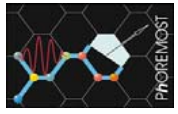
New Fabrication Methods for Photonics

J. Ahopelto
VTT Micro and Nanoelectronics
Espoo, Finland



NaPa
Emerging Nanopatterning Methods

Outline

- Integrated Project NaPa
- Examples of fabrication methods
- Examples of applications
- Summary

NaPa session

Thursday and Friday, June 29-30

European dimension

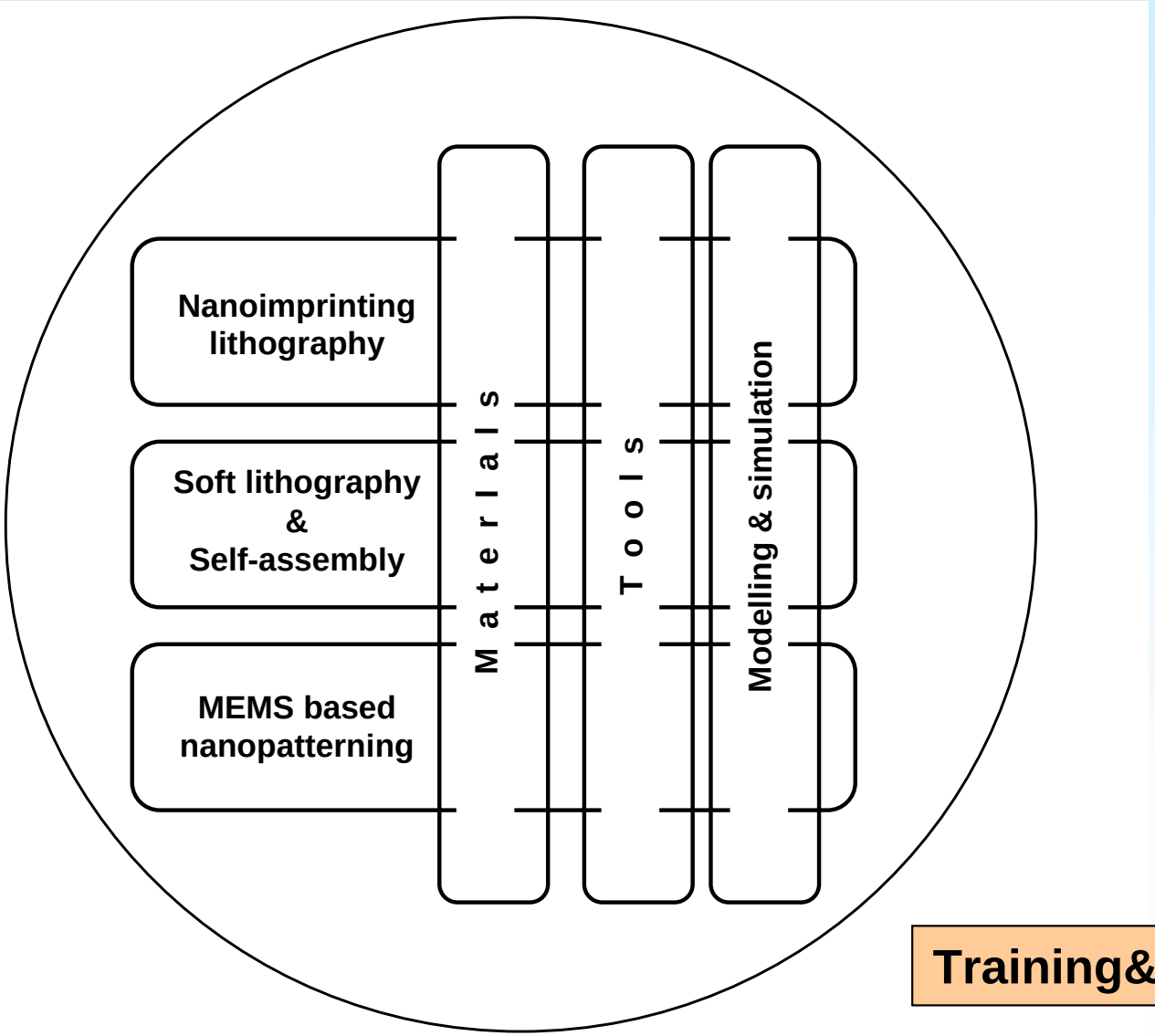
NaPa

Emerging Nanopatterning Methods

- FP6 Integrated Project
- NMP Priority
- 35 groups from 14 countries
- Coordinator: J. Ahopelto, VTT
- March 2004- February 2008
- Volume 31 M€
- 1/3 industrial partners
- 1/3 research institutes
- 1/3 universities

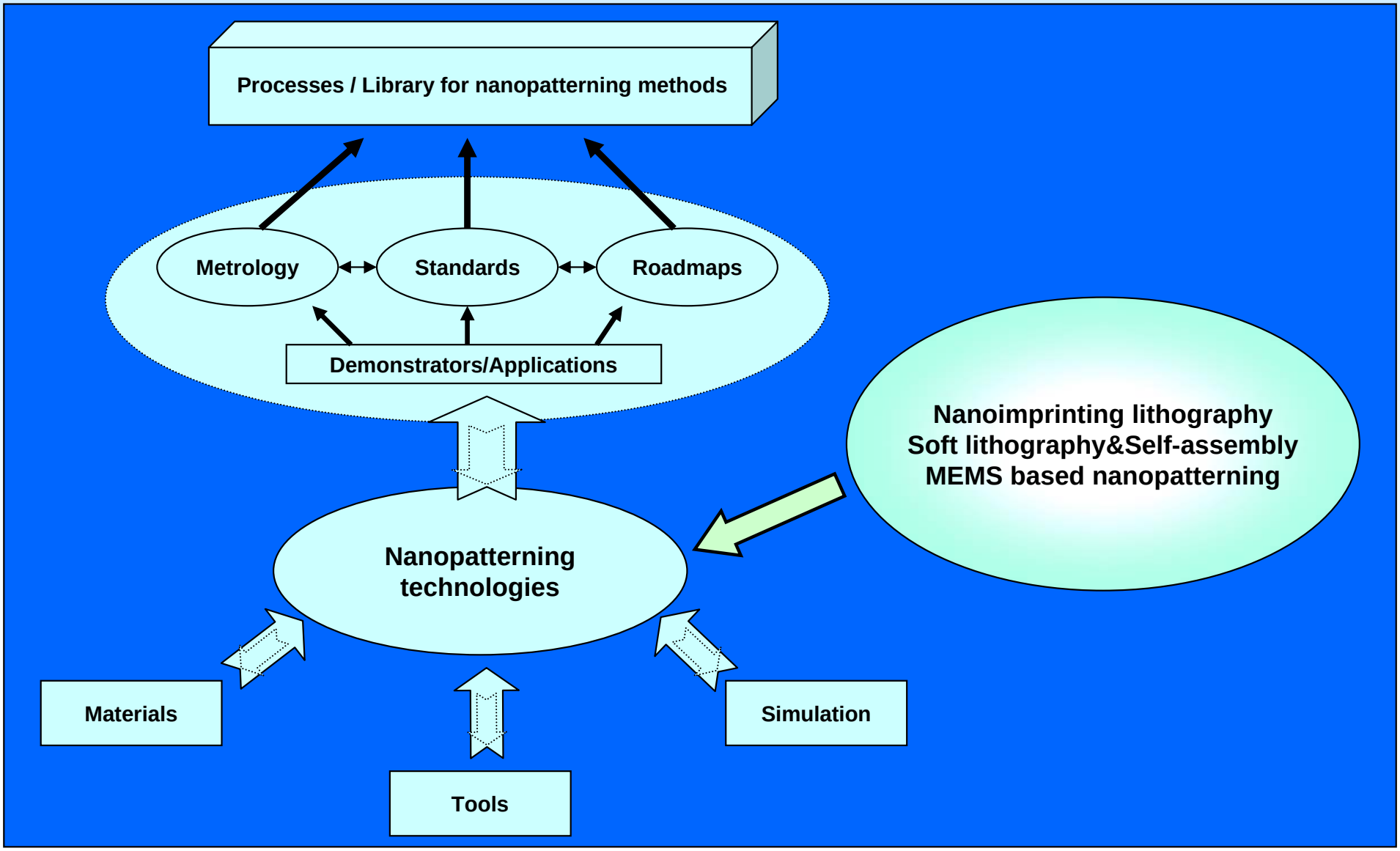
www.phantomsnet.net/NAPA/index.php

Emerging nanopatterning methods



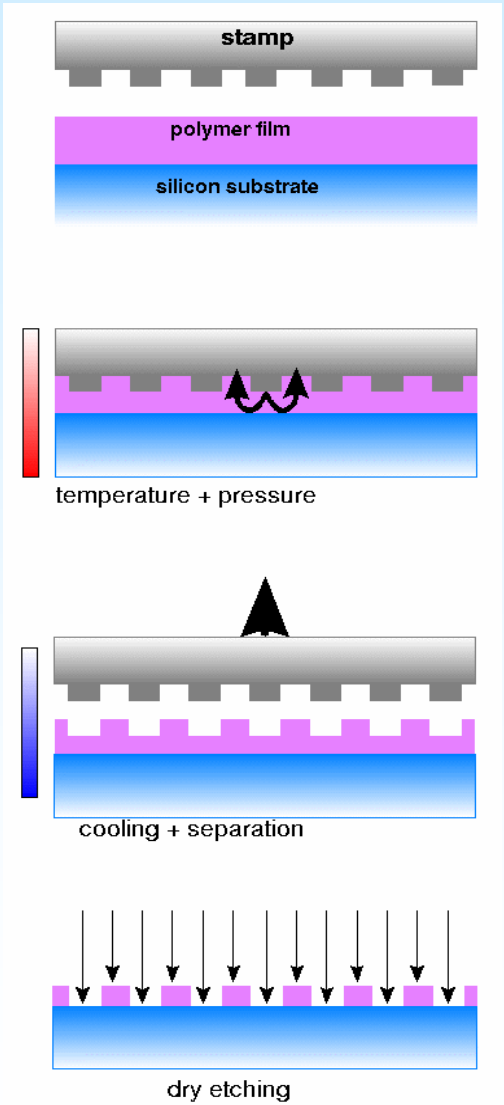
Training&Education

Aim


Processes / Library for nanopatterning methods
Metrology
Standards
Roadmaps
Demonstrators/Applications
Nanoimprinting lithography
Soft lithography&Self-assembly
MEMS based nanopatterning
Nanopatterning technologies
Materials
Tools
Simulation

Examples of Fabrication Methods

Thermal Nanoimprinting

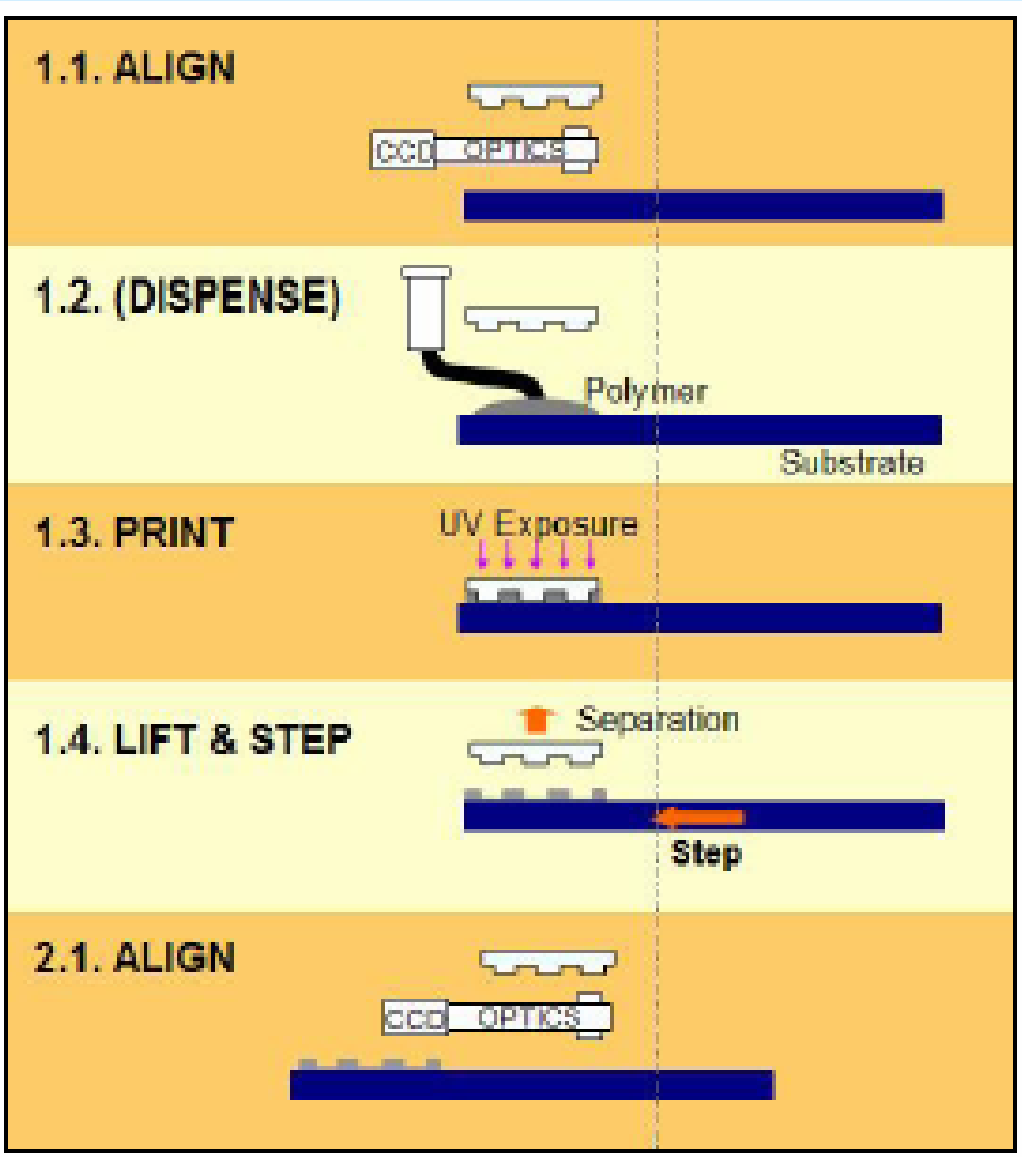


Heating + pressure

Cooling + demoulding

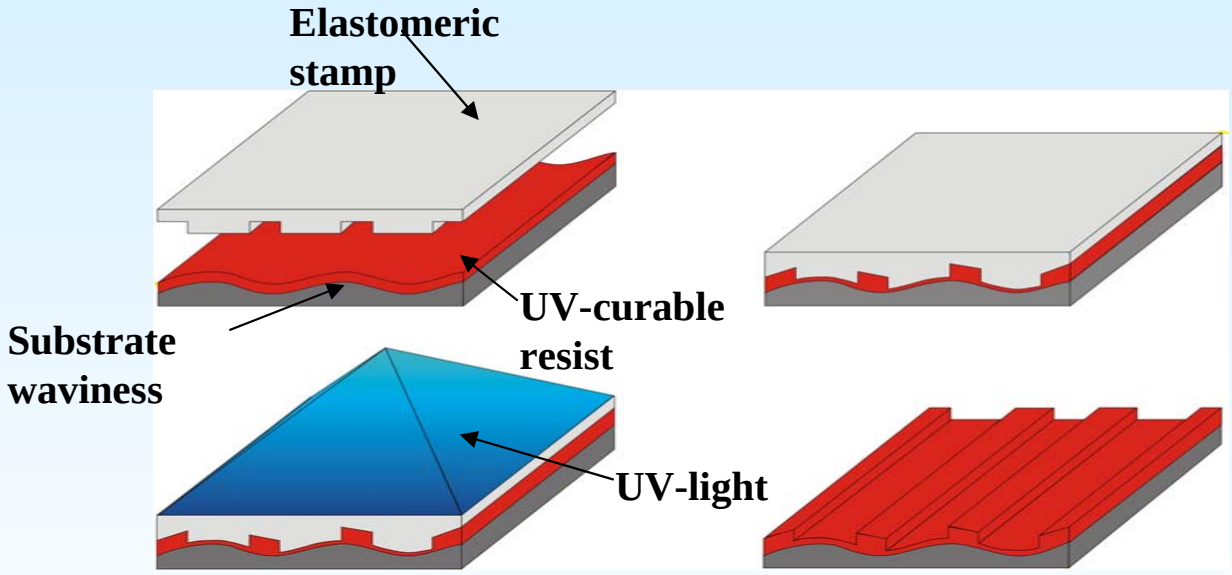
Removal of the residual layer

UV Nanoimprinting



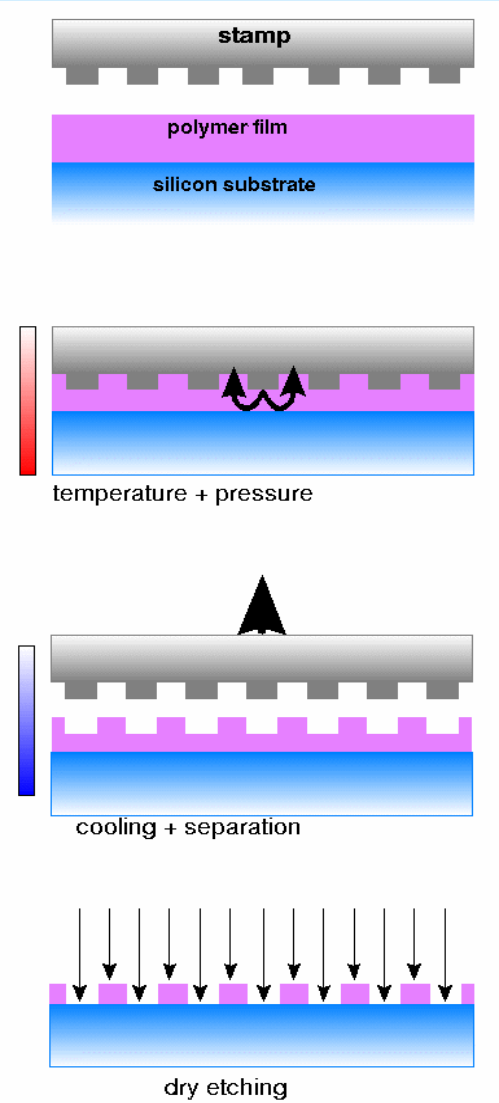
SUSS MicroTec

Soft lithography

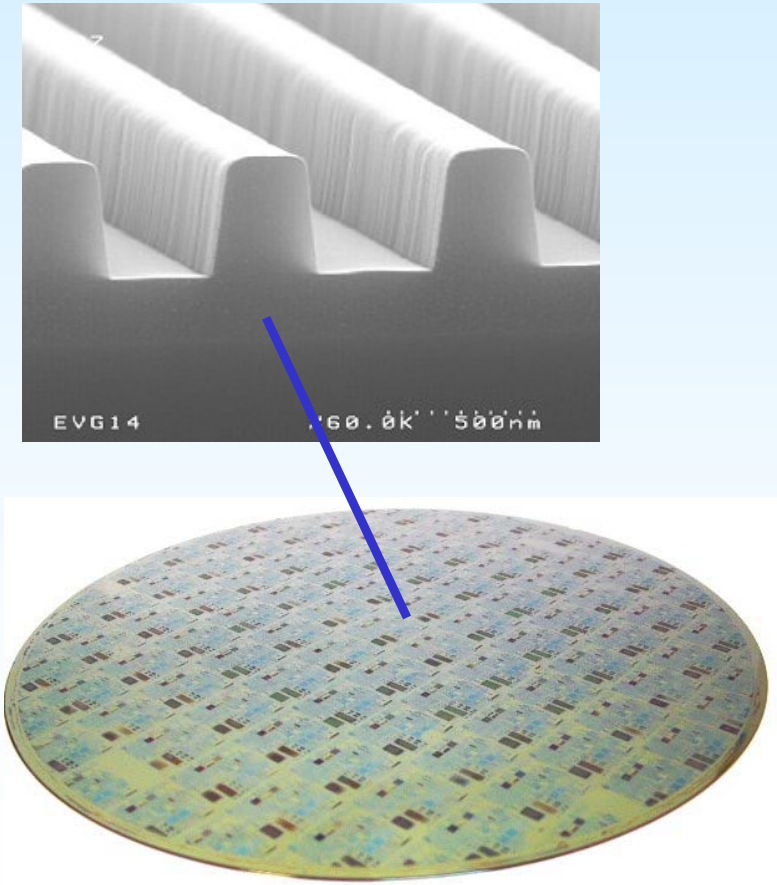


H. Wolf et al., IBM Research

Large Area Parallel NIL



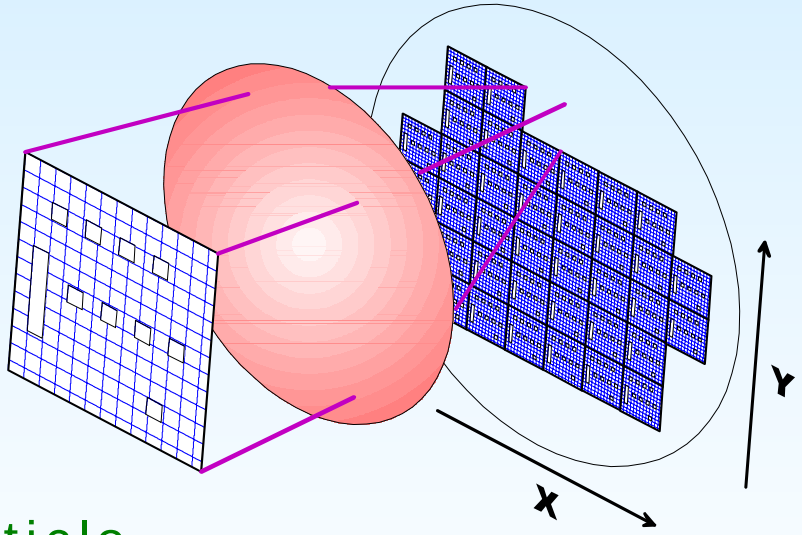
NIL on 200 mm wafer



C. Gourgon et al., CNRS

Step&Stamp nanoimprinting lithography I

Projection aligner

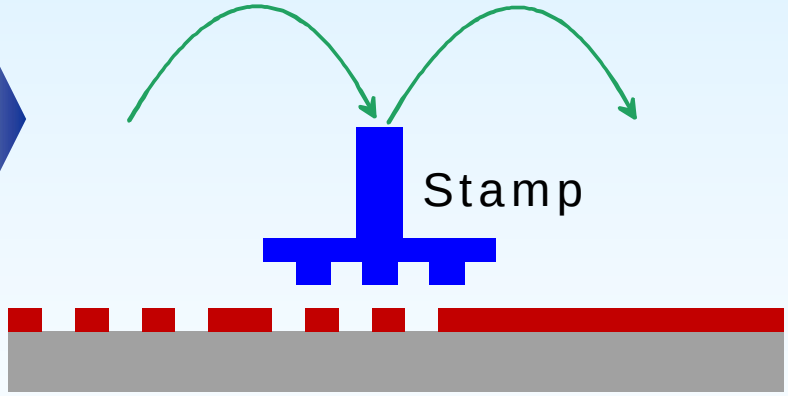


Reticle

Optics

Wafer

Step&Stamp imprinting



T. Haatainen et al., VTT 2000

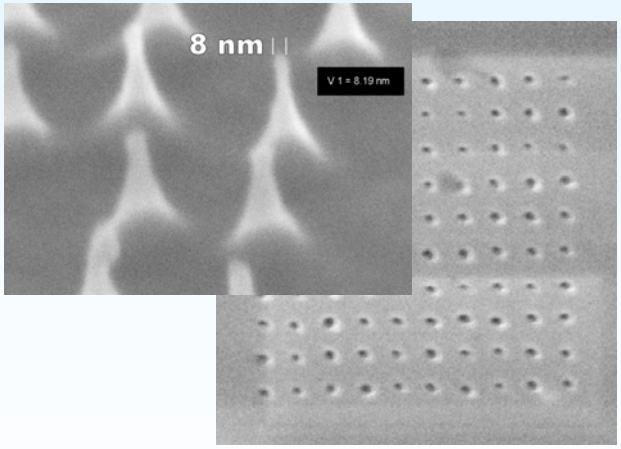
Step&Stamp nanoimprinting lithography II

NPS 300 Nano imPrinting Stepper

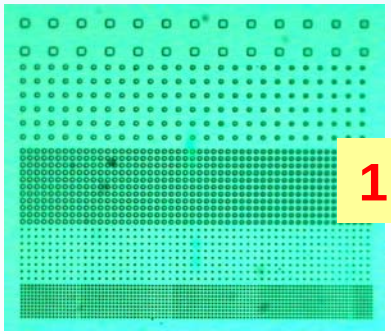
- **Thermal + UV nanoimprinting**
- **Up to 300 mm wafers**
- **Sub-20 nm features**
- **250 nm overlay accuracy**
- **Automatic alignment**
- **C2C loading available**

SUSS NPS300

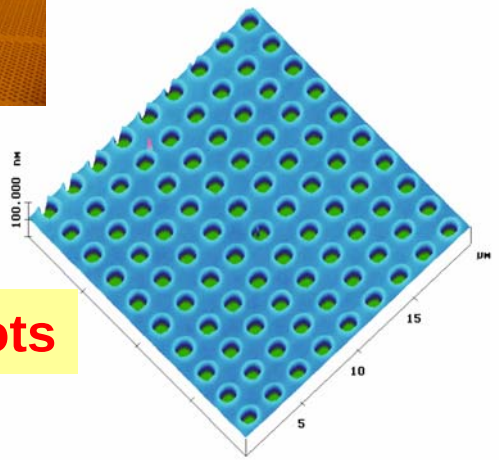
Prototype installed at VTT



~10 nm holes in polymer

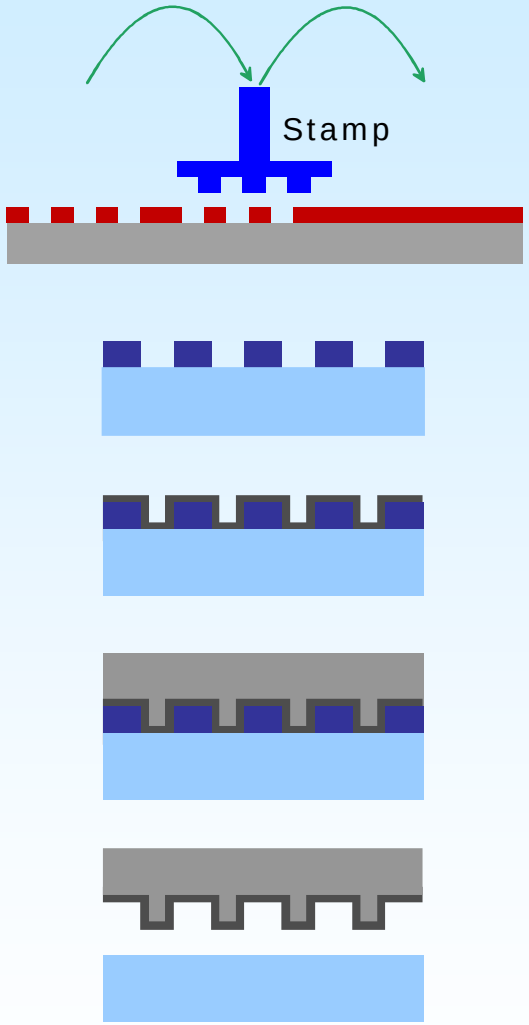


1 μm dots

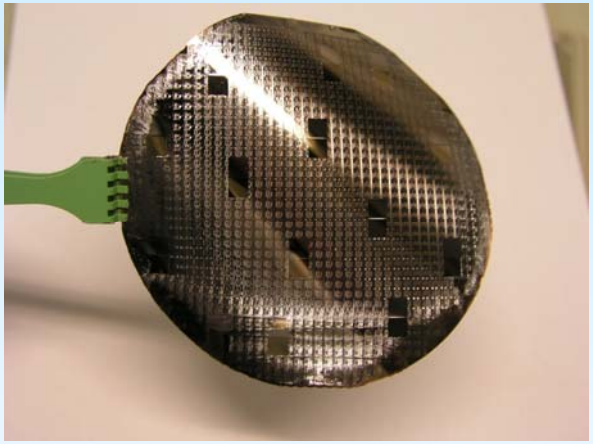


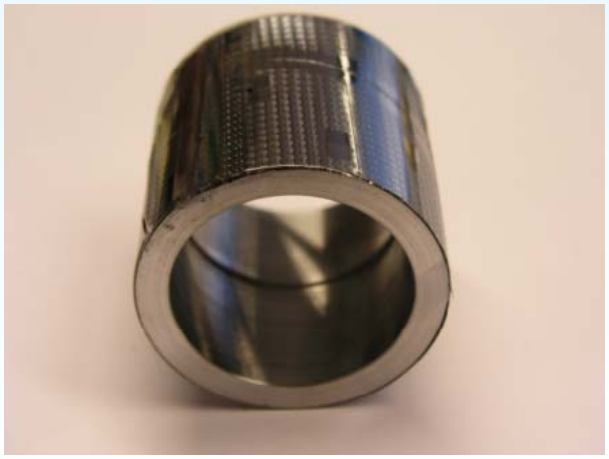
AFM image of the imprint into mr-I 8000 resist

Stamp fabrication for Roll-to-Roll imprinting

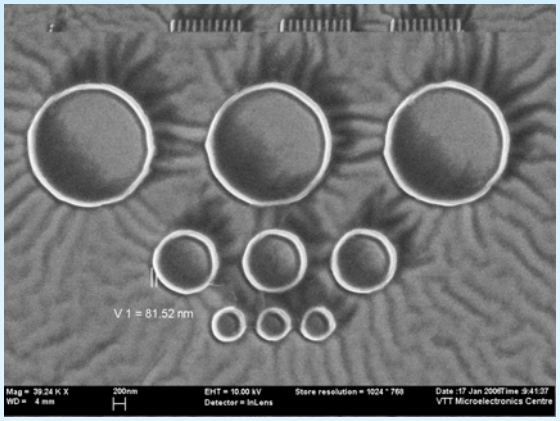


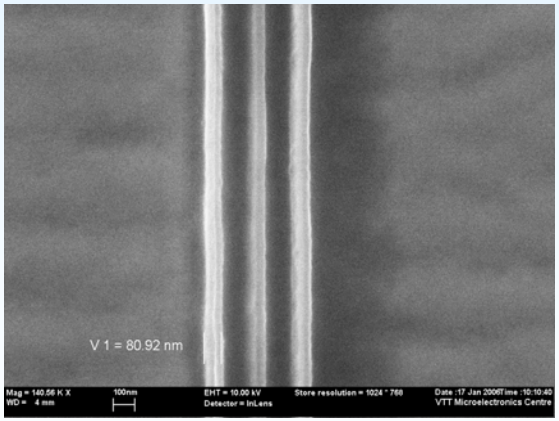
Ni stamp fabrication process





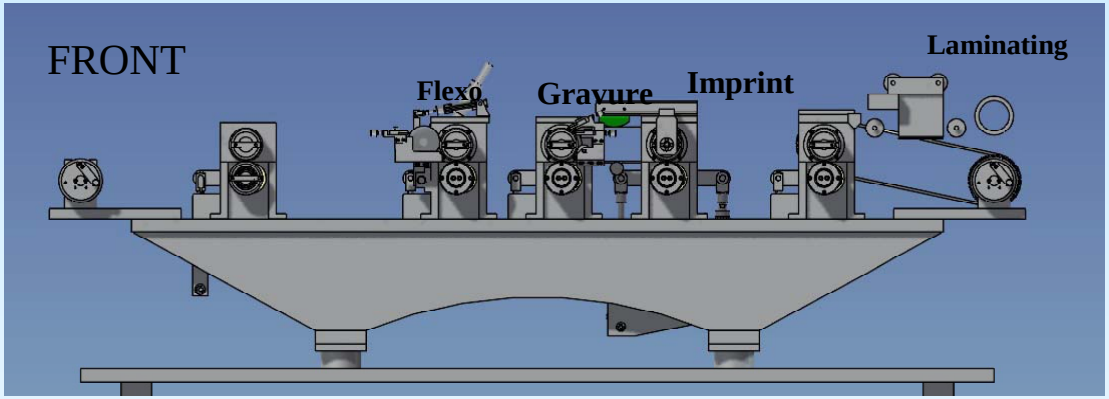
Bendable Ni stamp for RtoR

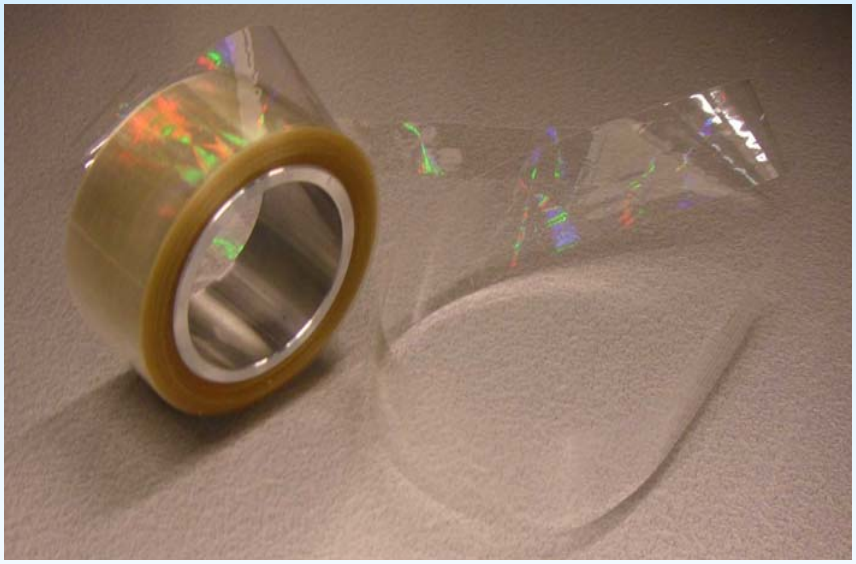




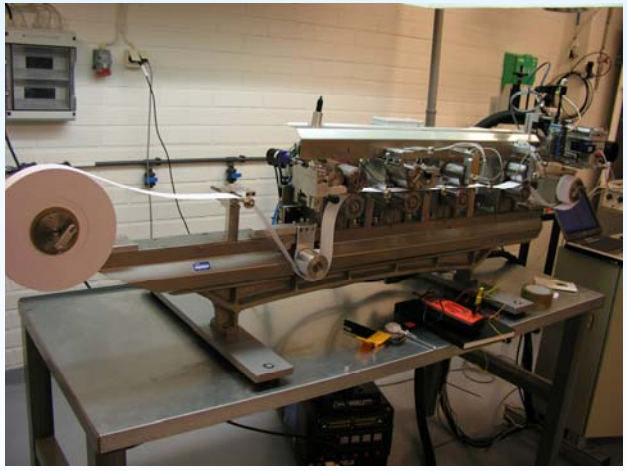
SEM image of an electroplated Ni stamp. SSIL imprinted polymer mr-I 7030 (line width ~ 80 nm)

Roll-to-Roll imprinting I





- Nanoimprinting
- Flexo
- Gravure
- Laminating
- Speed up to 20 m/min



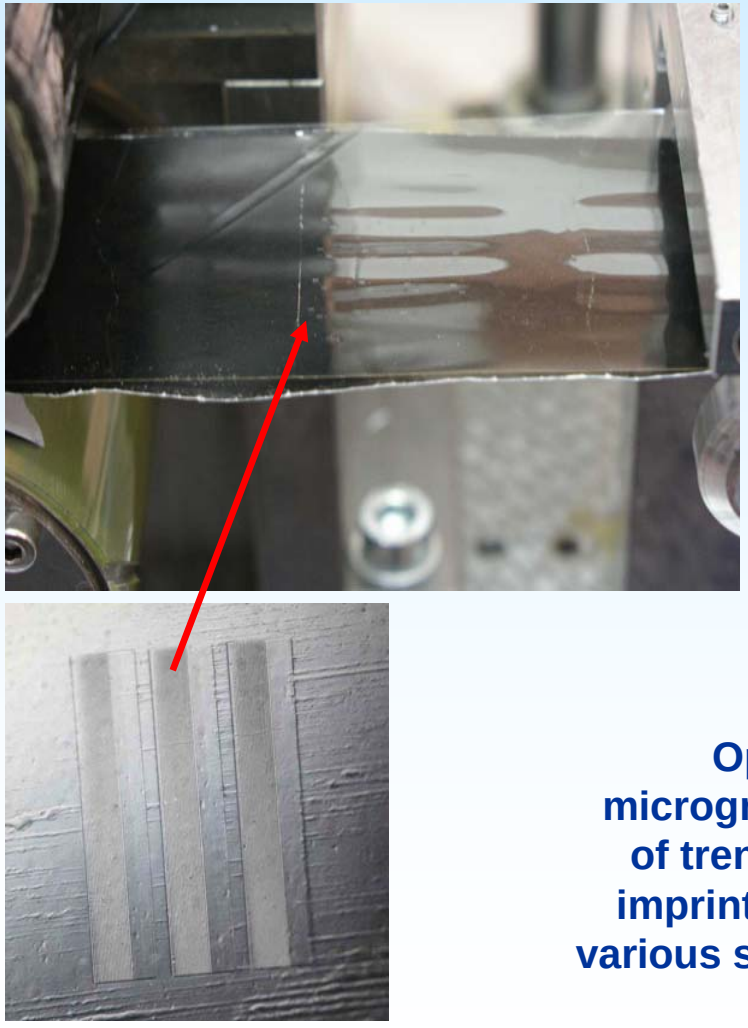
T. Mäkelä et al., VTT

Web: Cellulose acetate, width 50 mm
Speed 1 m/min
Temperature 105 °C
Pressure 5 MPa
Also: PANI-DBSA, conducting polymer

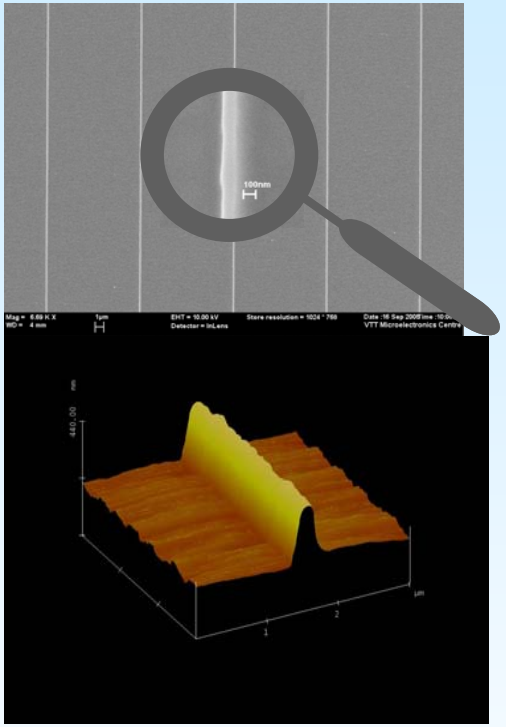
NaPa
Emerging Nanopatterning Methods

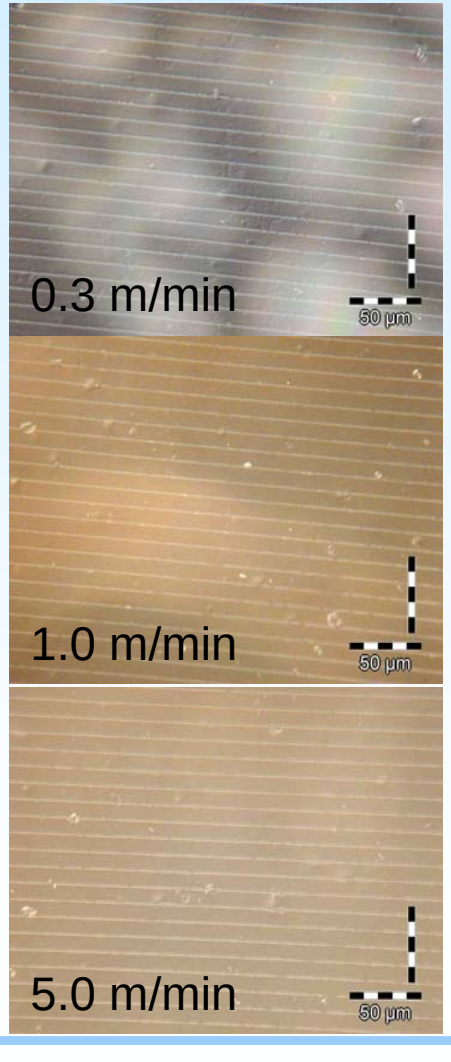
Roll-to-Roll imprinting II

Roll-to-Roll imprinted lines in cellulose acetate



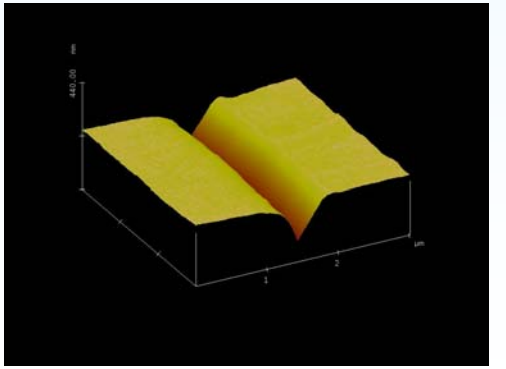
SEM and AFM image of Ni stamp with 100 nm wide and 170 nm high ridges





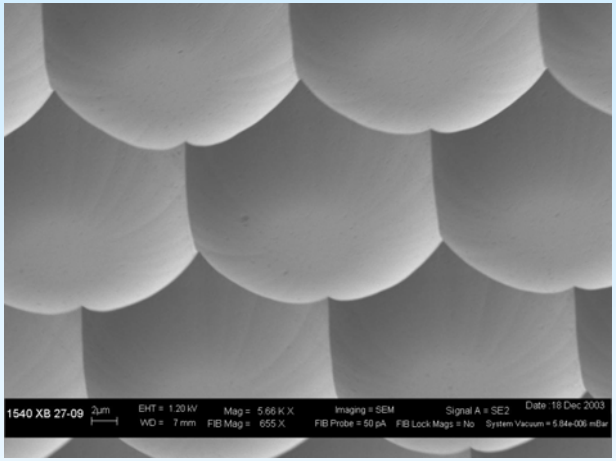
Optical micrographs of trenches imprinted at various speed

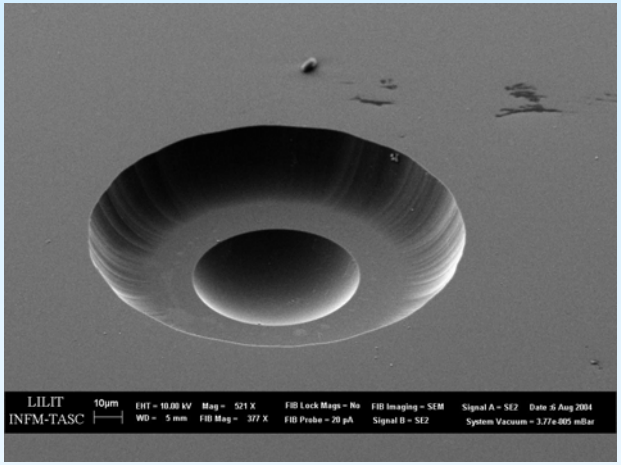
AFM image of imprinted trench

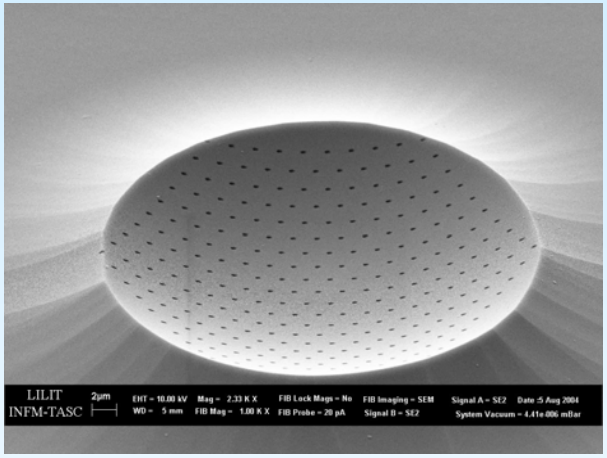


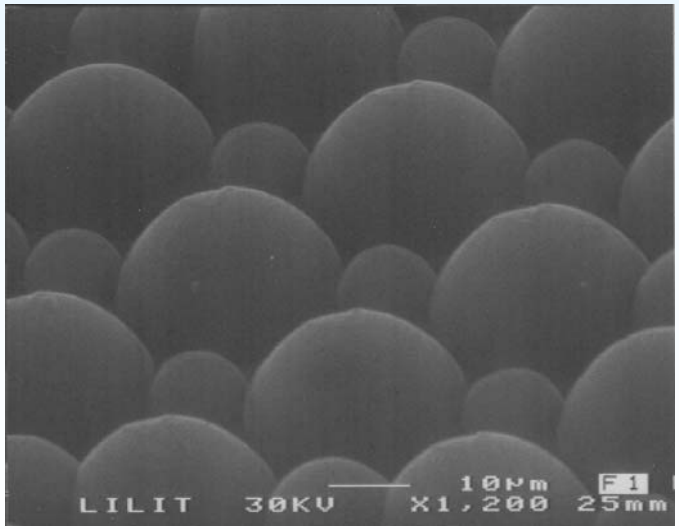
3-dimensional structures I

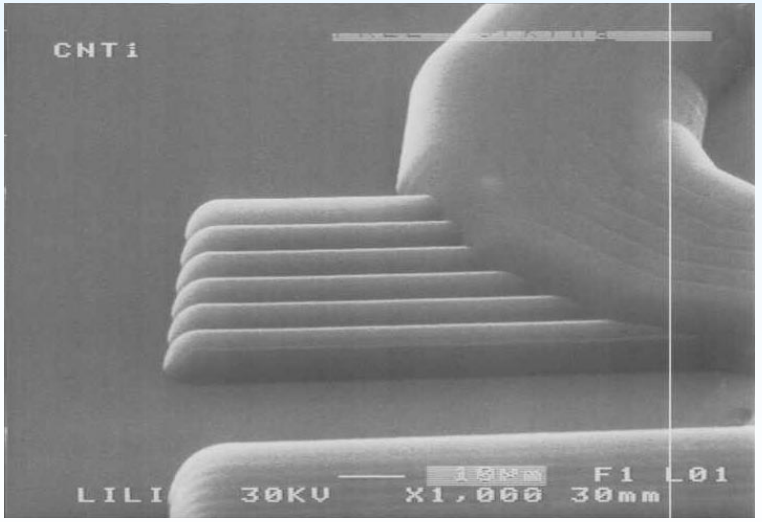
3D stamps





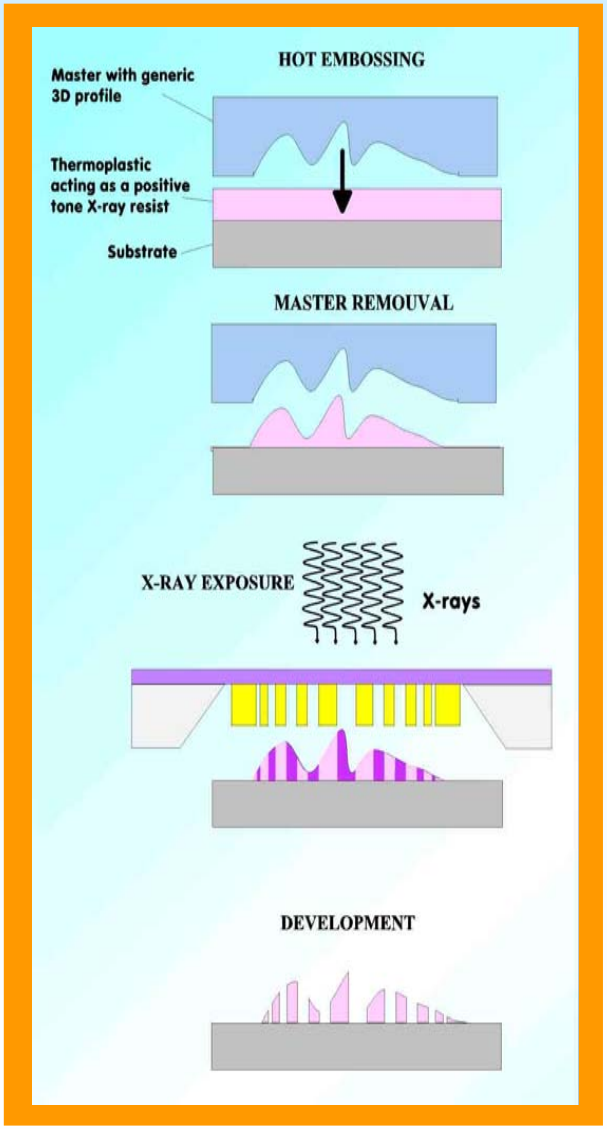


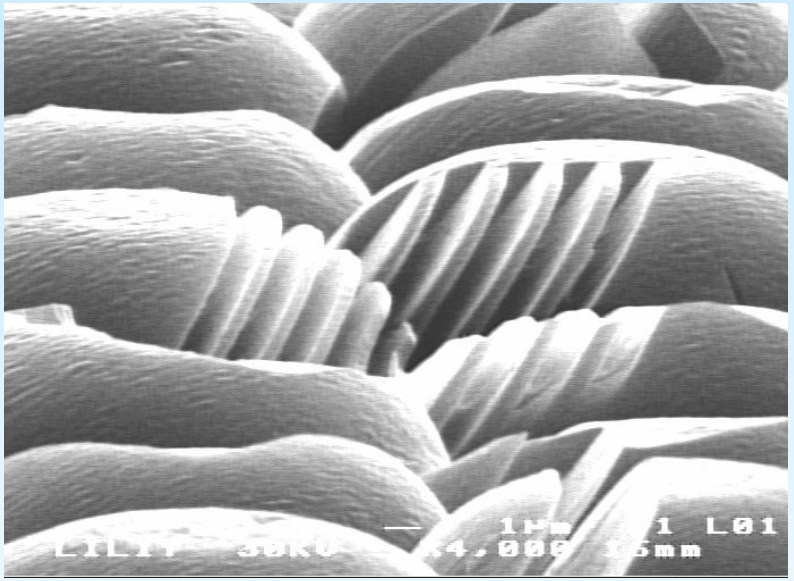


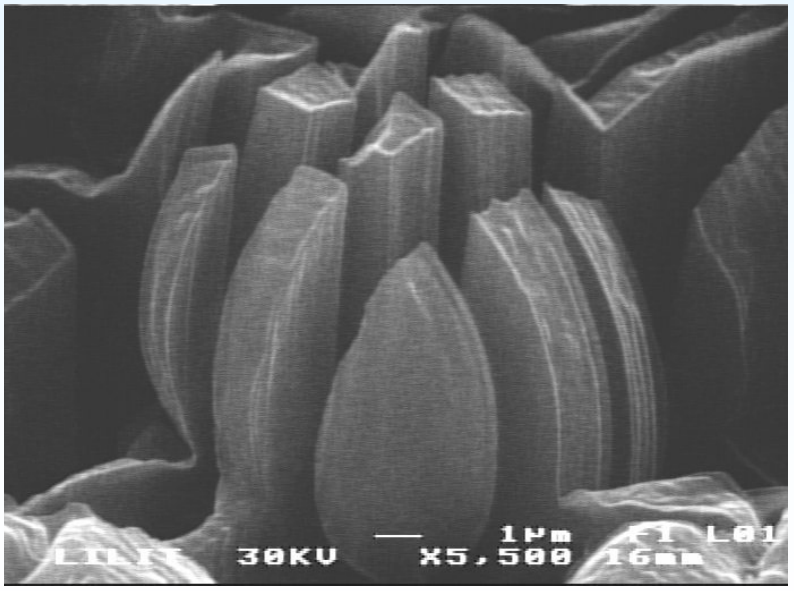


3D imprints

3-dimensional structures II



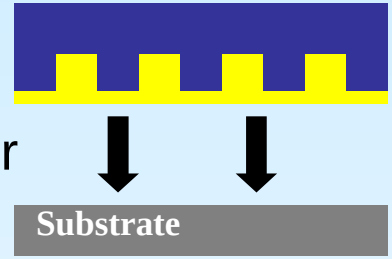




M. Tormen et al.
TASC

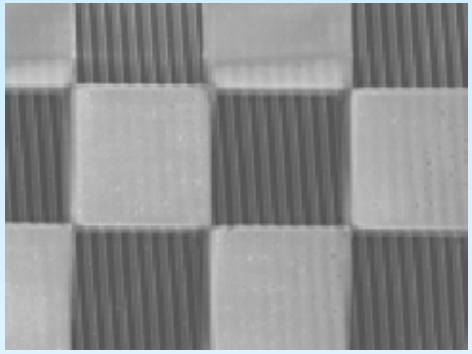
Reverse nanoimprinting for 3D structures

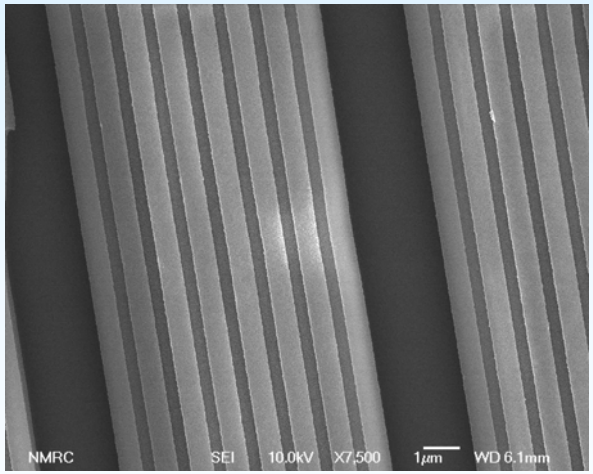
Spin coated polymer



Reverse Imprint

Separation of stamp from polymer





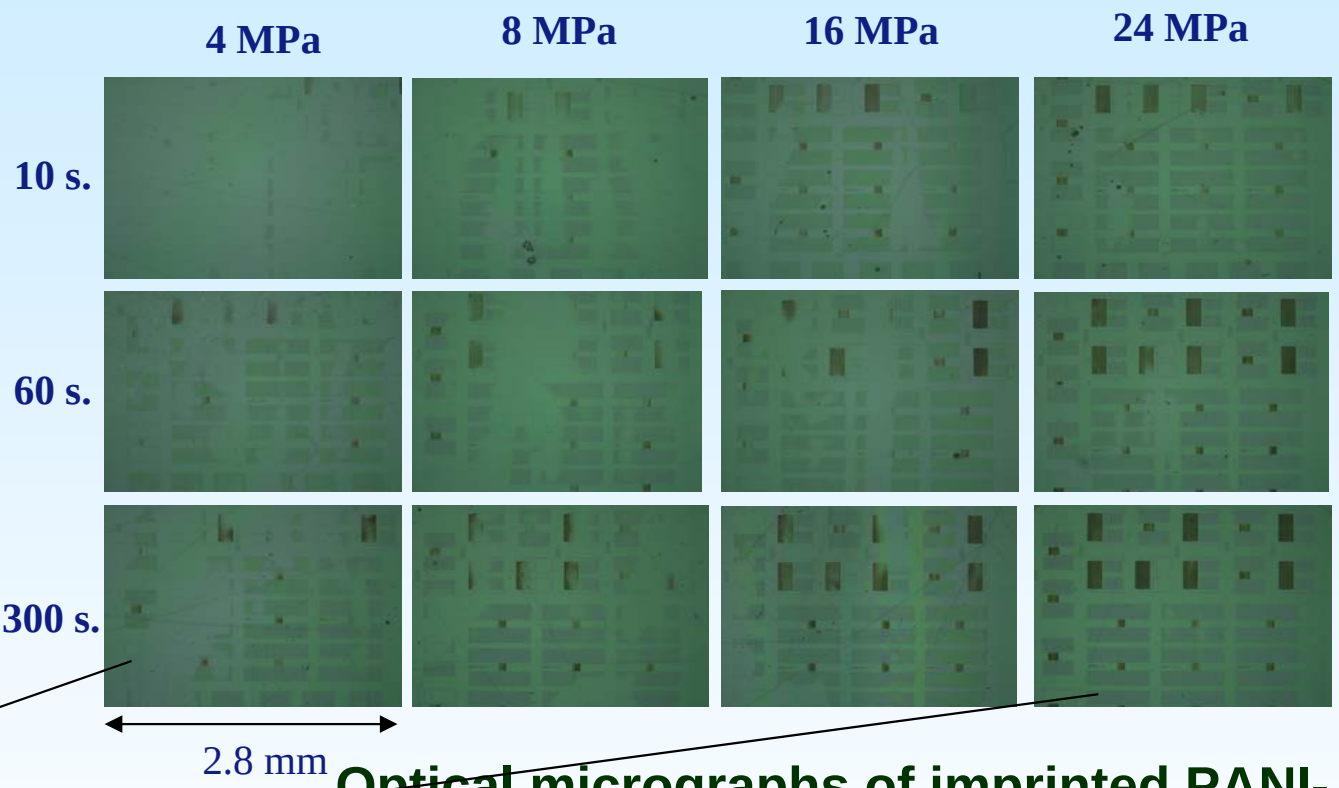
800nm pitch

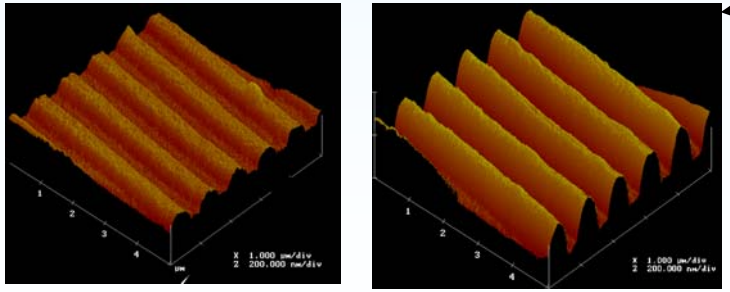
N. Kehagias et al., TNI

mr-L 6000

Imprinting of conducting polyaniline at RT

- PANI-DBSA spin coated on PET
- Si stamp, 350 line/space





4 MPa 24 MPa

Optical micrographs of imprinted PANI-DBSA structures on PET substrate. Imprinting at 24 ºC. Time was varied from 10 s – 300 s and pressure from 4 MPa – 24 MPa. The best imprint was obtained at 24 MPa with 300 s imprint time.

Assembly and transfer of ordered clusters

Assembly

Convective **Capillary**

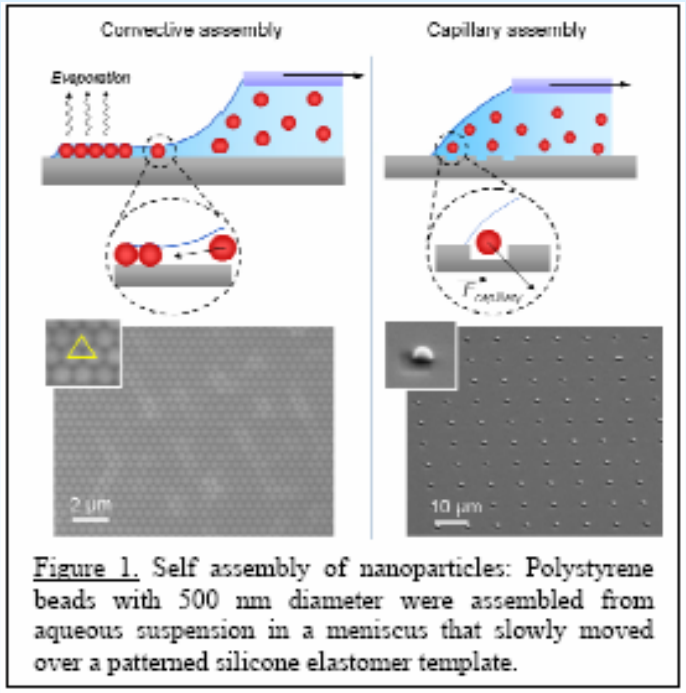
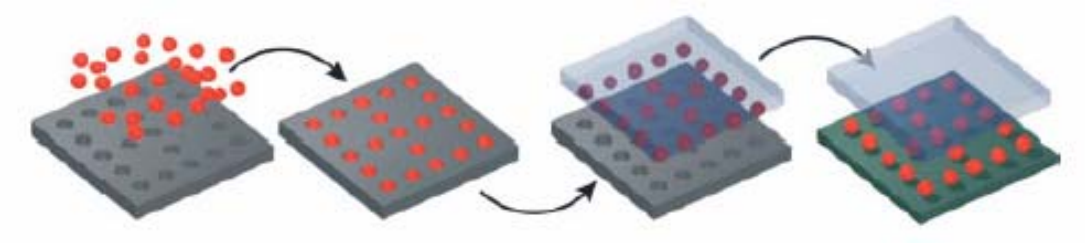
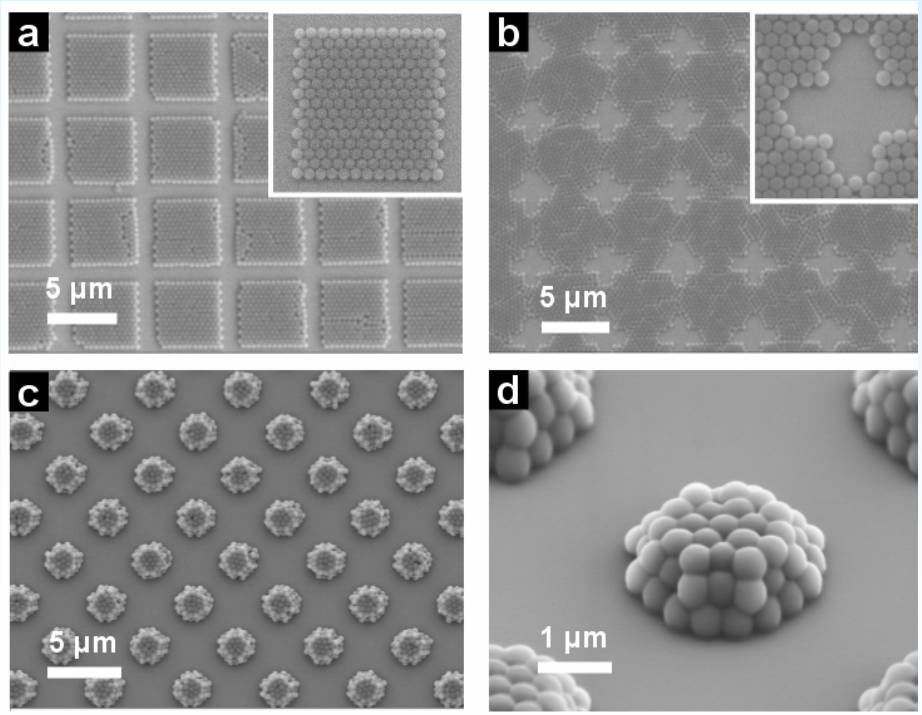


Figure 1. Self assembly of nanoparticles: Polystyrene beads with 500 nm diameter were assembled from aqueous suspension in a meniscus that slowly moved over a patterned silicone elastomer template.



Transfer to another substrate

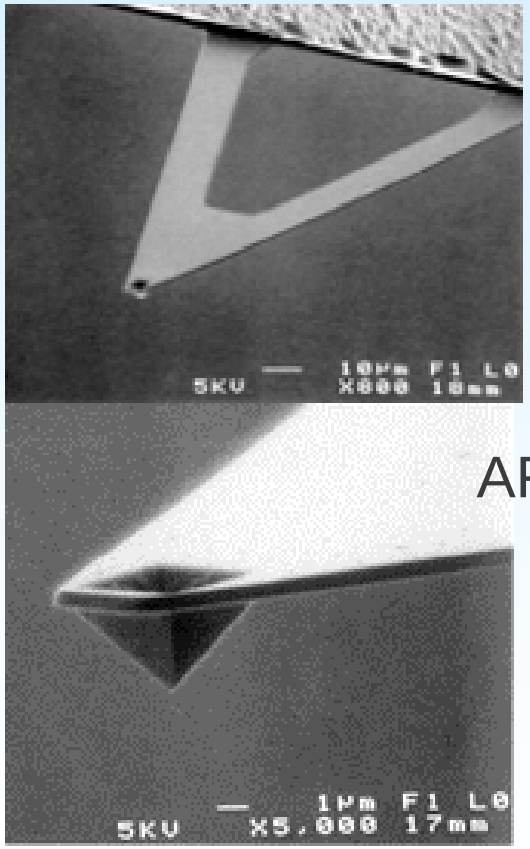


Polystyrene beads transferred onto silicon substrate

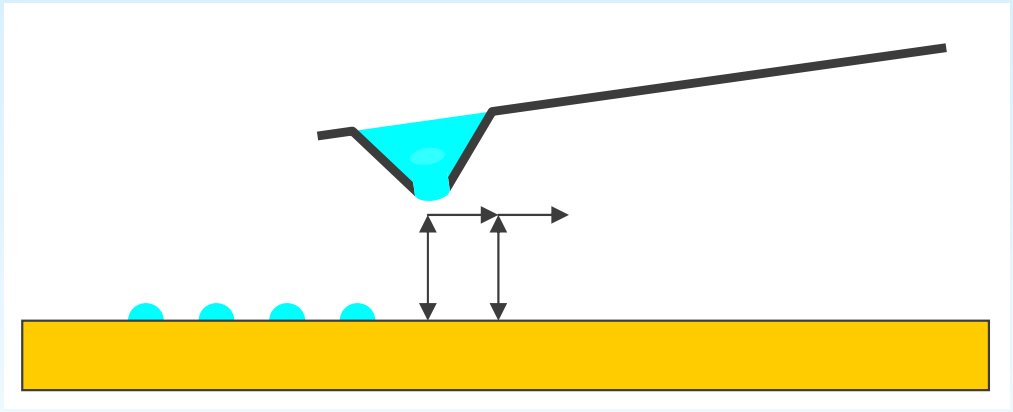
H. Wolf et al., IBM Zürich Research Laboratory

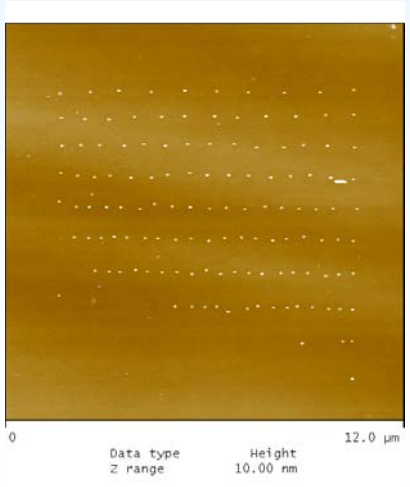
Nanodispensing

Apertured AFM probe as a miniaturized fountain pen for nanoscale dispensing (NADIS) of liquids



AFM probe

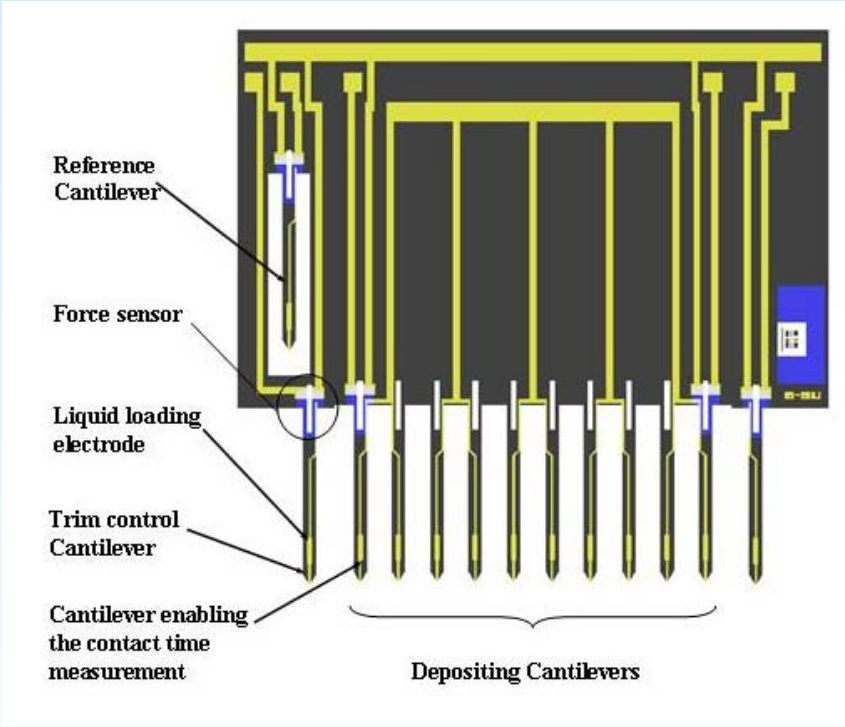


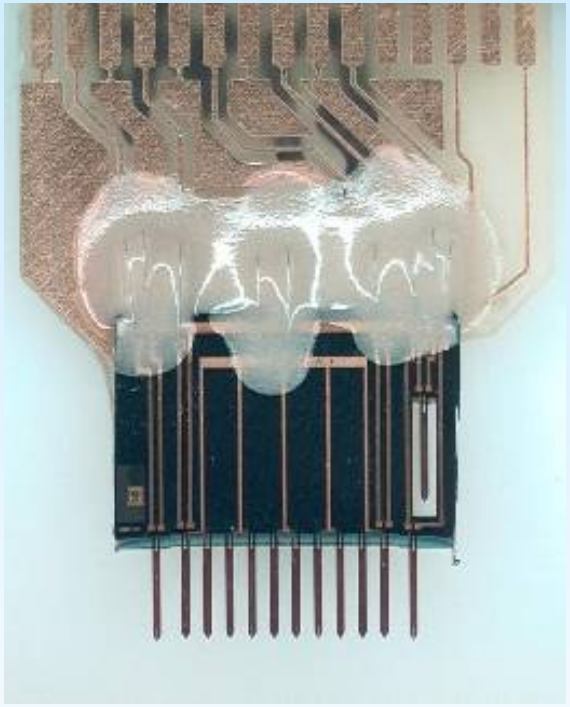


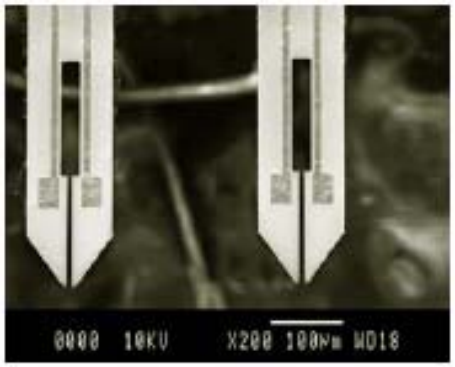
Dots spacing: 410 nm
Droplet height: 70 nm

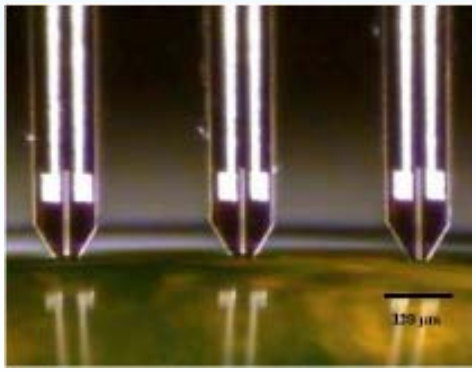
Estimated droplet volume: 5 attoliters

BioPlume

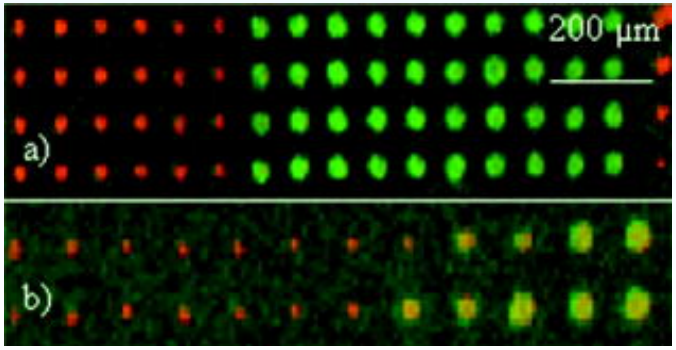








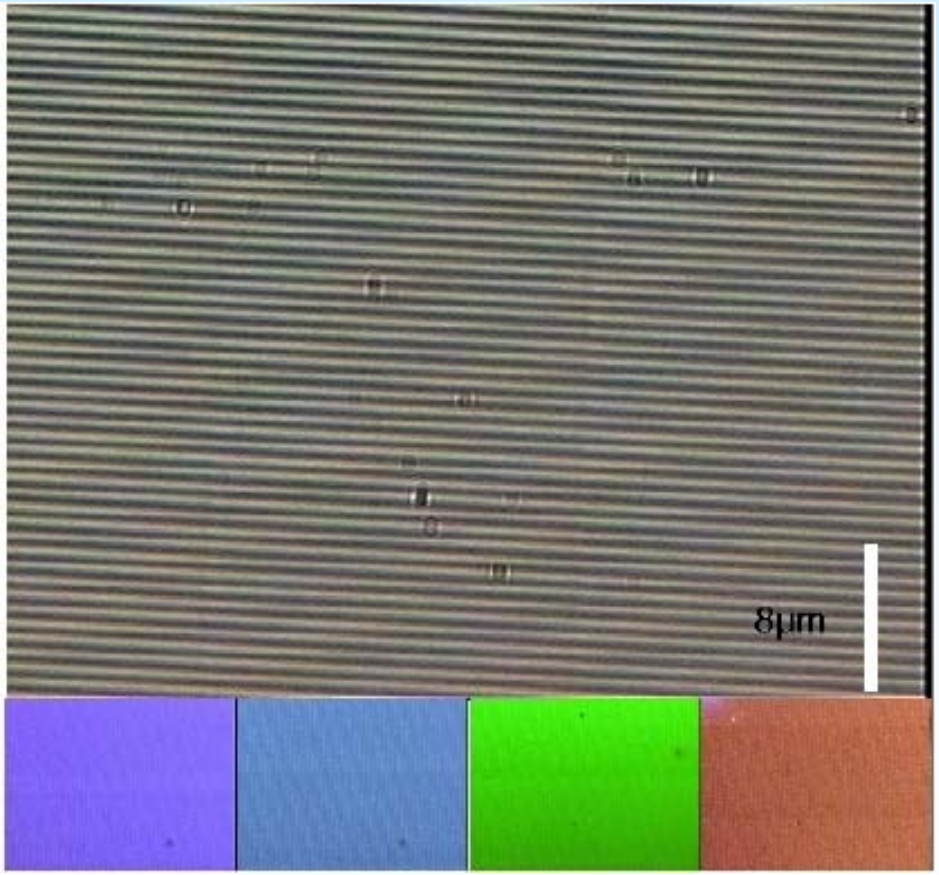
Loading by electrowetting



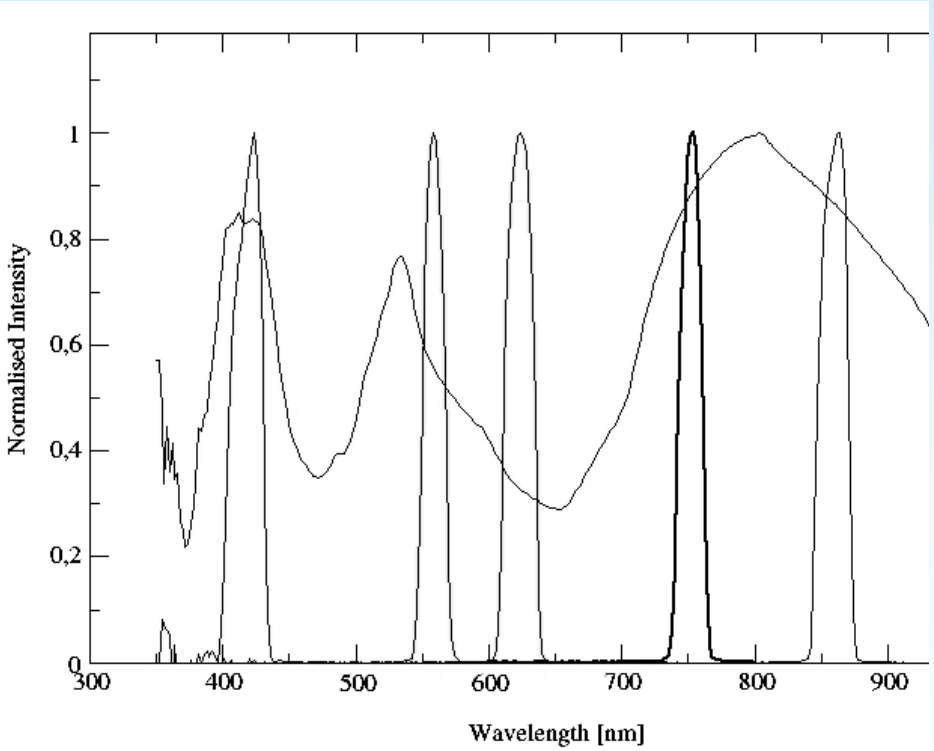
Fluorescent droplets

Examples of Applications

Gratings



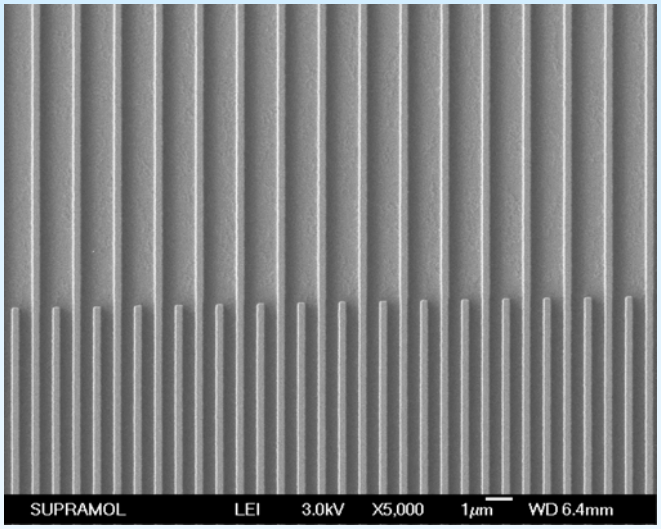
800 nm pitch

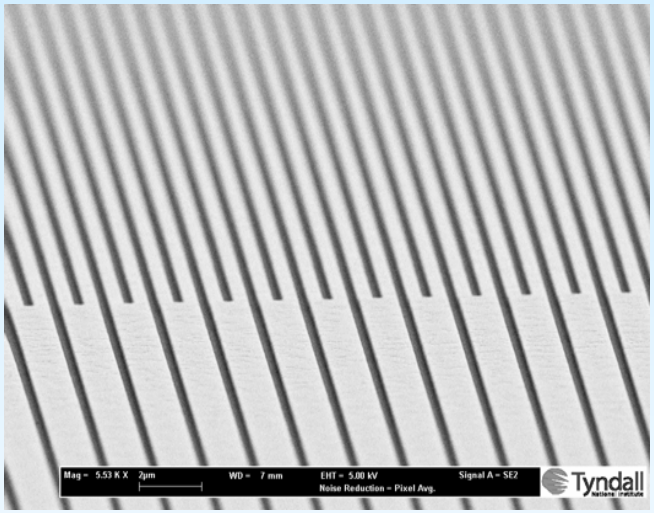


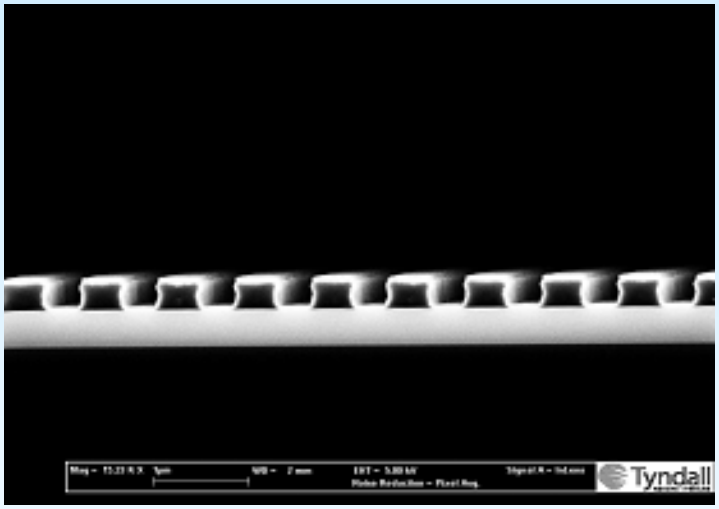
Diffraction at different angles

J. Seekamp et al., Univ. Wuppertal

Interdigitated fingers by nanoimprinting







- SEM image of silicon stamp patterned using e-beam lithography
- Ridge width 150-550 nm
- Anti-adhesive treatment

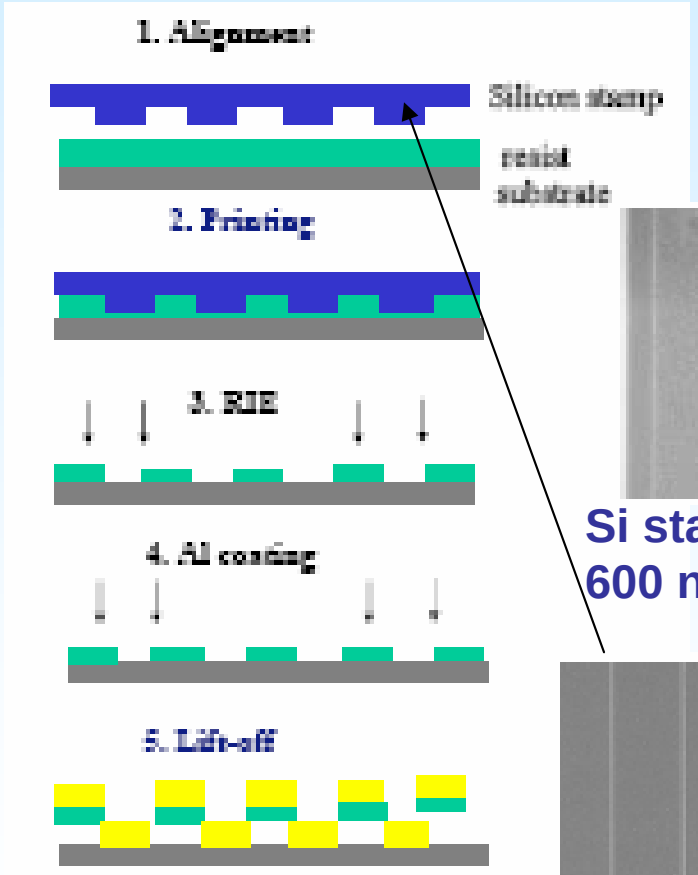
- Imprint in 75K PMMA
- T=170 °C, p=60 bar, t=5min

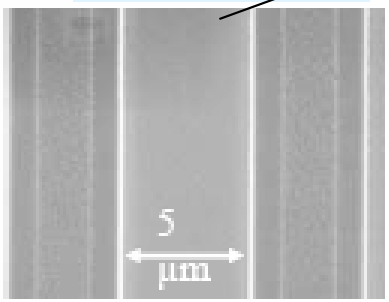
Cross-section after removing the residual layer

N. Kehagias et al., TNI

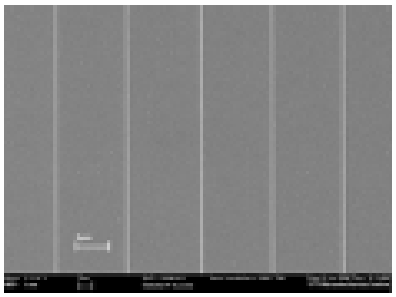
Step&Stamp Nanoimprinting

Interdigitated fingers with different workfunctions

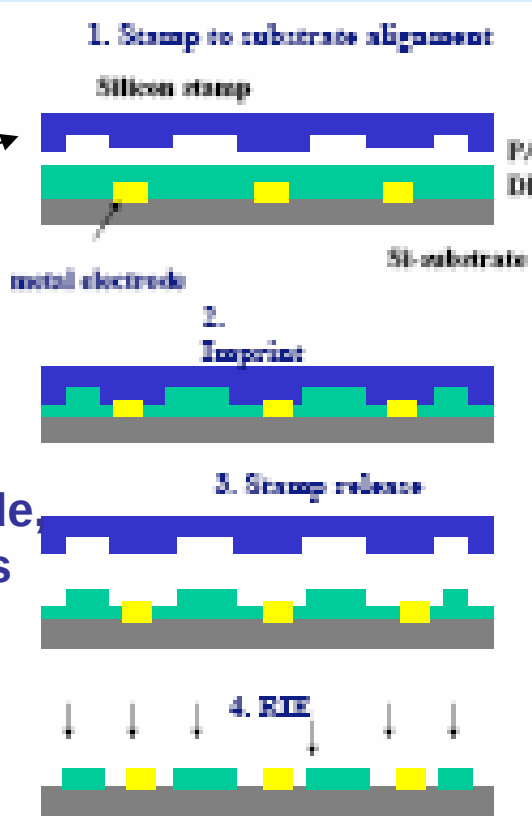




Si stamp, 5 um wide, 600 nm high ridges

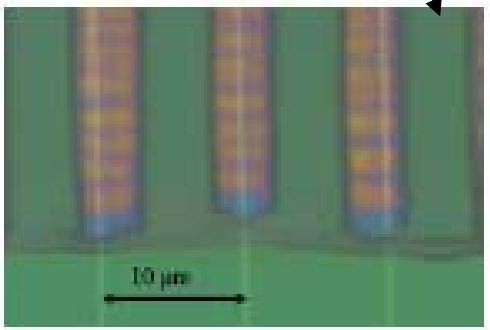


Si stamp with 100 nm wide, 300 nm high ridges



PANI-DBSA

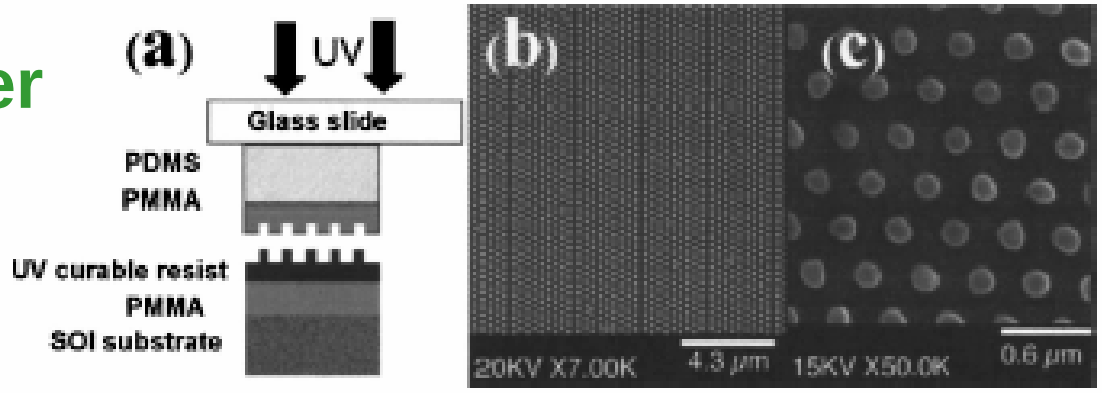
Al wires



T. Haatainen et al., VTT

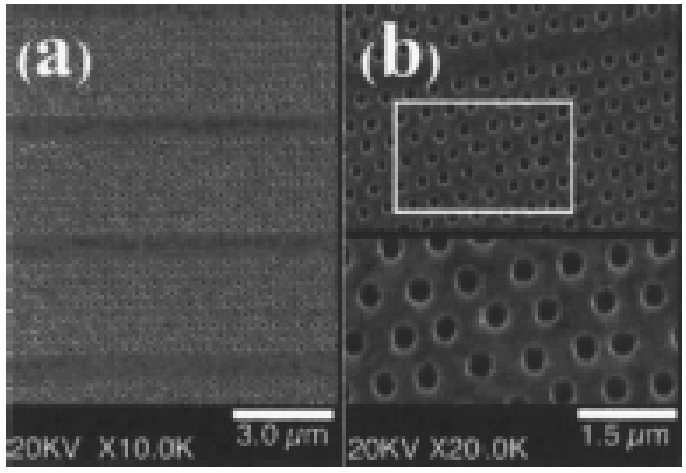
Replication of photonic crystals by soft UV NIL

Tri-layer stamp



Pattern transferred into PMMA

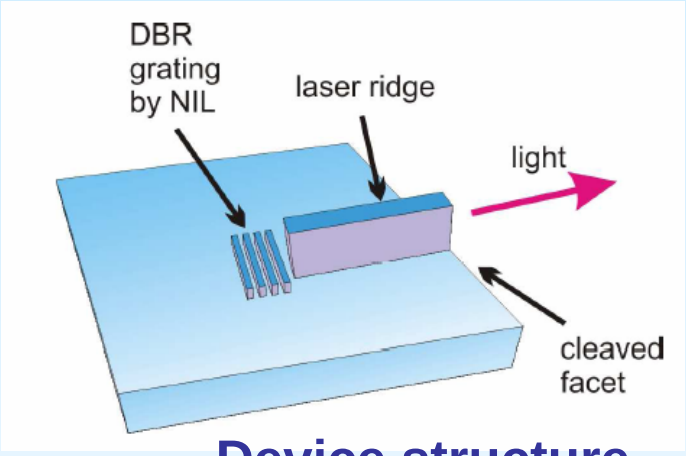
Ni lift-off and dry etching



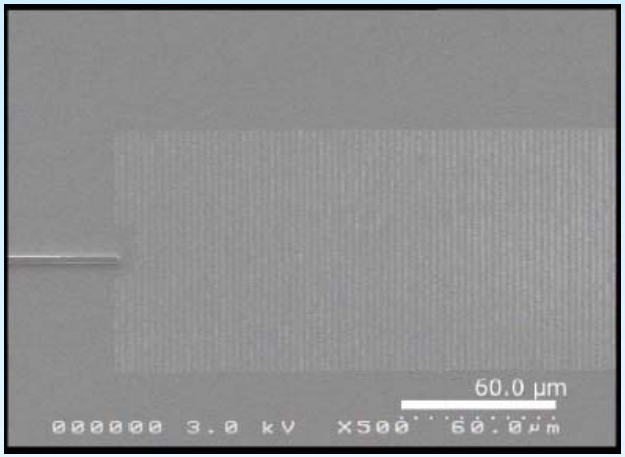
PhC in 260 nm thick SOI

M. Belotti et al., CNRS

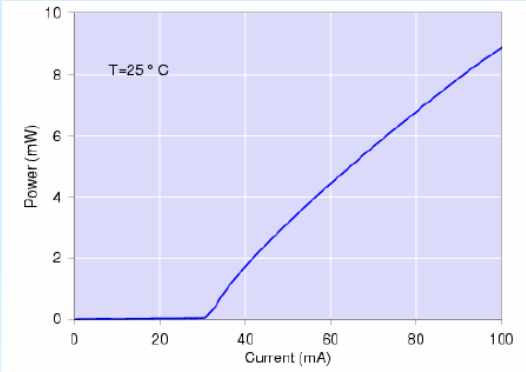
DBR Laser Diode



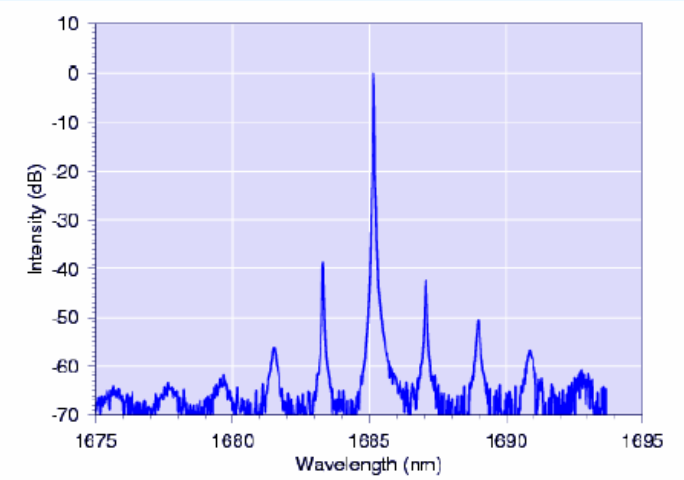
Device structure



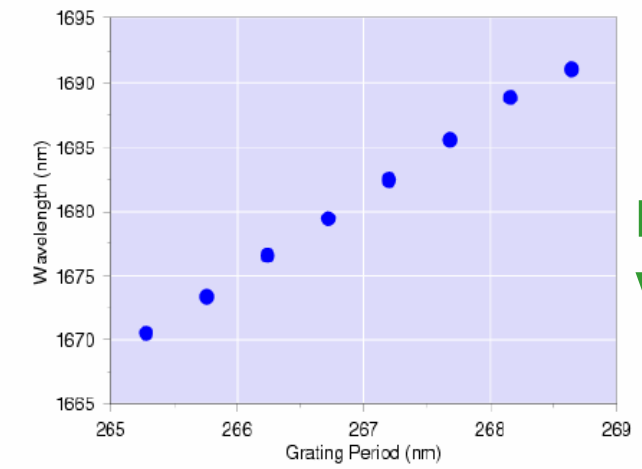
Cr grating by imprinting and lift-off, ~270 nm period, 85 nm linewidth



CW operation at RT

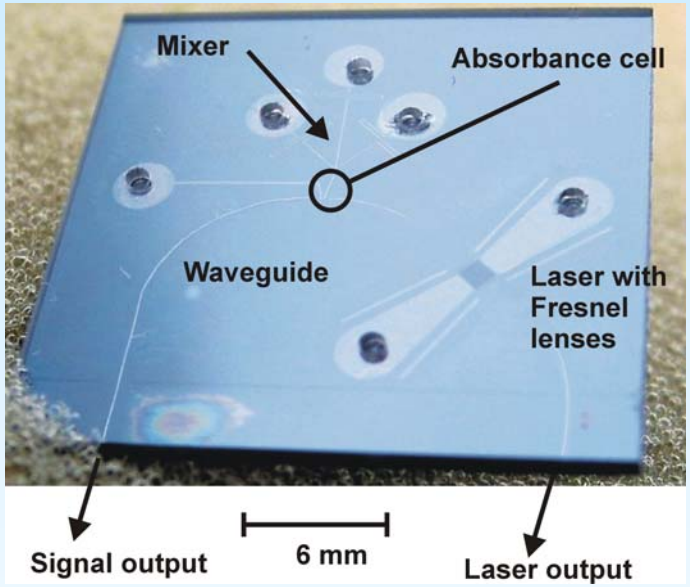


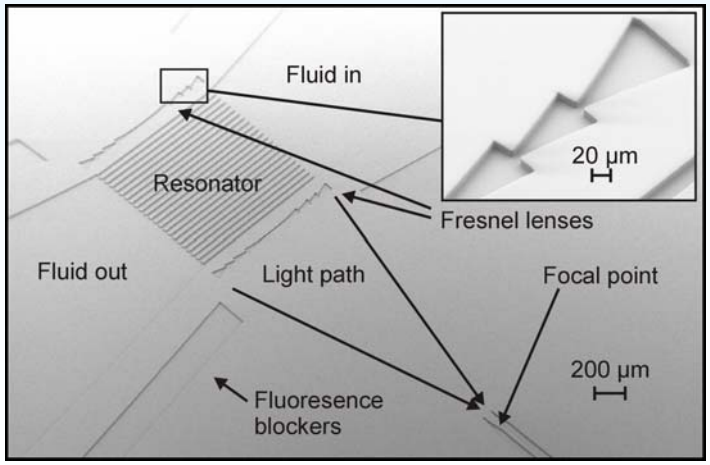
Side mode supression ~40 dB



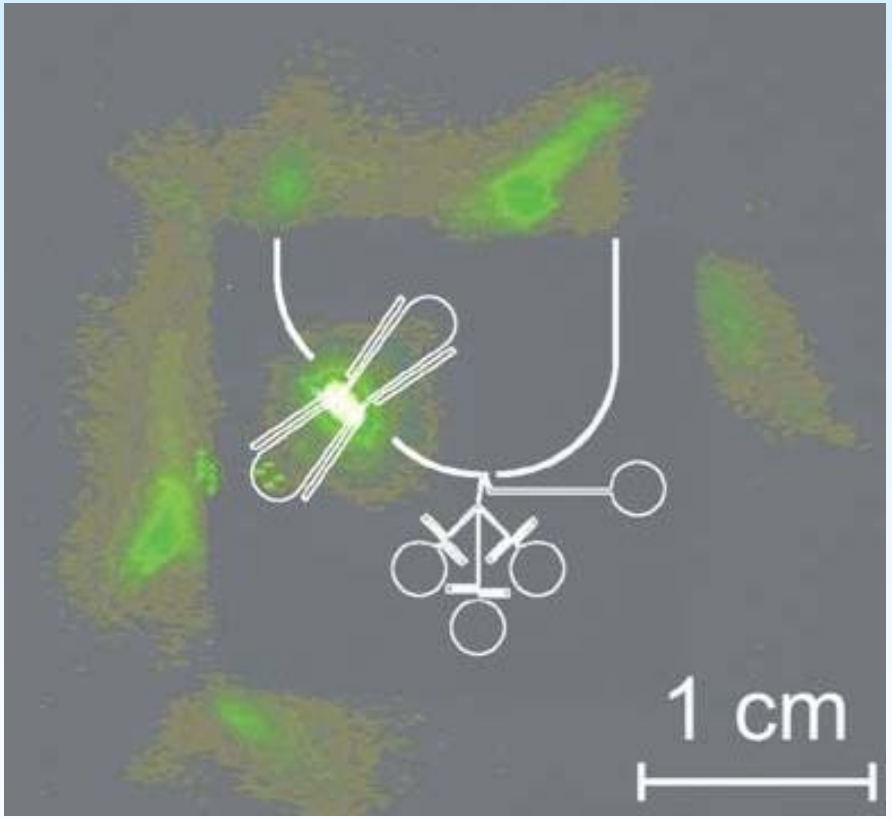
Emission wavelength vs. grating period

Bio-chip with different functions integrated



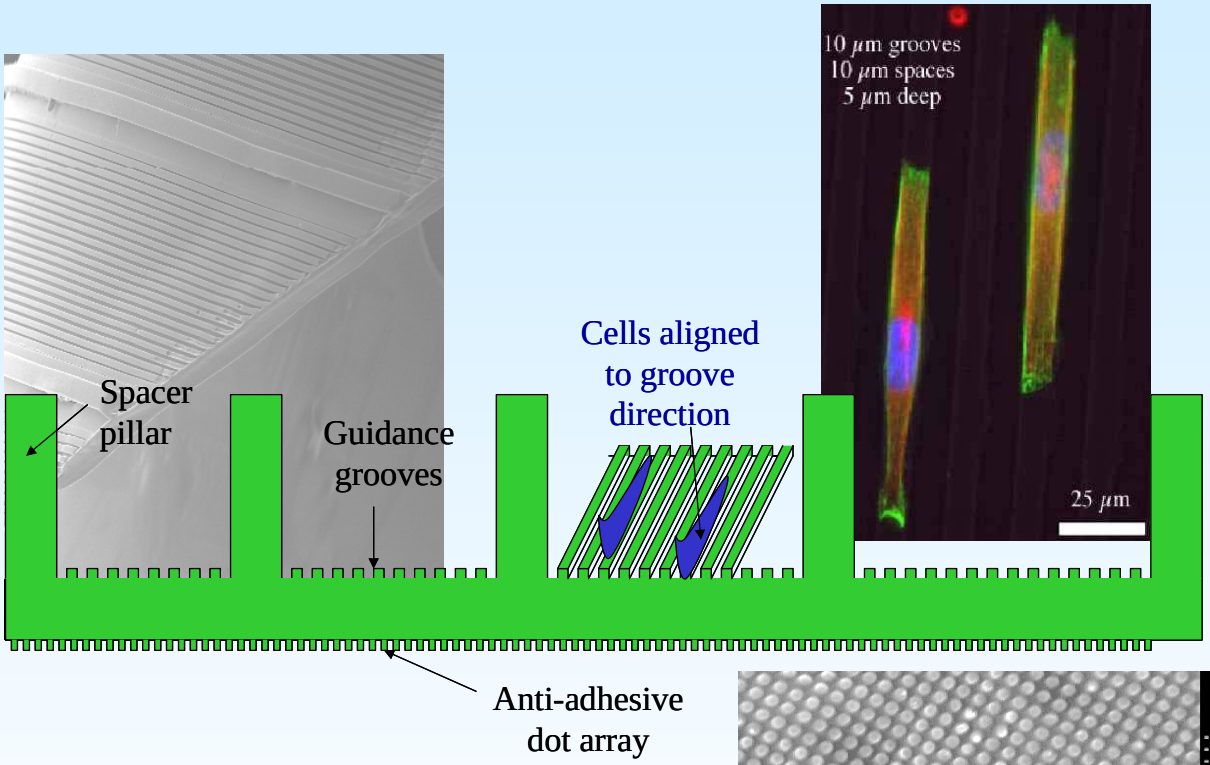


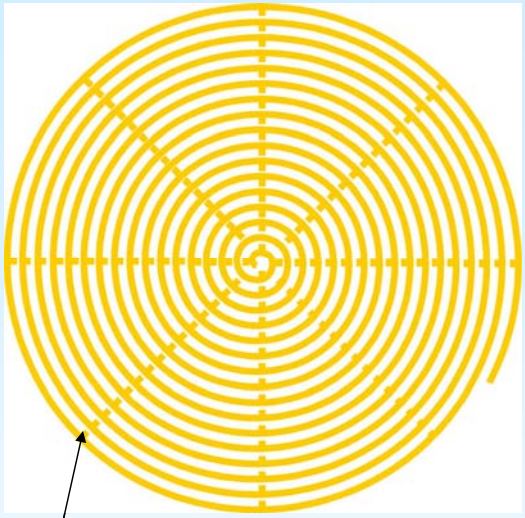
One imprint step into Topas®

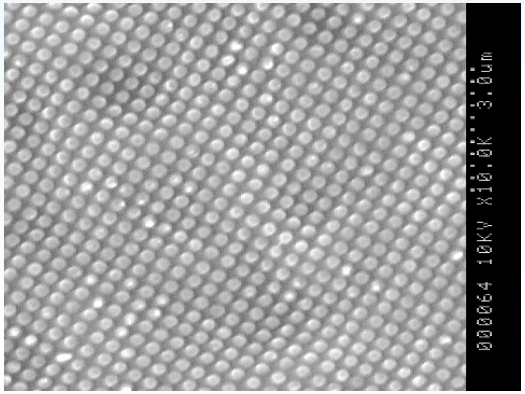


A. Kristensen et al., MIC/ DTU

3-D patterning for cell implants





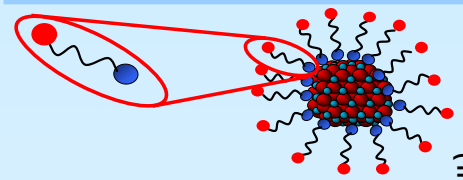


Sheet of biodegradable polymer (poly-caprolactone) embossed on both sides

The embossed sheet rolled up into a spiral. The cells are aligned by the grooves along the direction of the axis of the ‘Swiss Roll’.

C. Wilkinson et al., Univ. Glasgow

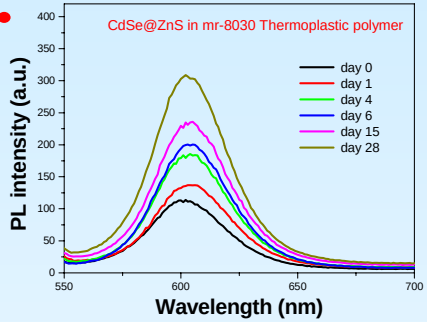
Functionalised polymers



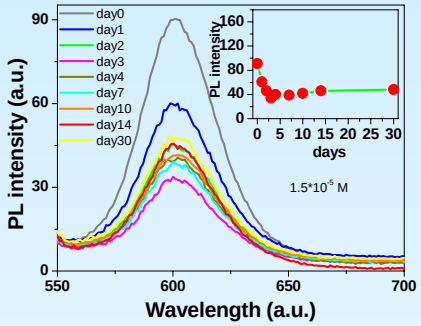
Functionalisation of thermoplastic polymers by incorporation of luminescent NCs

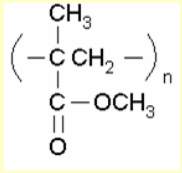
in collaboration with mrt

NCs in mr-8030

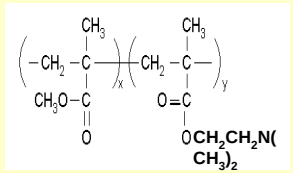


NCs in mr-L 6000.3

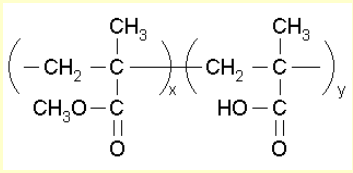




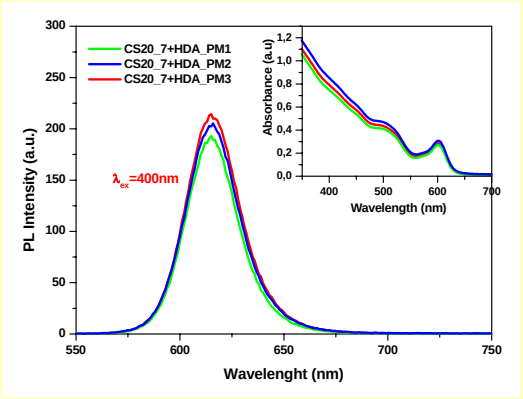
PM1



PM2

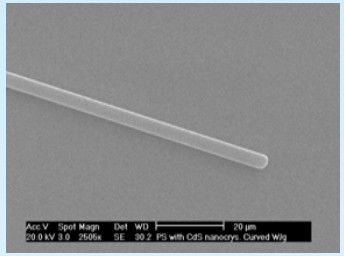


PM3



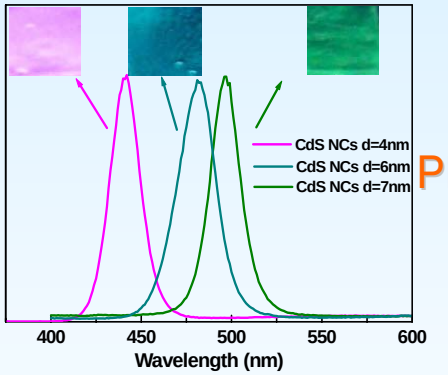
NC incorporation in PMMA Co-polymers

in collaboration with CIDETEC



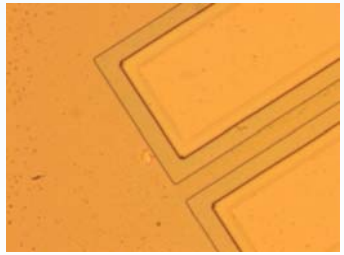
PS

Imprinted polystyrene ridge containing CdS NCs (in collaboration with Tyndall)



PMMA

Luminescent CdS NCs in PMMA



TOPAS

CdSe@ZnS NCs in TOPAS: imprinted laser ridges (in collaboration with MIC)

M Curri et al.,CNR-IPCF

NaPa
Emerging Nanopatterning Methods

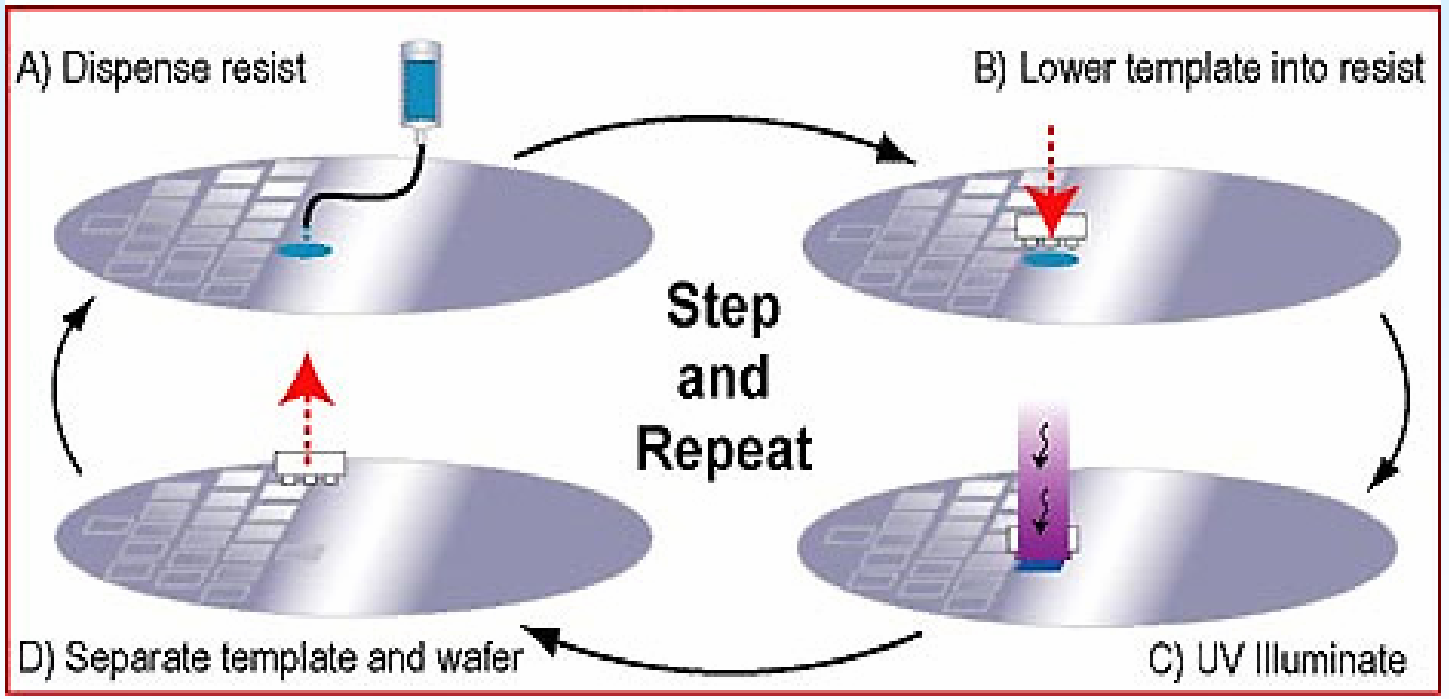
Summary

- **Emerging patterning/fabrication methods are being developed in NaPa:**
  - **Nanoimprinting (thermal/UV)**
  - **Soft lithography**
  - **Self-assembly**
  - **Nanodispensing**
  - **Nanostenciling**
  - **Materials**
  - **Tools**
  - **Simulation tools**
- **High potential for low cost and high throughput production ⟵ Processes/Library**
- **New applications**

Acknowledgements

NaPa consortium

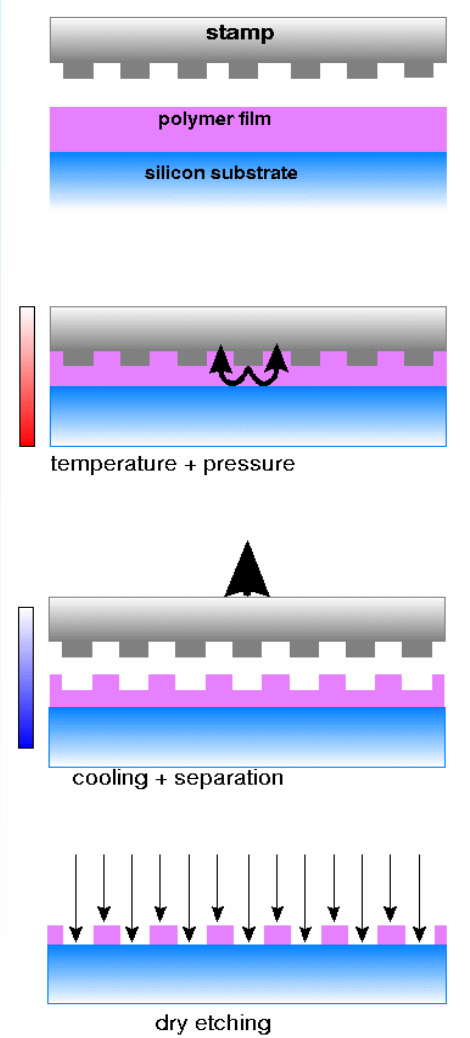
European Commission
(Grant NMP4-CT-2003-500120)



[Molecular Imprints Inc.]

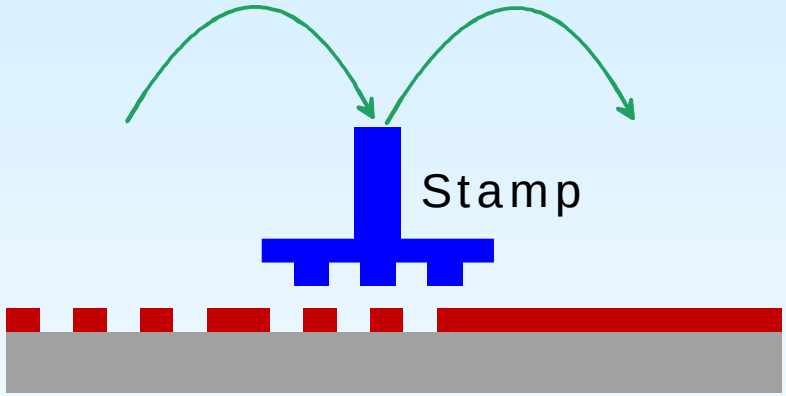
Step&Stamp Nanoimprinting (VTT)

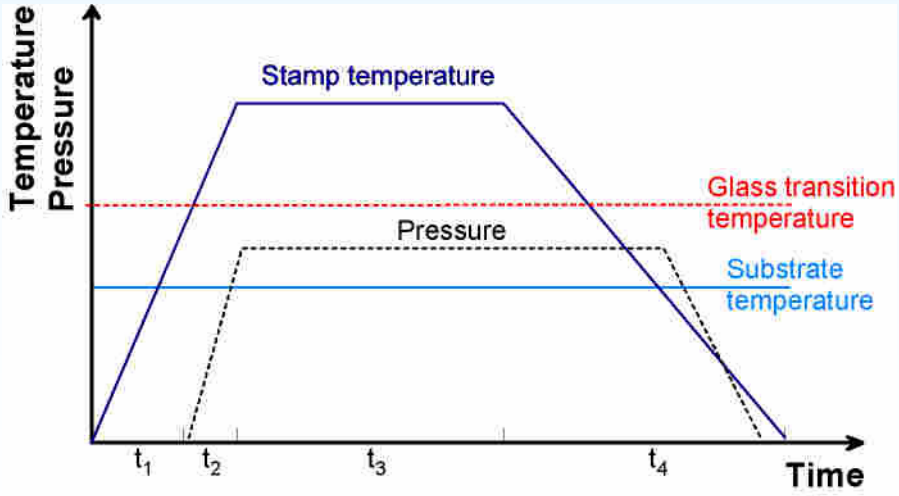
Parallel

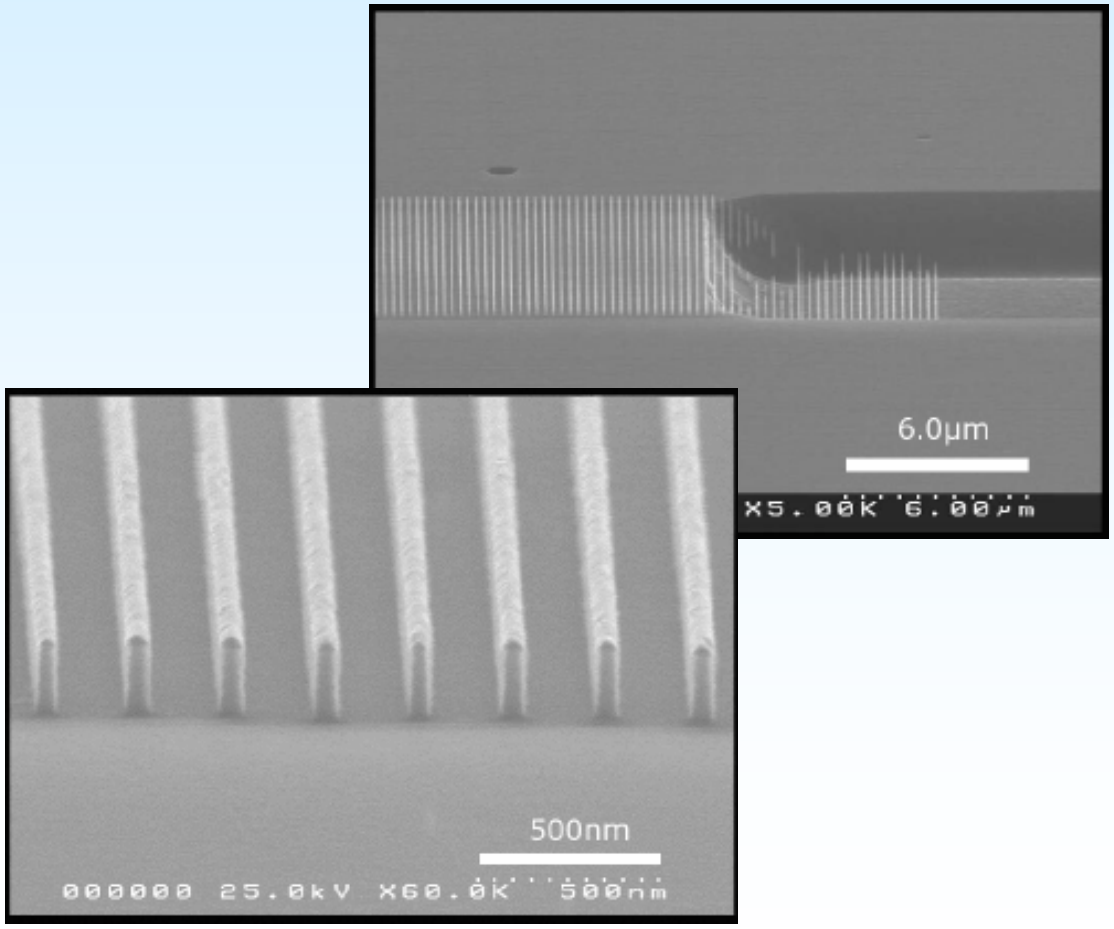


Sequential

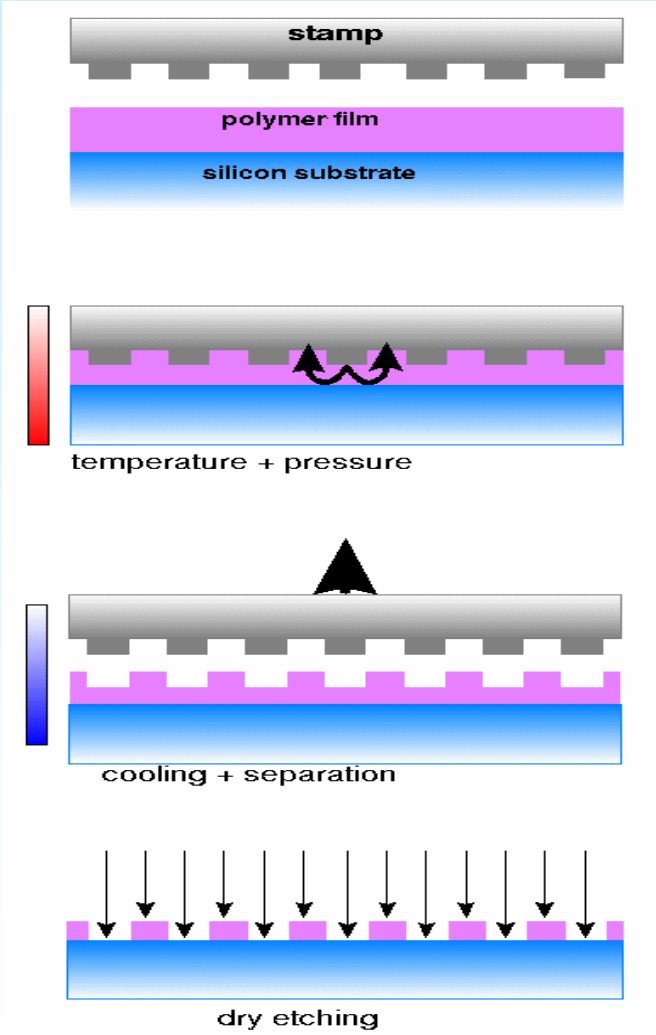
Step&Stamp imprinting



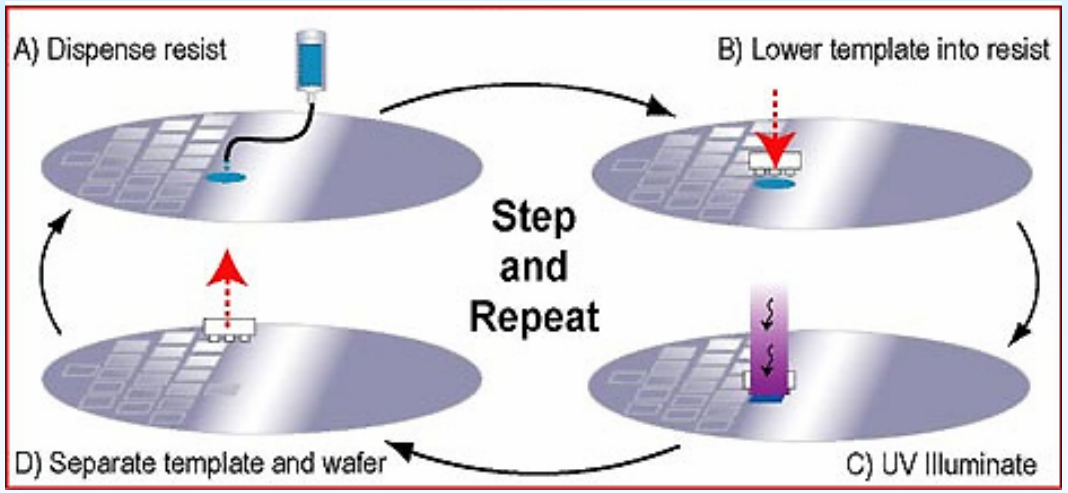



6.0µm
X5.00K 6.00µm
500nm
000000 25.0kV X60.0K 500nm

Nanoimprinting lithography



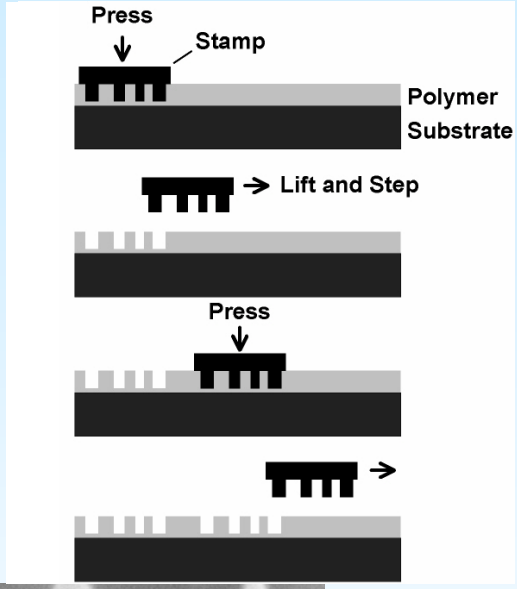
Thermal NIL

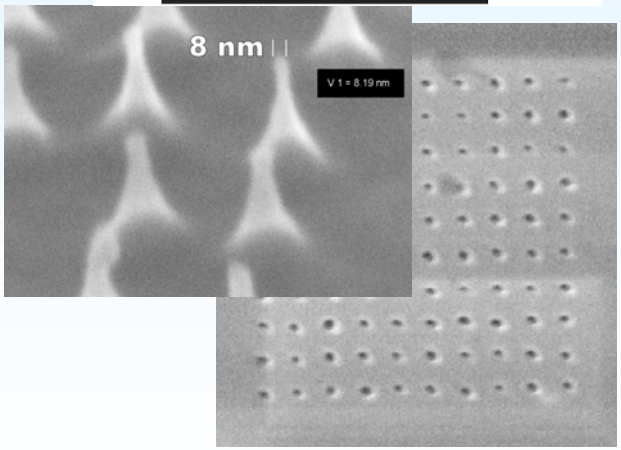


[Molecular Imprints Inc.]

UV-NIL

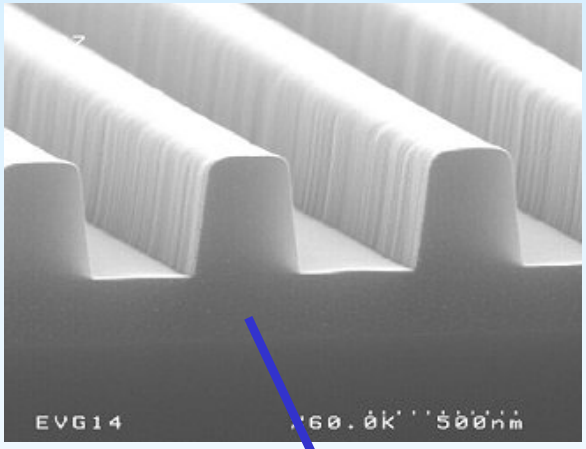
NIL variants

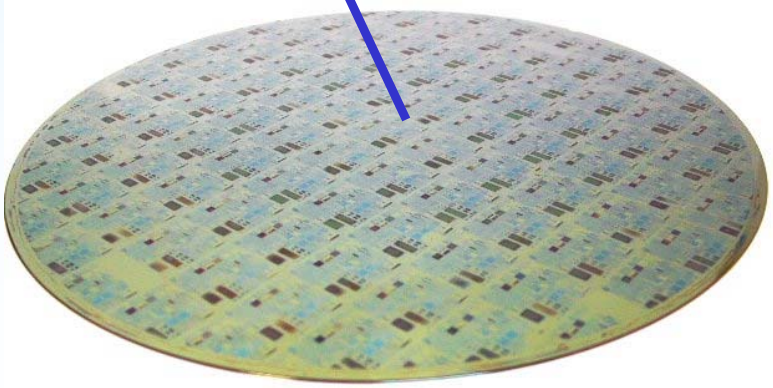




Step&Stamp

NIL on 200 mm wafer

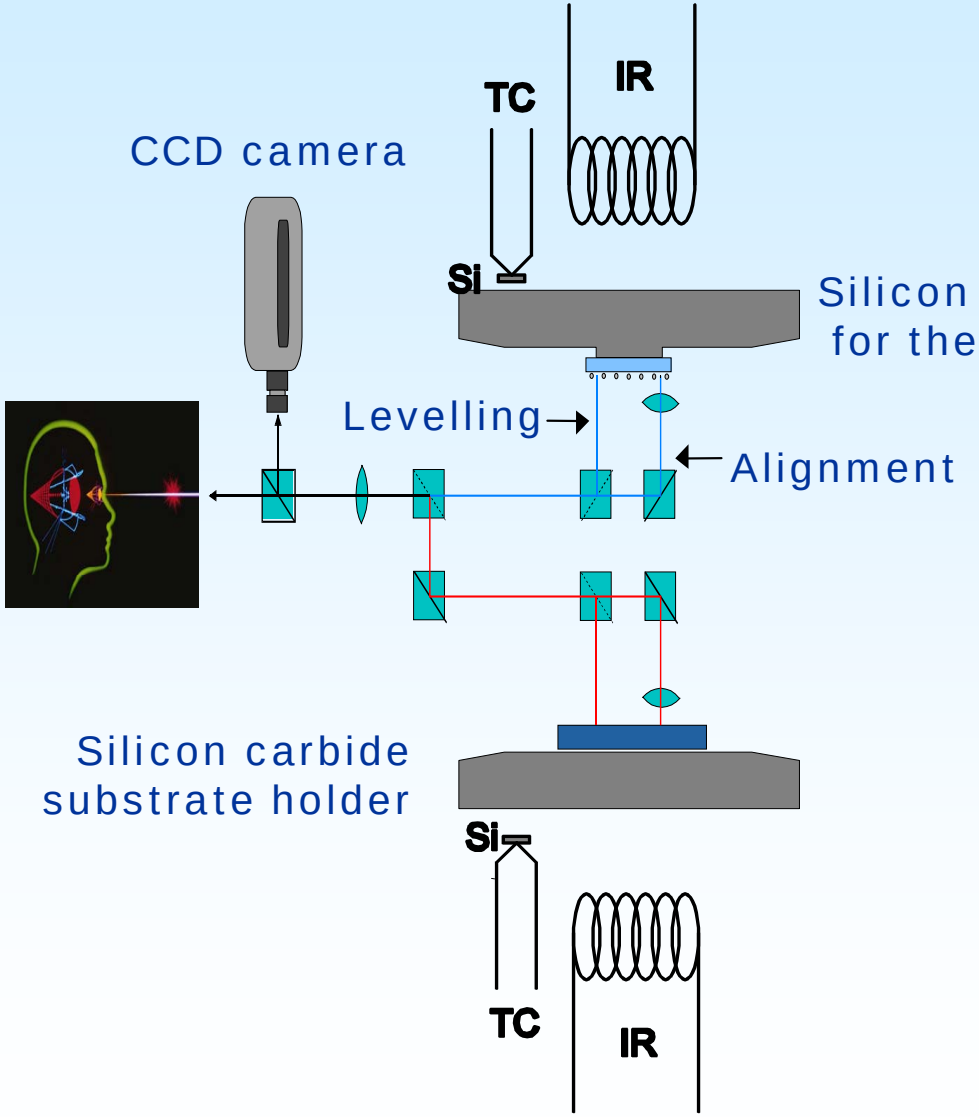




Roll-to-roll

C. Gourgon, CRNS

Step&Stamp Nanoimprinting (VTT)

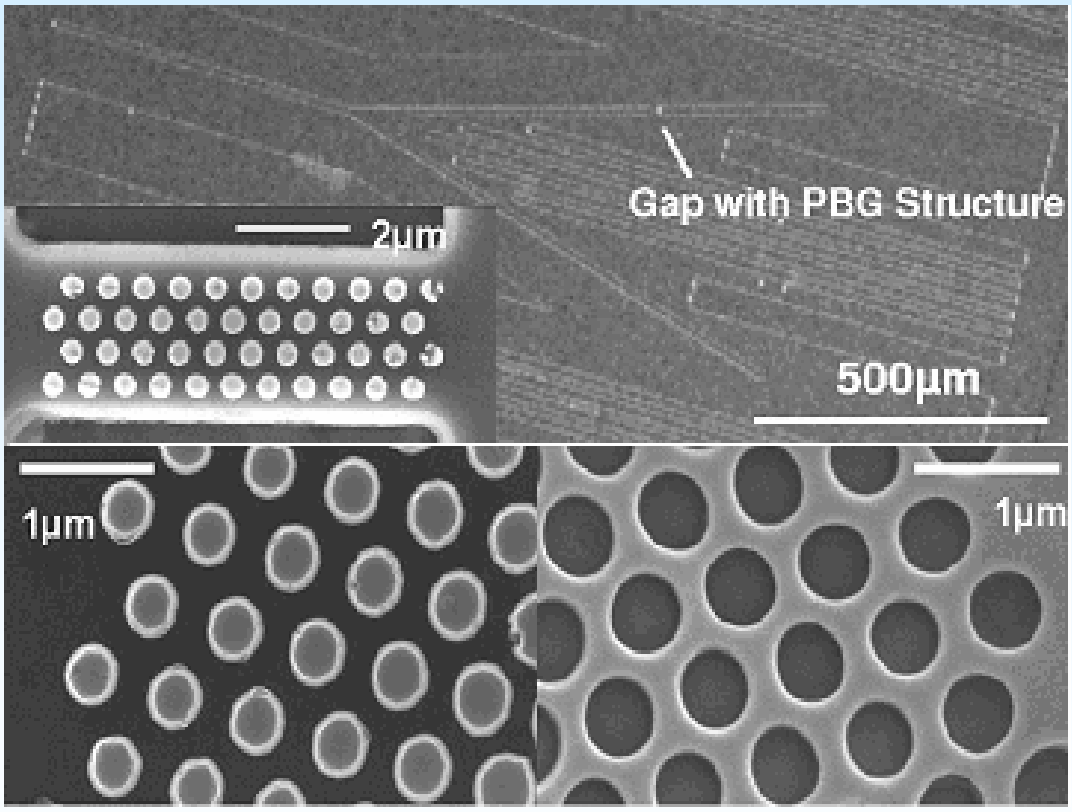


- Stamp attachment with silicone adhesive
- IR shielding by Al coating

Karl-Suss FC150 flip-chip bonder

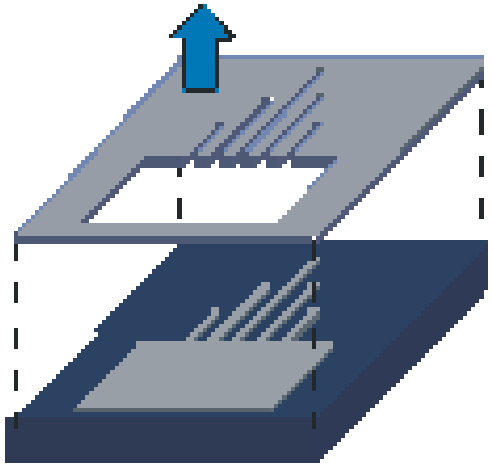
PBG structures: example

- Mix-and-match stamp for a Y branch structure with a photonic crystal in the upper arm
- Imprint made into 400 nm thick PMMA on SOI

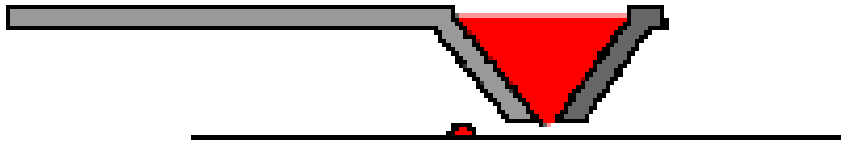


MEMS based nanopatterning

MEMS based nanopatterning



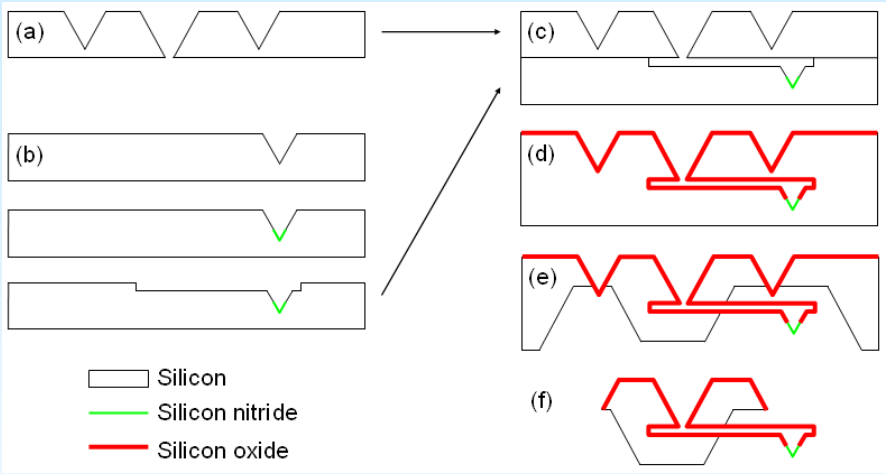
Nanostencil

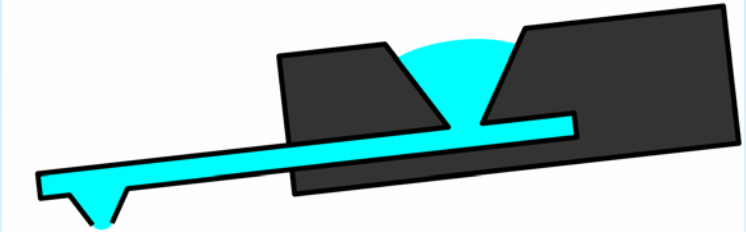


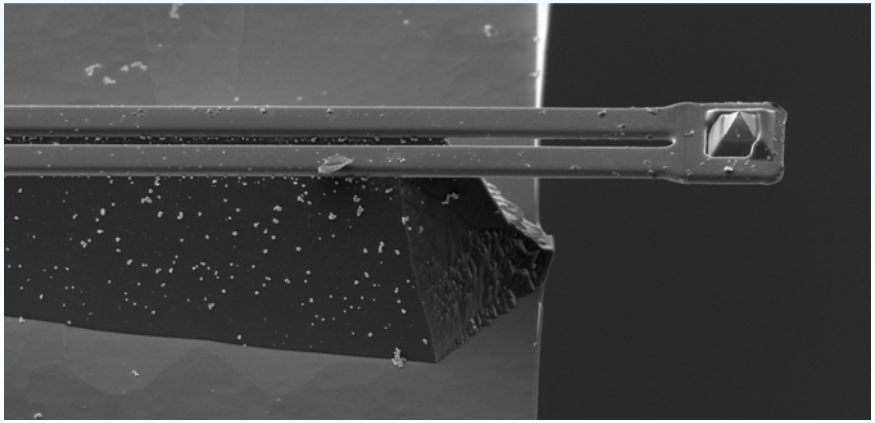
NADIS

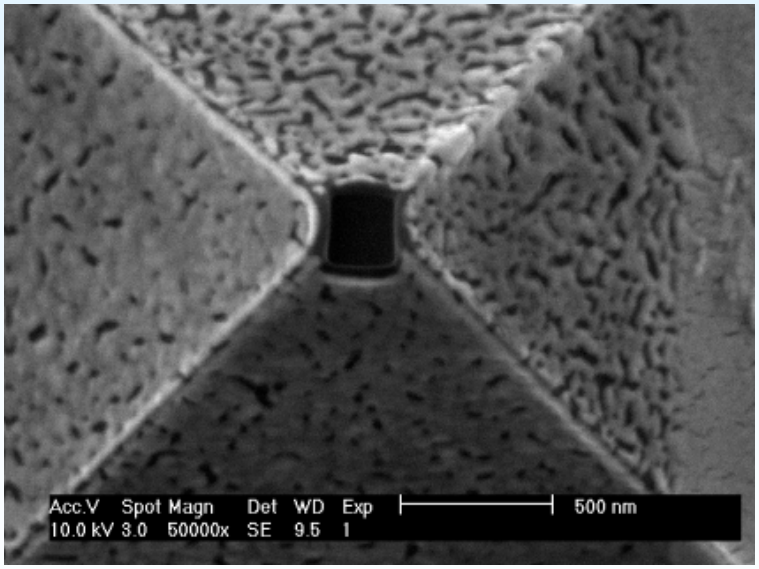
Nanodispensing II

Cantilevers with microfluidic channels





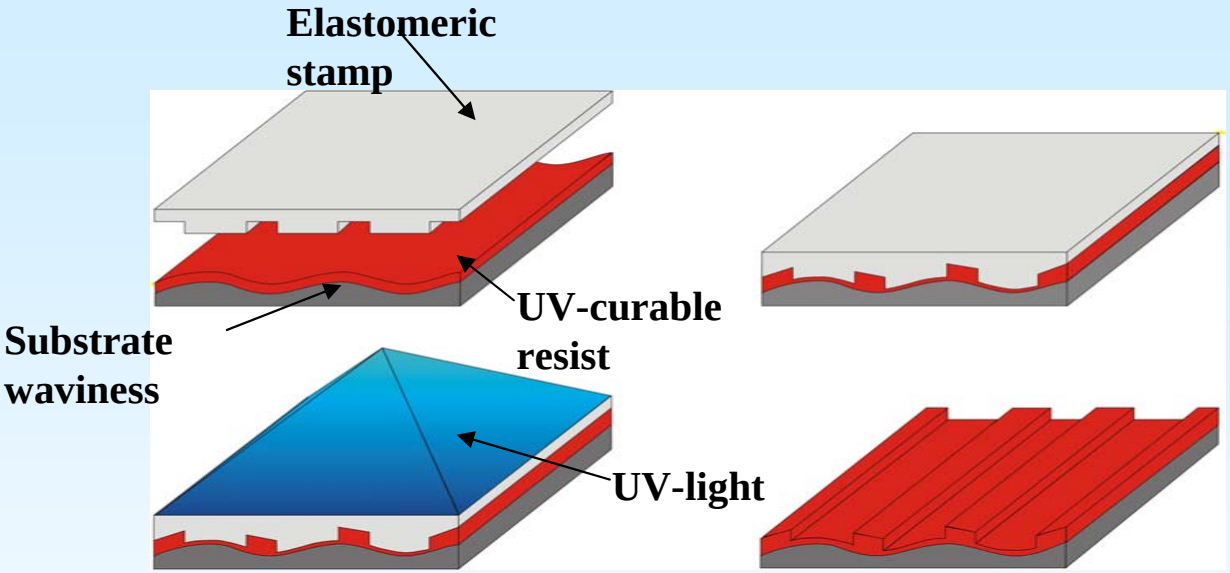




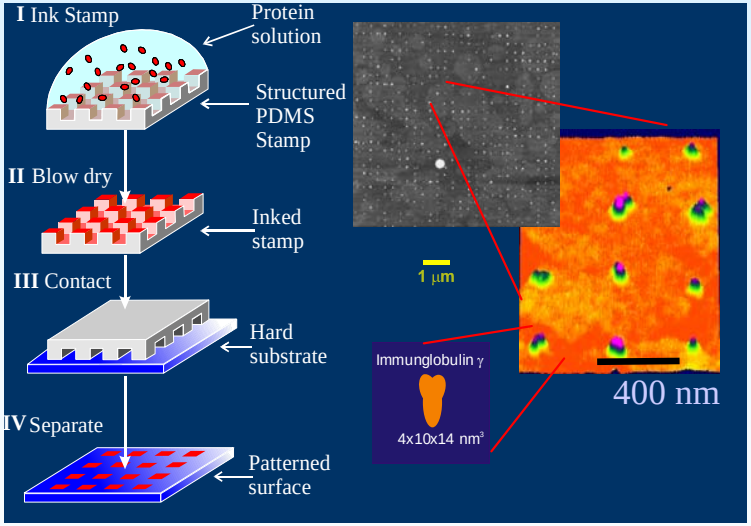
Aperture at the tip apex realized by FIB

A. Meister et al. csem centre suisse d'électronique et de microtechnique

Soft lithography



Soft lithography



Surface chemical patterning by microcontact printing

Self Assembling Monolayers