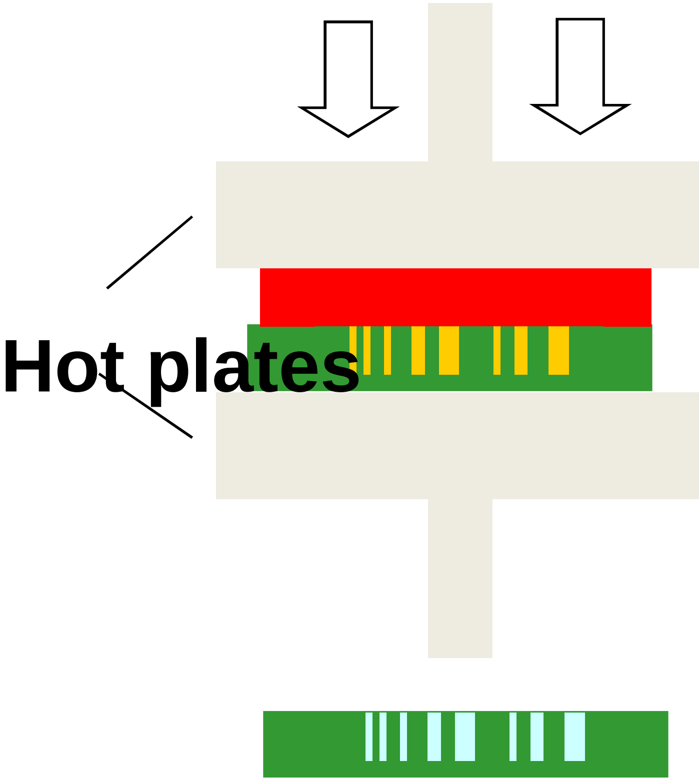
growth rate for Ni ≈ 13 μm/hour

Electrolythic bath

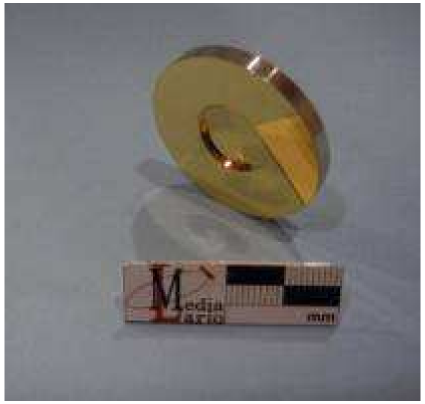


Hot embossing of high accuracy optics

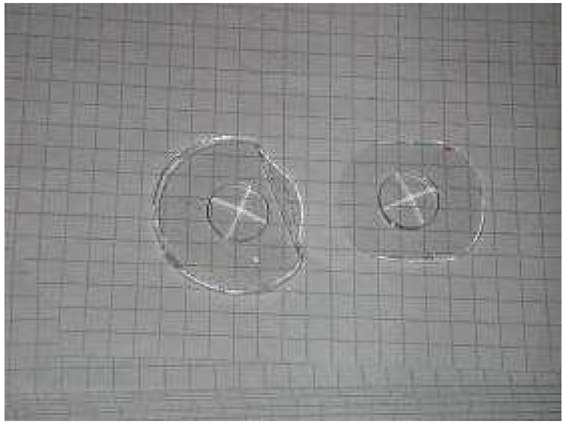
Hot embossing



Hot plates

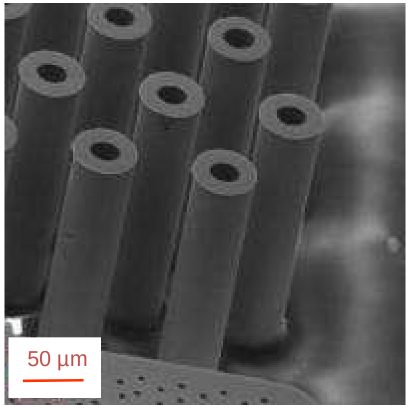


Mould



Pyramid wavefront sensors

Example of Copper electroplated test structures



Special features of the LIGA process

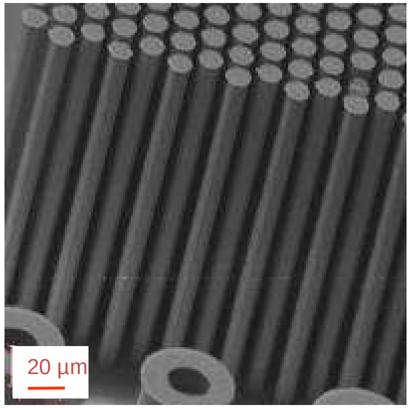
Freedom in lateral shaping

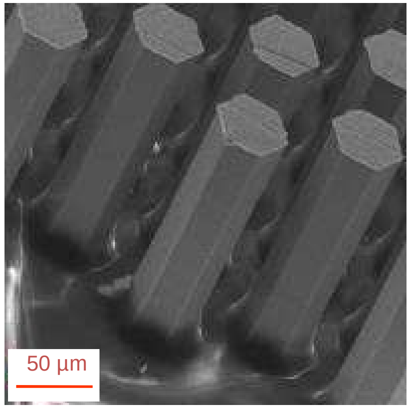
Structure heights up to 2-3 mm

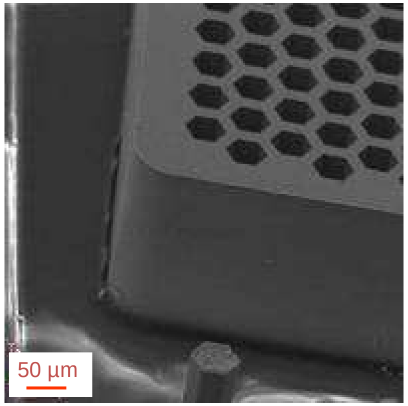
High aspect ratio (height/lateral dimension)

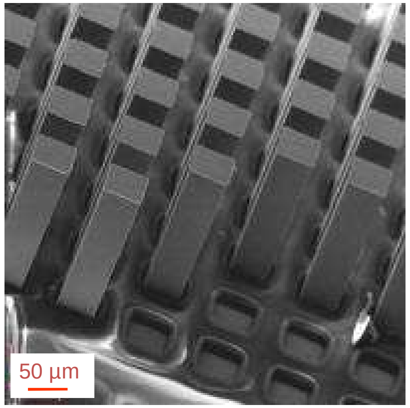
Roughness of side walls < 30 nm

Choice of material





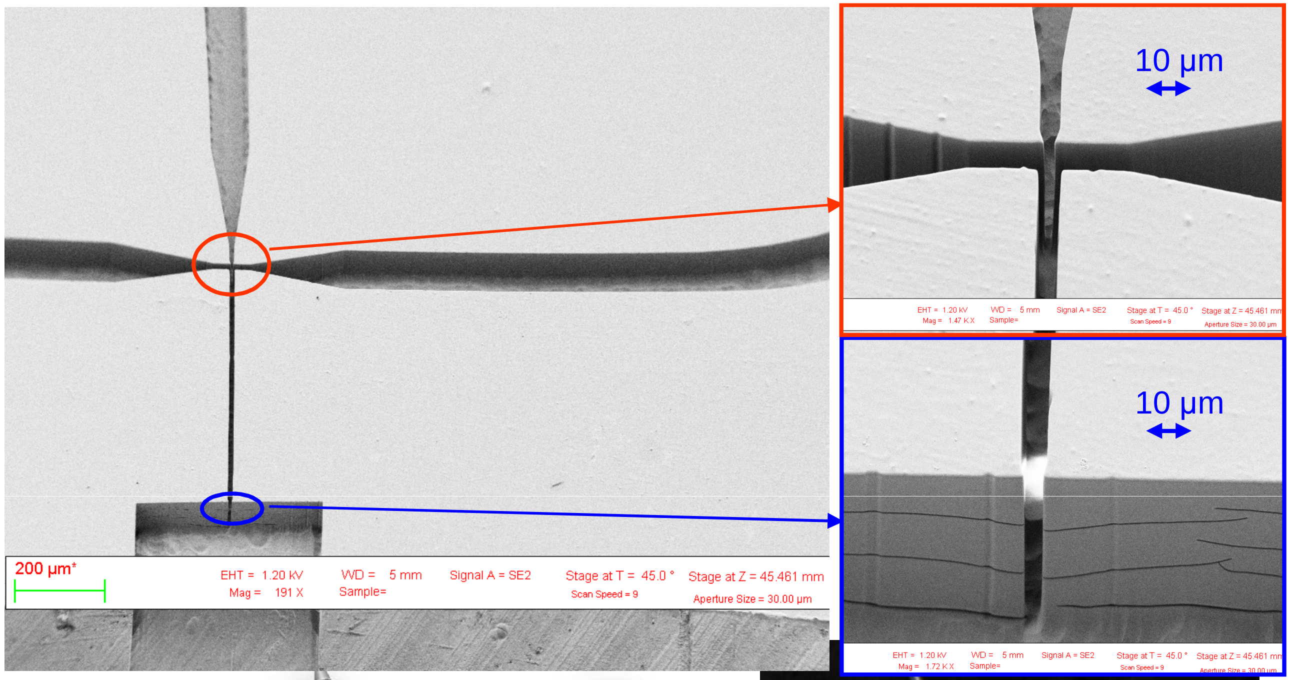




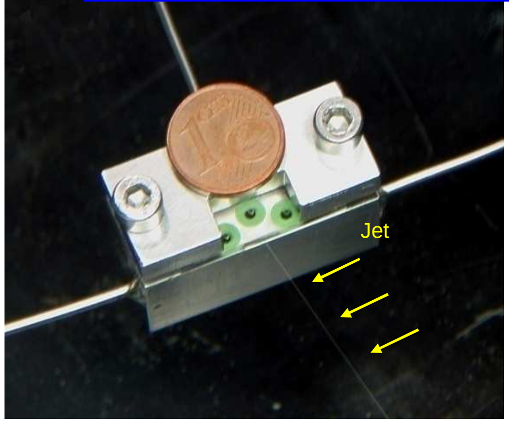
Fabrication of the device: results

Resulting device in PMMA:

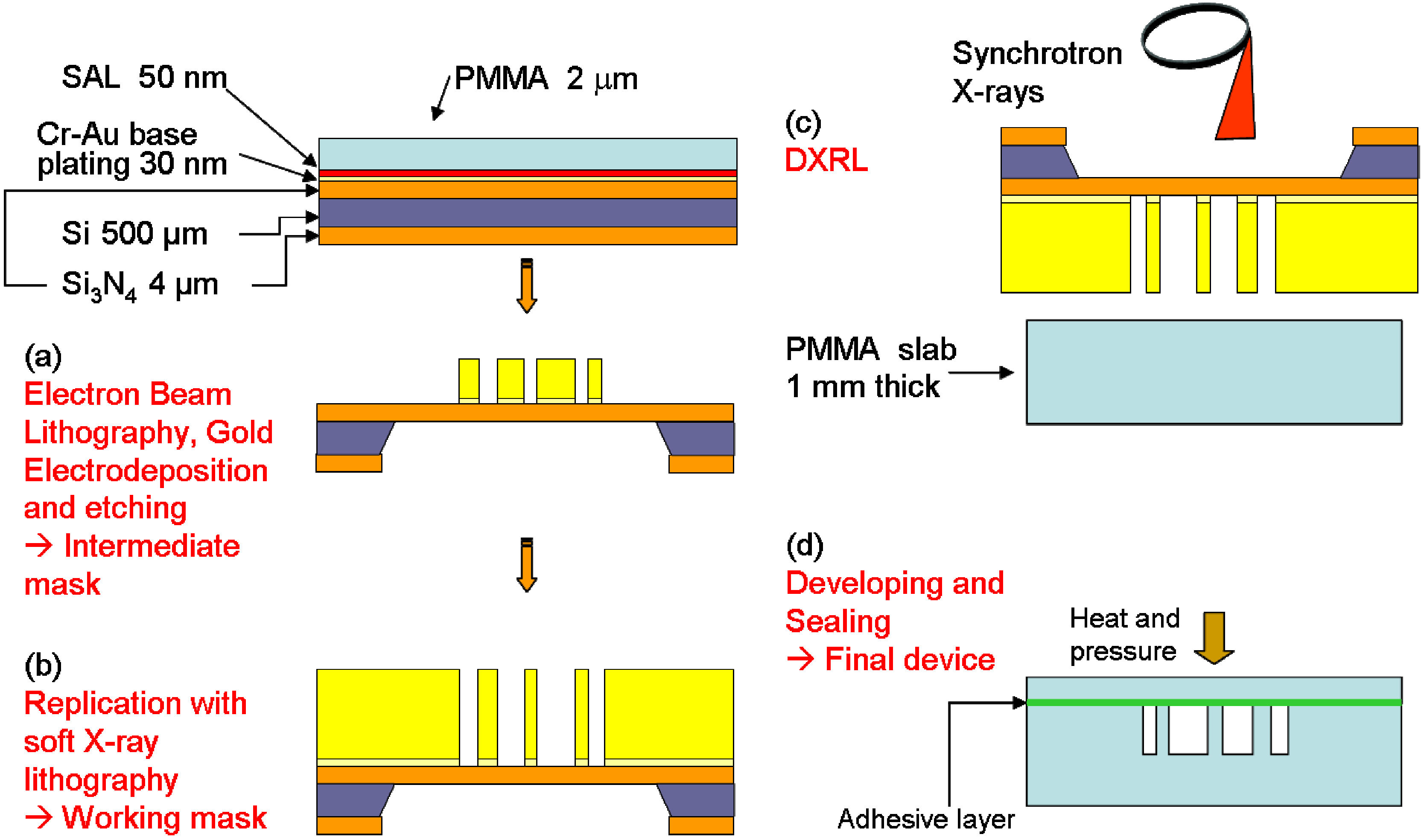
- 60 µm deep channels
- inlet nozzle 5 µm wide
- outlet nozzle 8 µm wide



Sample holder designed to improve connections with pumps and flexibility of the alignment



Fabrication of the device: overview of the process



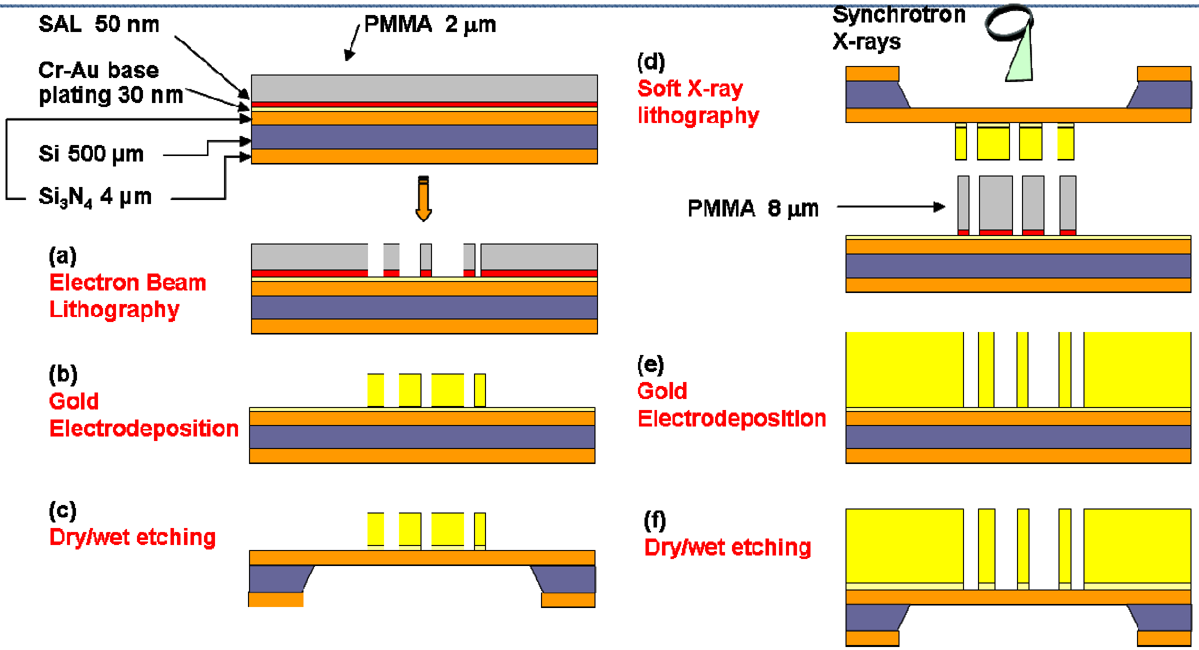
(a)
Electron Beam Lithography, Gold Electrodeposition and etching
→ Intermediate mask

(b)
Replication with soft X-ray lithography
→ Working mask

(c)
DXRL

(d)
Developing and Sealing
→ Final device

Fabrication of the device: making of the mask (2)



SAL 50 nm

PMMA 2 µm

Cr-Au base plating 30 nm

Si 500 µm

Si_3N_4 4 µm

(a)
Electron Beam Lithography

(b)
Gold Electrodeposition

(c)
Dry/wet etching

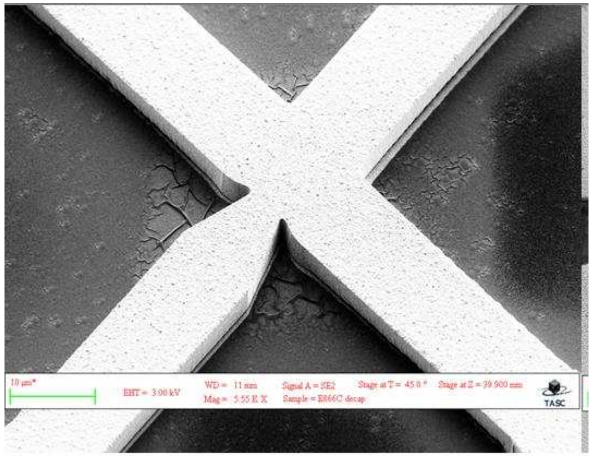
Synchrotron X-rays

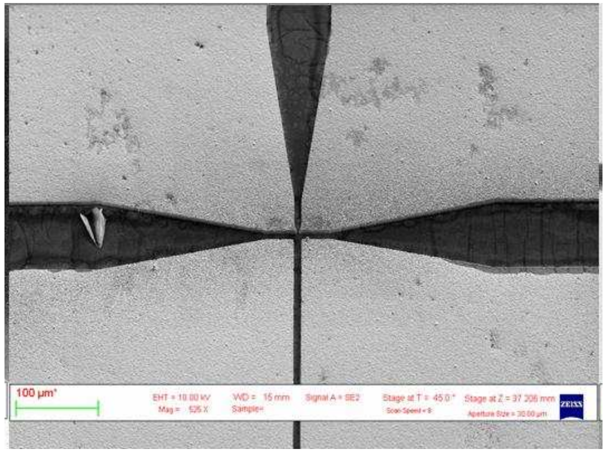
(d)
Soft X-ray lithography

PMMA 8 µm

(e)
Gold Electrodeposition

(f)
Dry/wet etching

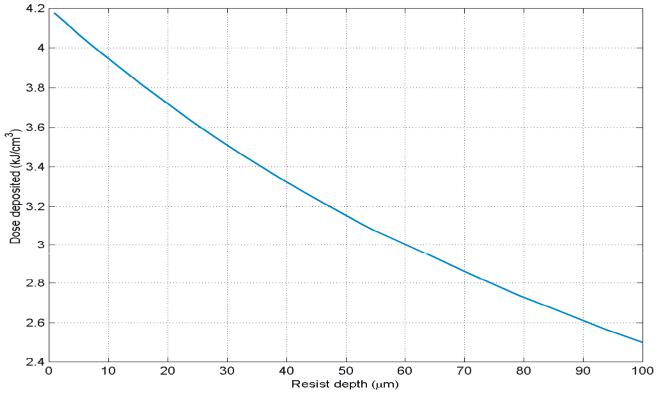


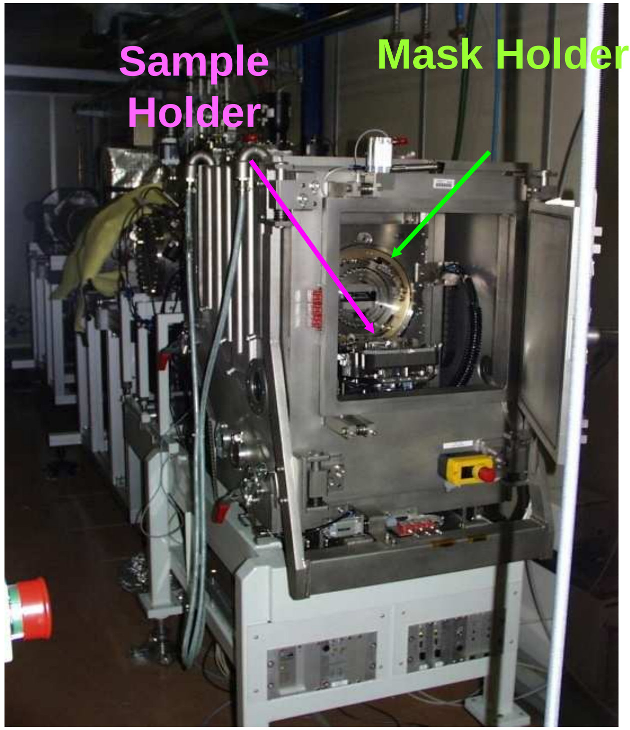


Fabrication of the device: exposure and developing

Selection of irradiation dose:

3 kJ/cm^3 at a PMMA depth of 100 µm





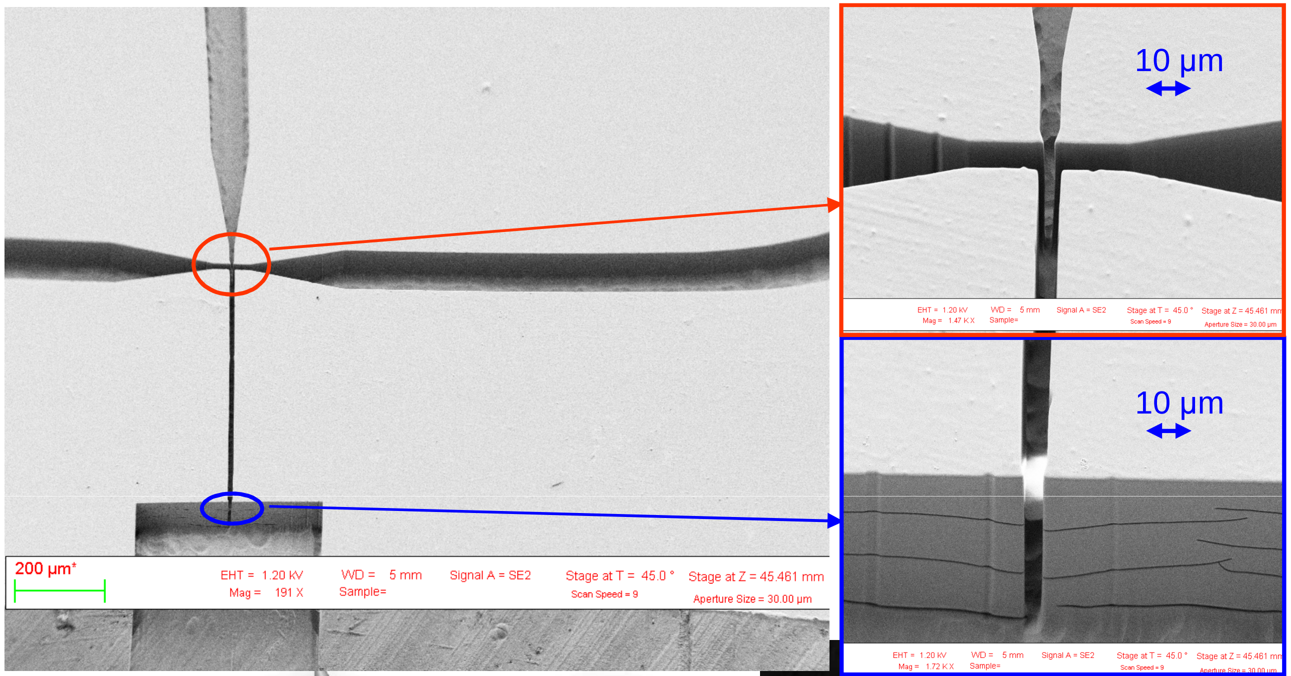
Typical exposure parameters:
- Bottom dose less than 4 kJ/cm^2
- Beam energy 2.0 GeV
- Scanner velocity 20 mm/s
- Sample mounted directly in contact with the mask (better resolution)

Developing in so-called GG solution, agitated and thermostatic at 24℃ (~ 2 h)

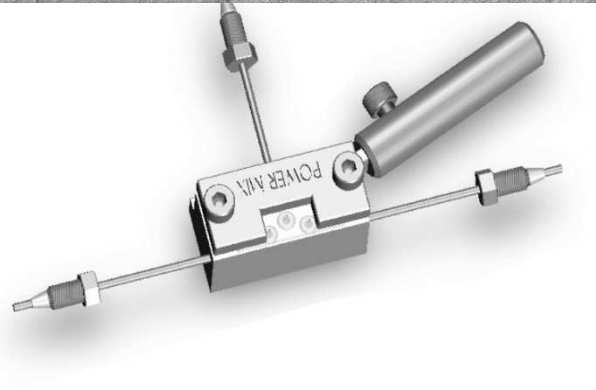
Fabrication of the device: results

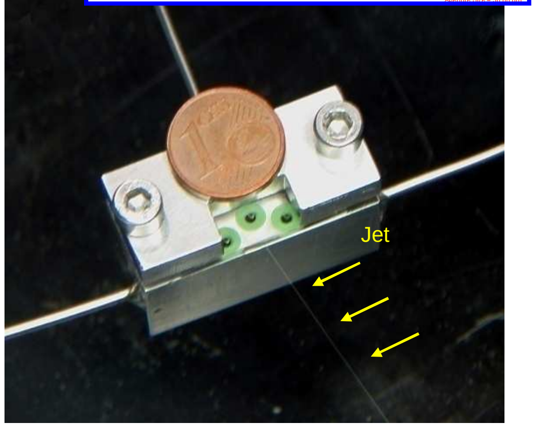
Resulting device in PMMA:

- 60 µm deep channels
- inlet nozzle 5 µm wide
- outlet nozzle 8 µm wide



Sample holder designed to improve connections with pumps and flexibility of the alignment

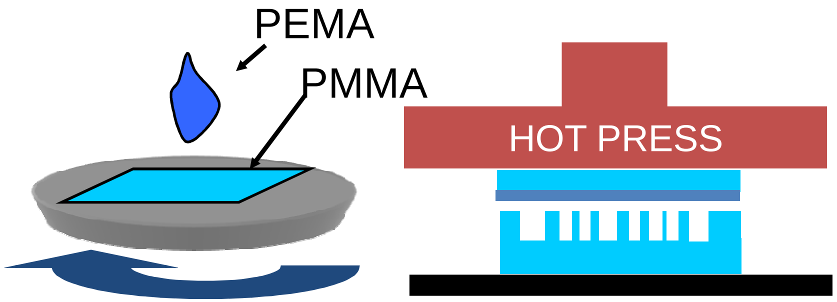




Fabrication of the device: sealing

Selection of method:

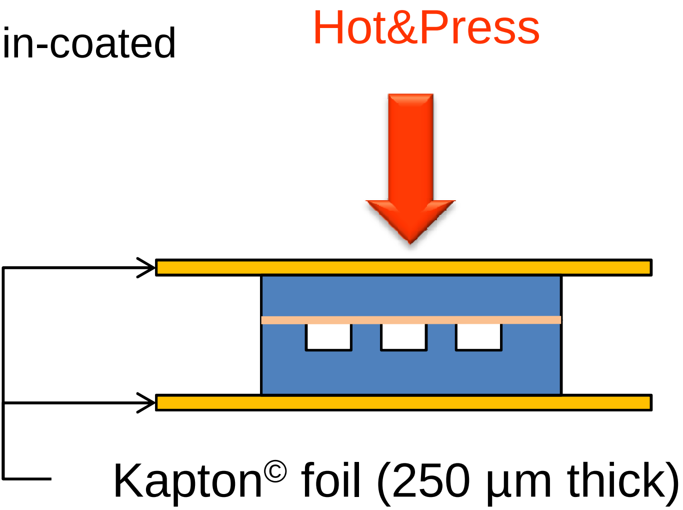
Thermal bonding with an intermediate PEMA layer



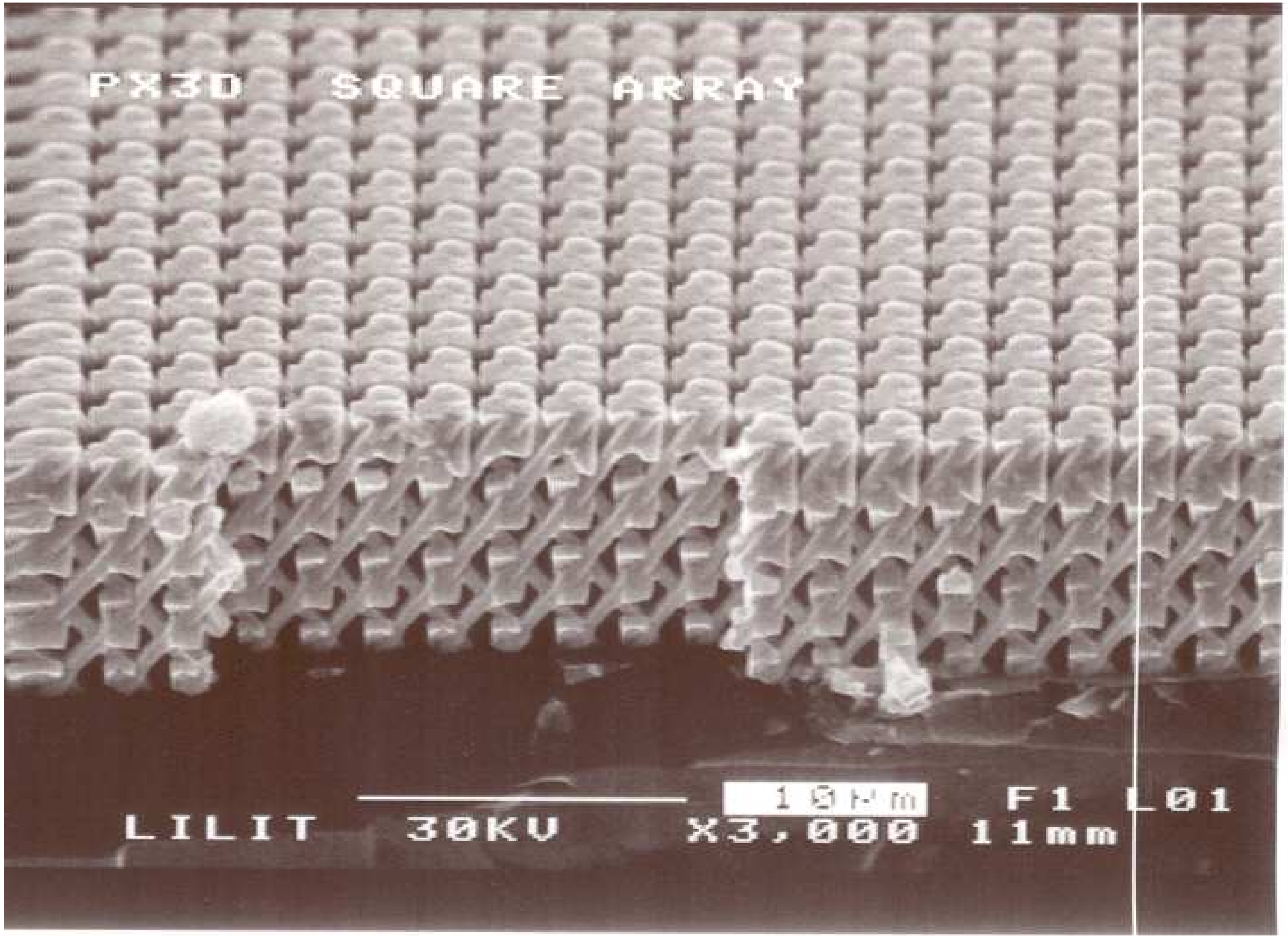
Process:

- A slide of impact modified PMMA, 500 µm thick, is spin-coated with thin (< 200 nm) PEMA layer
- Heating of press up to 85℃
- Positioning of the stack of the sample into the press
- Pressing and holding at 0.4 kN for 10 min
- Cooling down to 30℃ with pressure
- Final release of the sealed device

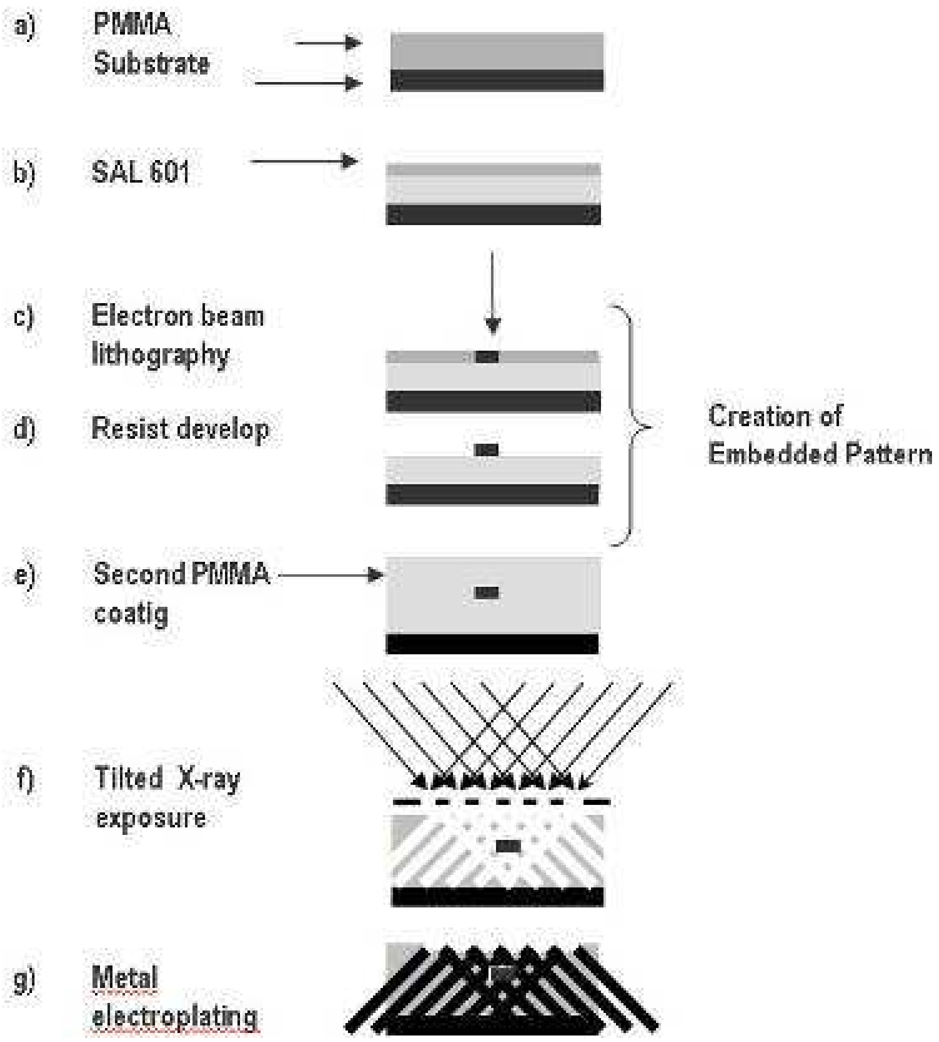
PEMA was chosen for its lower Tg, respect to PMMA.



Three-dimensional structures



Three-dimensional structures



a) PMMA
Substrate

b) SAL 601

c) Electron beam lithography

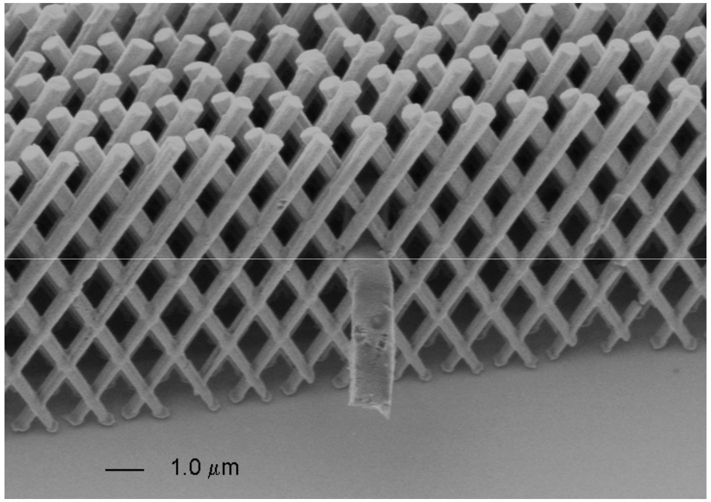
d) Resist develop

Creation of Embedded Pattern

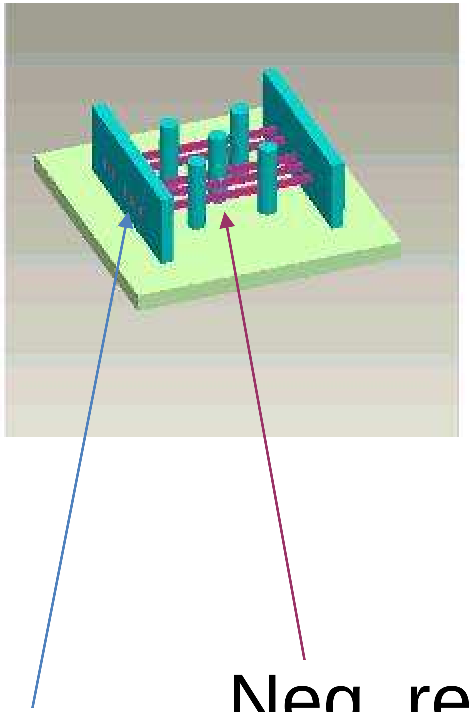
e) Second PMMA coatig

f) Tilted X-ray exposure

g) Metal electroplating

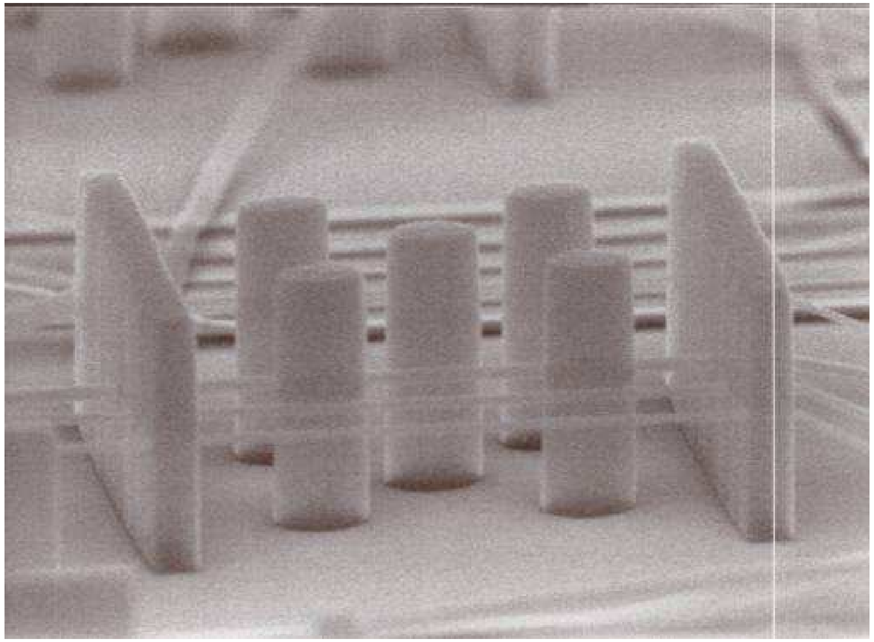


3D building block for microfluidic

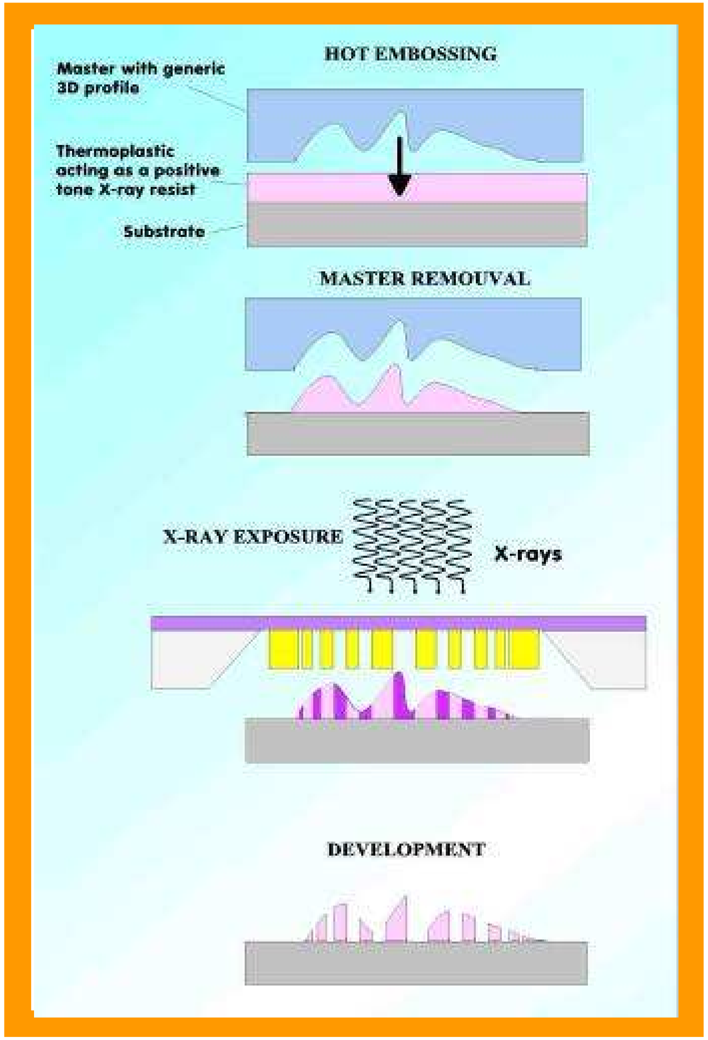


Neg. resist

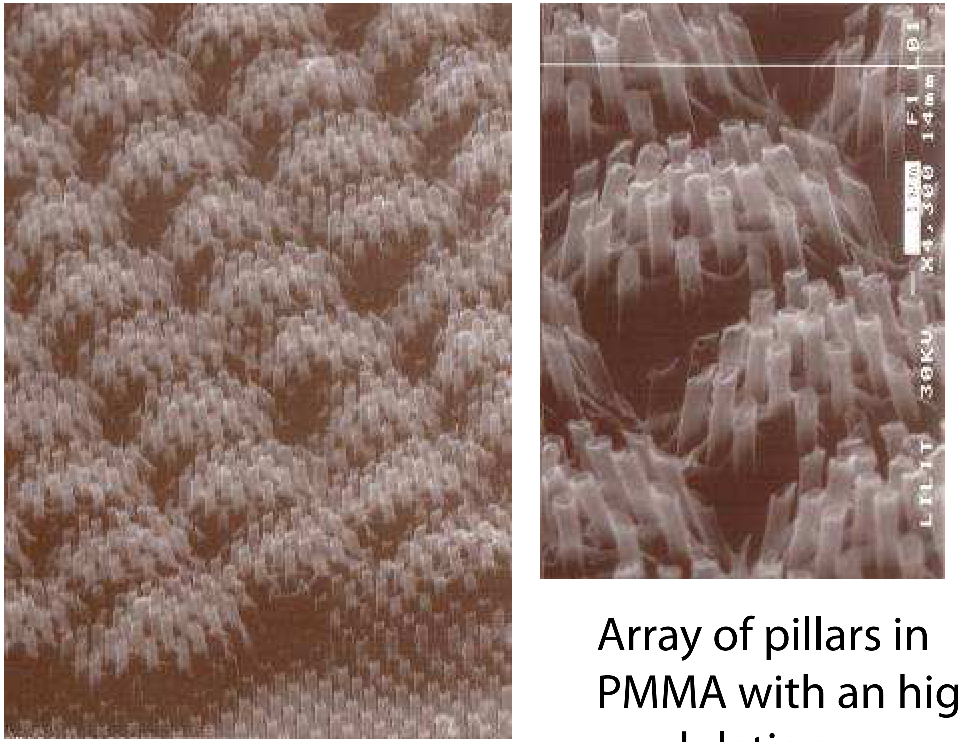
Posit. resist



Hybrid approaches

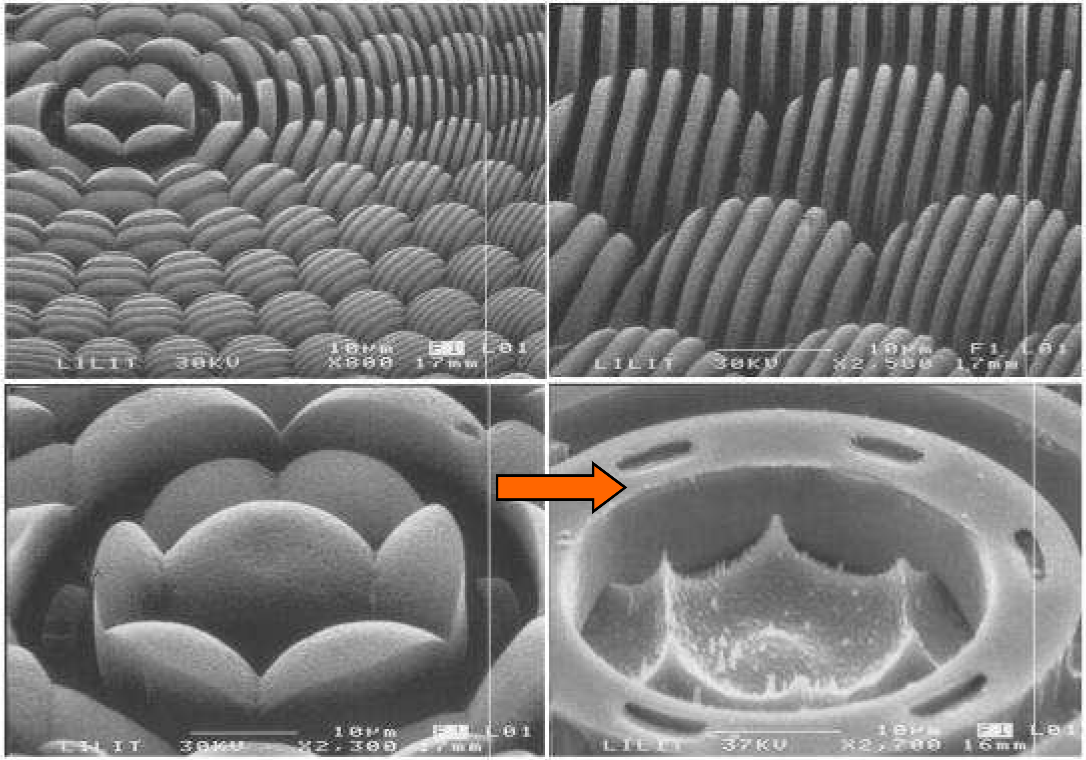


Hybrid approaches



Array of pillars in PMMA with an hight modulation

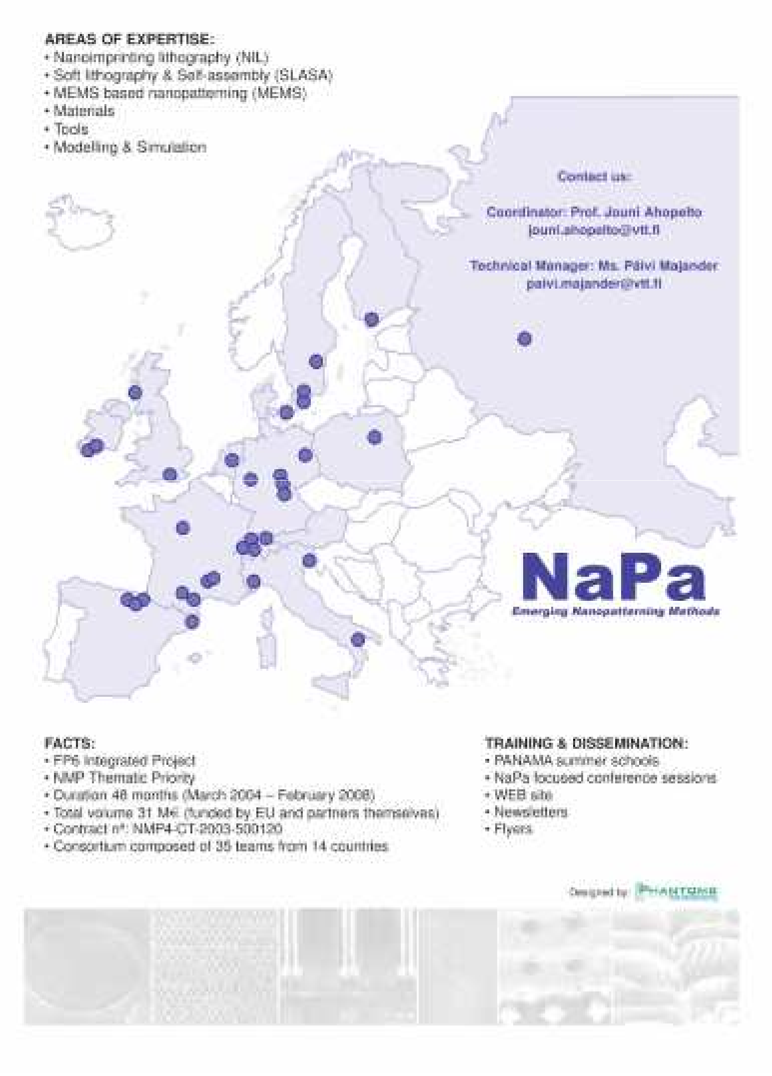
Hybrid approaches



Combination of a diffractive (ZP) and refractive optics (lenses)

Ni mould by electroplating

EU projects on “alternative” Nanofabrication



AREAS OF EXPERTISE:
- Nanoimprinting lithography (NIL)
- Soft lithography & Self-assembly (SLASA)
- MEMS based nanopatterning (MEMS)
- Materials
- Tools
- Modelling & Simulation

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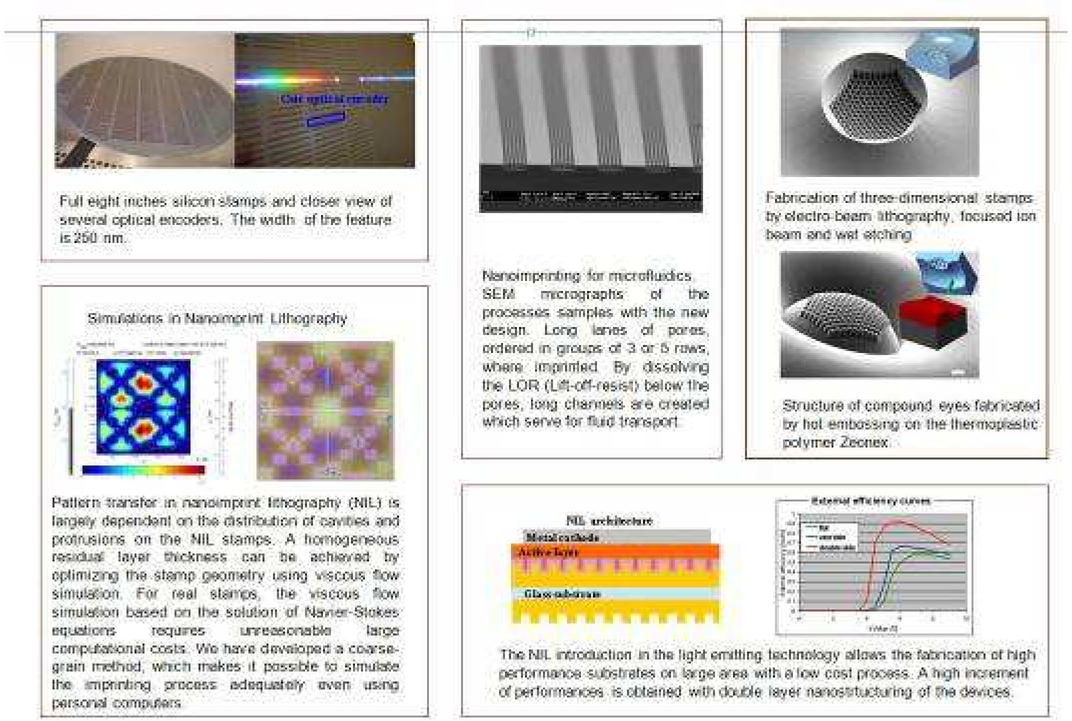
NaPa
Emerging Nanopatterning Methods

FACTS:
- FP6 Integrated Project
- NMP Thematic Priority
- Duration 48 months (March 2004 – February 2008)
- Total volume 31 M€ (funded by EU and partners themselves)
- Contract nº: NMP4-CT-2003-500120
- Consortium composed of 35 teams from 14 countries

TRAINING & DISSEMINATION:
- PANAMA summer schools
- NaPa focused conference sessions
- WEB site
- Newsletters
- Flyers

Designed by: PHANTOMS



Full eight inches silicon stamps and closer view of several optical encoders. The width of the feature is 250 nm.

Simulations in Nanoimprint Lithography

Pattern transfer in nanoimprint lithography (NIL) is largely dependent on the distribution of cavities and protrusions on the NIL stamps. A homogeneous residual layer thickness can be achieved by optimizing the stamp geometry using viscous flow simulation. For real stamps, the viscous flow simulation based on the solution of Navier-Stokes equations requires unreasonable large computational costs. We have developed a coarse-grain method, which makes it possible to simulate the imprinting process adequately even using personal computers.

Nanoimprinting for microfluidics. SEM micrographs of the processes samples with the new design. Long lanes of pores, ordered in groups of 3 or 5 rows, where imprinted. By dissolving the LOR (Lift-off-resist) below the pores, long channels are created which serve for fluid transport.

Fabrication of three-dimensional stamps by electro-beam lithography, focused ion beam and wet etching.

Structure of compound eyes fabricated by hot embossing on the thermoplastic polymer Zeonex.

The NIL introduction in the light emitting technology allows the fabrication of high performance substrates on large area with a low cost process. A high increment of performances is obtained with double layer nanostructuring of the devices.

1. Nanoimprinti Lithography
2. Soft Lithography &Self Assembling
3. Nanodispensing
4. Simulation & Materials

Acknowledgements

advanced technology and nanoscience
TASC national laboratory
tecnologie avanzate e nanoscienza

Lilit group

Luca Businaro
Dan Cojoc
Gianluca Grenci
Filippo Romanato
Simone Dal Zilio
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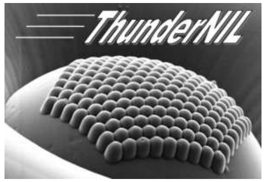
NaPa
Emerging Nanopatterning Methods

NaPaNIL

nanoscale



Heiko Wolf, IBM
Helmut Schift, PSI
Anders Kristensen, DTU