Introduction to Nanolithography

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Outline

- Introduction
- Photolithography
- Soft Lithography
- Nanoimprint Lithography (NIL)
- NIL System Overview
- Conclusion

Nanolithography

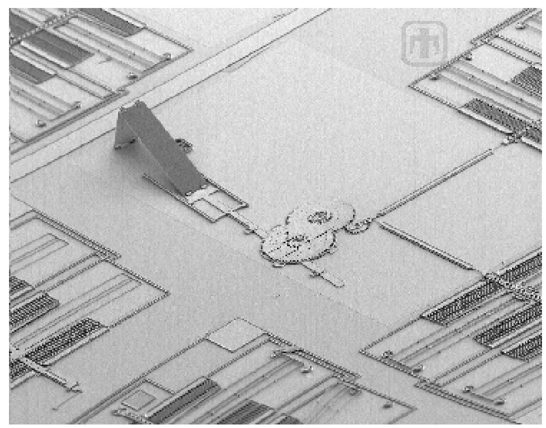
Nanolithography is the branch of nanotechnology concerned with the study and application of fabricating nanometer-scale structures, meaning patterns with at least one lateral dimension between the size of an individual atom and approximately 100 nm.

Introduction

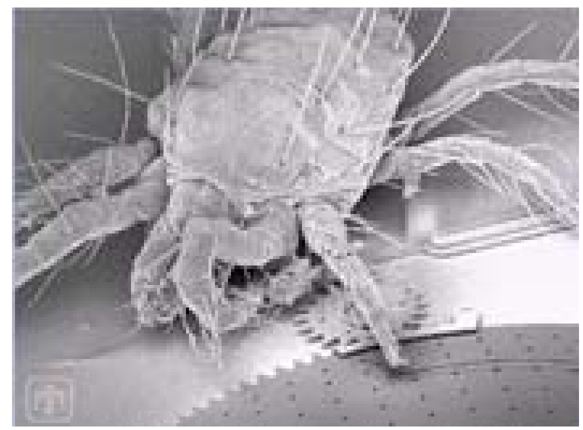
- Why we need micro/nano pattern?

MEMS (Micro electronic mechanical system)

A MEMS device
[Sandia National Laboratories]



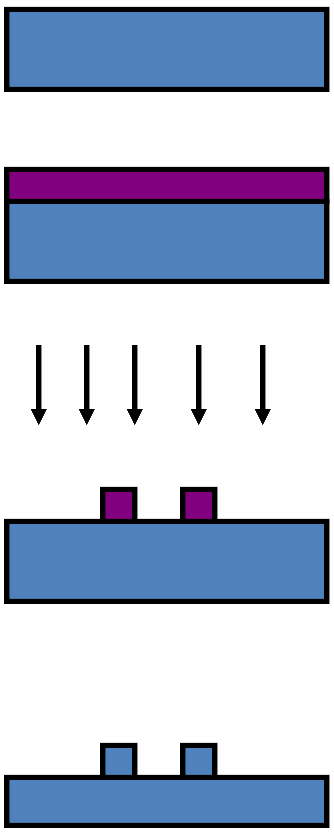
optical switch
(Sandia)



ratcheted microgear
(Sandia)

Top-down Versus Bottom-up

Top Down Process



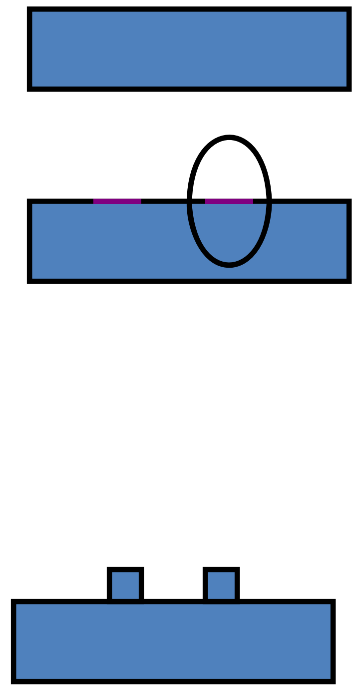
Start with bulk wafer

Apply layer of photoresist

Expose wafer with UV light through mask and etch wafer

Etched wafer with desired pattern

Bottom Up Process



Start with bulk wafer

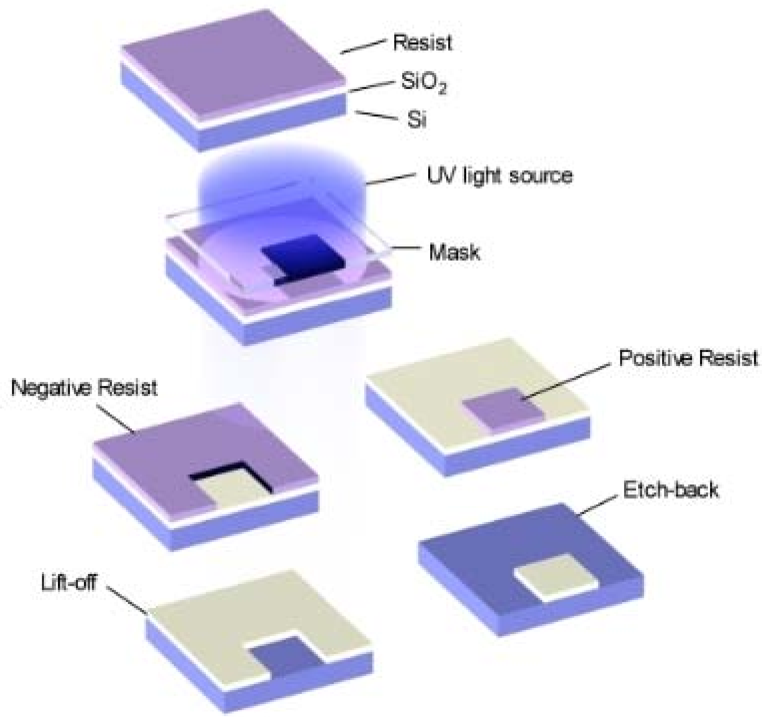
Alter area of wafer where structure is to be created by adding polymer or seed crystals or other techniques.

Grow or assemble the structure on the area determined by the seed crystals or polymer. (self assembly)

Similar results can be obtained through bottom-up and top-down processes

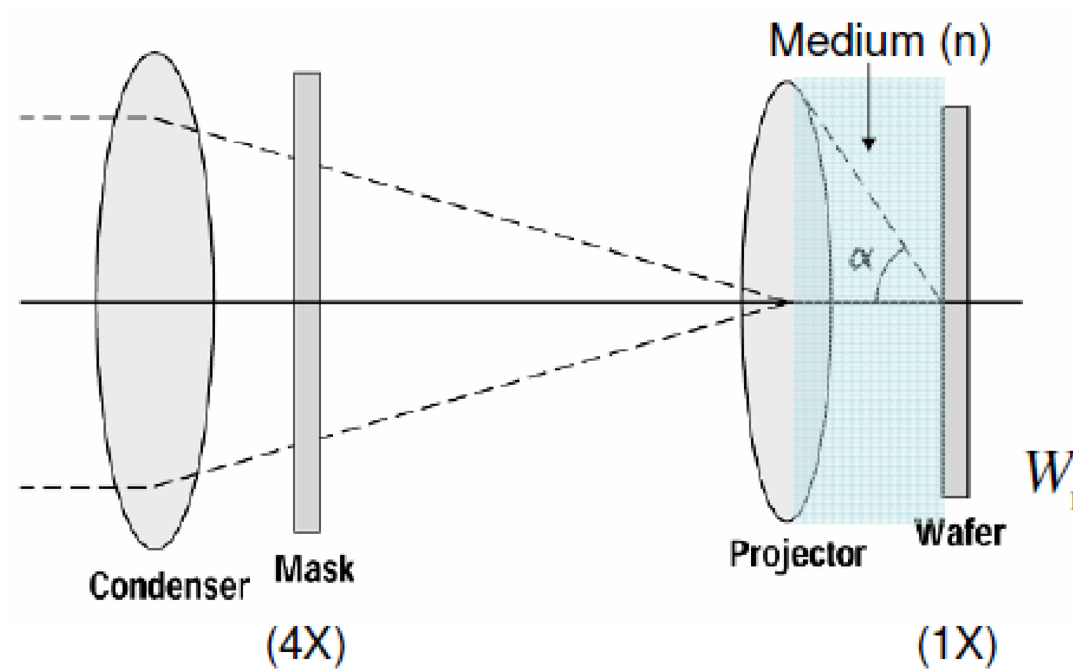
Photolithography

https://www.youtube.com/watch?v=1bxf9QRVesQ



Optical Projection Printers

- Most widely used litho for IC manufacturing



NA=n sinα
typically {0.16-0.8}

Rayleigh's equation

$$W_{min} = k\frac{\lambda}{NA}$$

$$W_{min} \downarrow: \lambda \downarrow, NA \uparrow, k \downarrow$$

$$\text{Depth of Focus} = \frac{\lambda}{NA^2}$$

- The resolution of optical projection lithography is limited by diffraction as described by the Rayleigh eqn
- k is function of resist & 'optical engineering' (OPC, PSM)

*S. Campbell, The Science and Engineering of Microelectronic Fabrication, 2nd Ed.
*ITRS, 2005

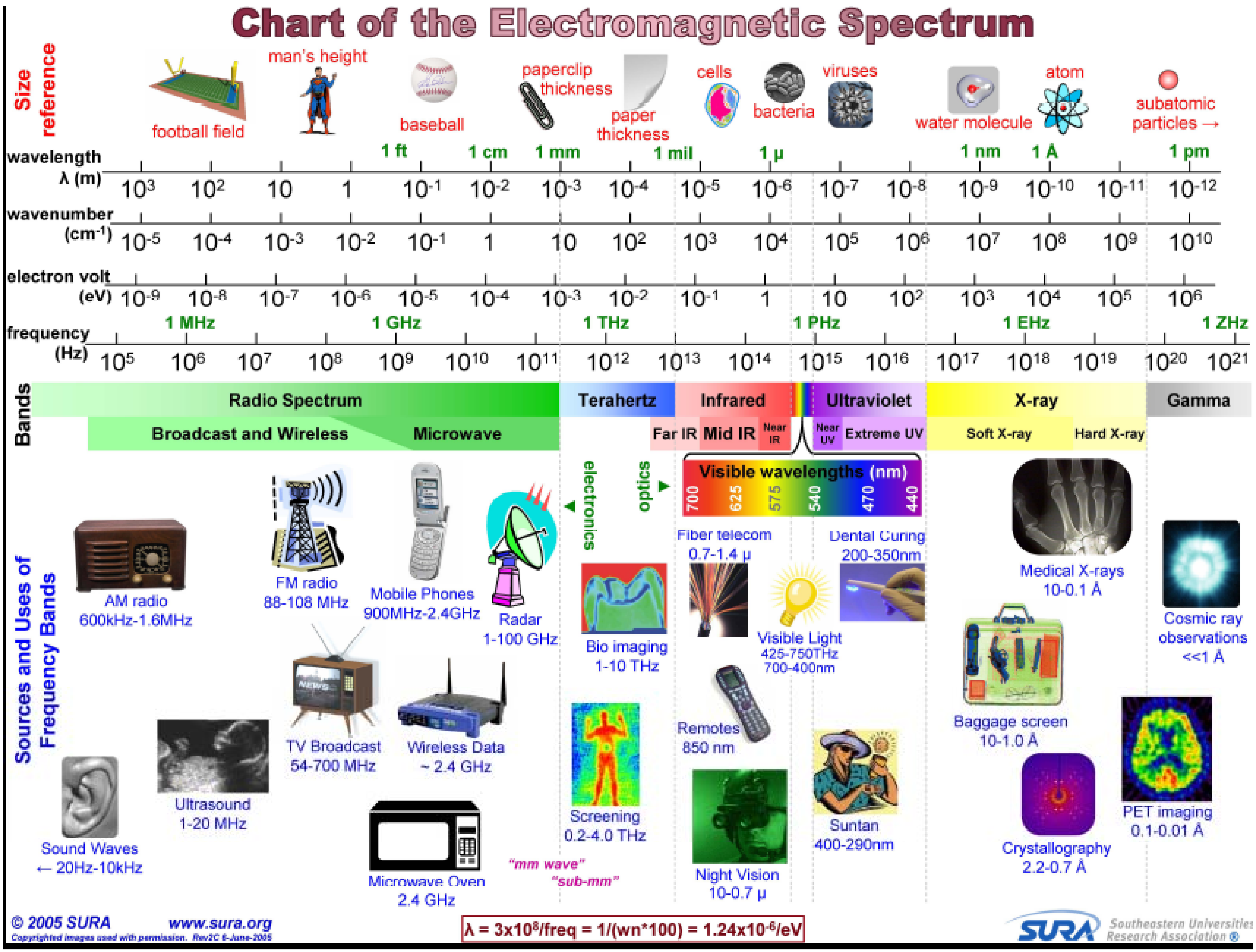


Chart of the Electromagnetic Spectrum
Size reference
football field
man's height
baseball
paperclip thickness
paper thickness
cells
bacteria
viruses
water molecule
atom
subatomic particles →
wavelength λ (m)
1 ft
1 cm
1 mm
1 mil
1 μ
1 nm
1 Å
1 pm
10³ 10² 10 1 10⁻¹ 10⁻² 10⁻³ 10⁻⁴ 10⁻⁵ 10⁻⁶ 10⁻⁷ 10⁻⁸ 10⁻⁹ 10⁻¹⁰ 10⁻¹¹ 10⁻¹²
wavenumber (cm⁻¹)
10⁻⁵ 10⁻⁴ 10⁻³ 10⁻² 10⁻¹ 1 10 10² 10³ 10⁴ 10⁵ 10⁶ 10⁷ 10⁸ 10⁹ 10¹⁰
electron volt (eV)
10⁻⁹ 10⁻⁸ 10⁻⁷ 10⁻⁶ 10⁻⁵ 10⁻⁴ 10⁻³ 10⁻² 10⁻¹ 1 10 10² 10³ 10⁴ 10⁵ 10⁶
frequency (Hz)
1 MHz
1 GHz
1 THz
1 PHz
1 EHz
1 ZHz
10⁵ 10⁶ 10⁷ 10⁸ 10⁹ 10¹⁰ 10¹¹ 10¹² 10¹³ 10¹⁴ 10¹⁵ 10¹⁶ 10¹⁷ 10¹⁸ 10¹⁹ 10²⁰ 10²¹
Bands
Radio Spectrum
Terahertz
Infrared
Ultraviolet
X-ray
Gamma
Broadcast and Wireless
Microwave
Far IR
Mid IR
Near IR
Near UV
Extreme UV
Soft X-ray
Hard X-ray
electronics
optics
Visible wavelengths (nm)
700 625 575 540 470 440
Sources and Uses of Frequency Bands
AM radio 600kHz-1.6MHz
FM radio 88-108 MHz
Mobile Phones 900MHz-2.4GHz
Radar 1-100 GHz
Bio imaging 1-10 THz
Fiber telecom 0.7-1.4 μ
Dental Curing 200-350nm
Medical X-rays 10-0.1 Å
Cosmic ray observations <<1 Å
Visible Light 425-750THz 700-400nm
Baggage screen 10-1.0 Å
TV Broadcast 54-700 MHz
Wireless Data ~ 2.4 GHz
Remotes 850 nm
Screening 0.2-4.0 THz
Suntan 400-290nm
PET imaging 0.1-0.01 Å
Crystallography 2.2-0.7 Å
Ultrasound 1-20 MHz
Sound Waves ← 20Hz-10kHz
Microwave Oven 2.4 GHz
"mm wave"
"sub-mm"
Night Vision 10-0.7 μ
© 2005 SURA
www.sura.org
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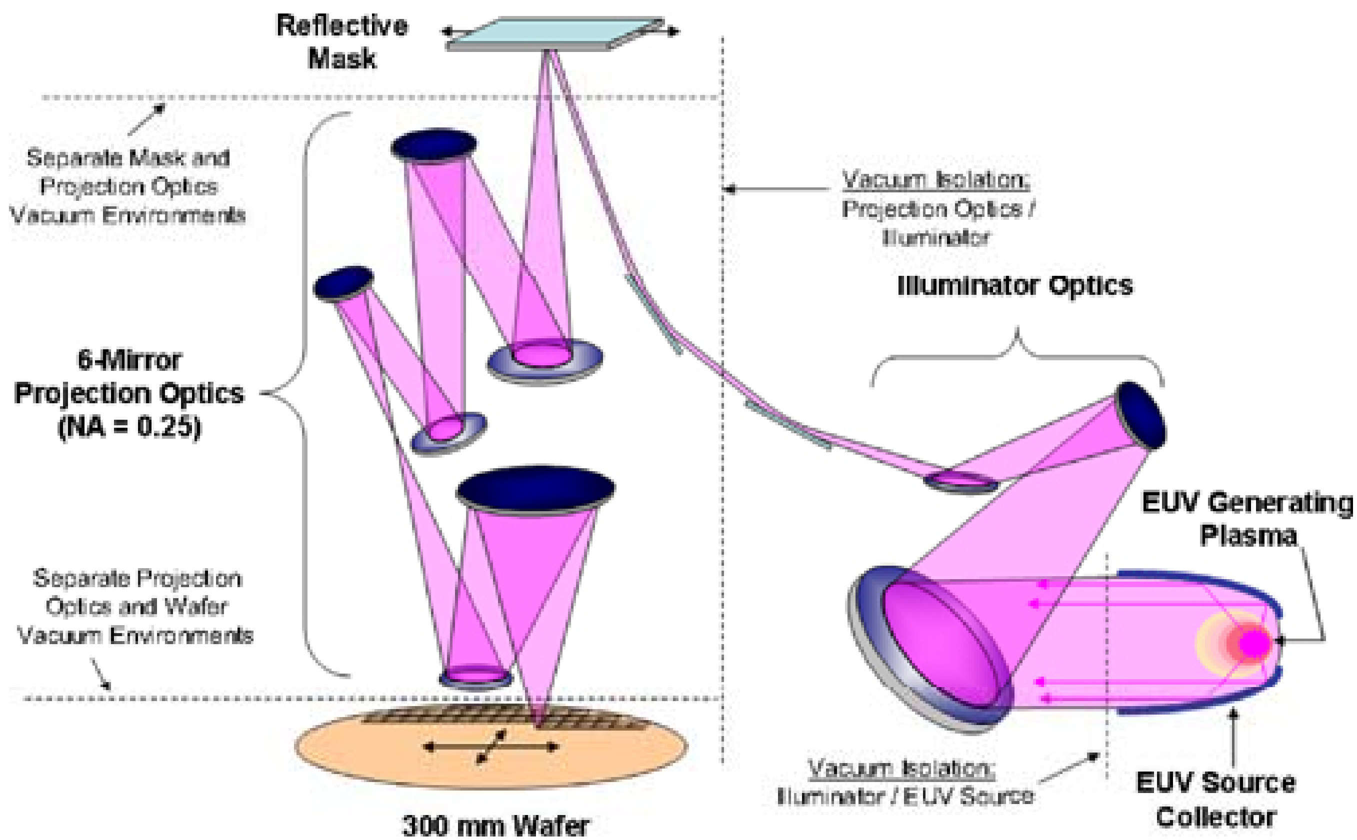
λ = 3x10⁸/freq = 1/(wn*100) = 1.24x10⁻⁶/eV
SURA Southeastern Universities Research Association ®

EUV lithography

- **Extreme ultraviolet lithography** (also known as *EUV* or *EUVL*) is a next-generation lithography technology using an EUV wavelength, currently expected to be 13.5 nm.



Photolithography Limits

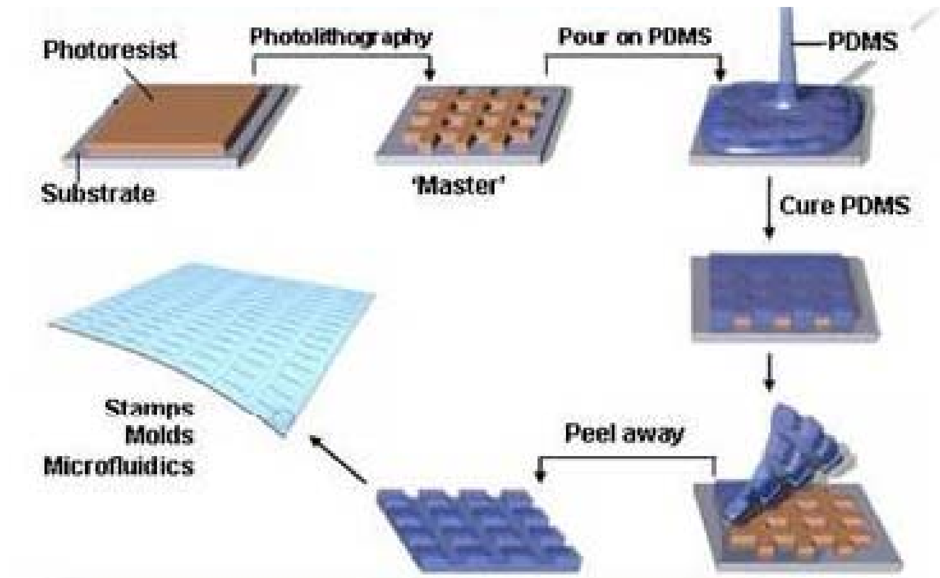
- It requires expensive instruments and facilities with high capital investment
- Pattern resolution is limited by optical diffraction
- The methods is not suitable for patterning all types of polymers, and only photosensitive resist materials can be directly patterned.
- The technique requires harsh processing conditions. (Limited application for sensitive materials such as biological samples with living cell)

Soft Lithography

- Introduction

George Whitesides

Department of Chemistry and Chemical Biology,
Harvard University



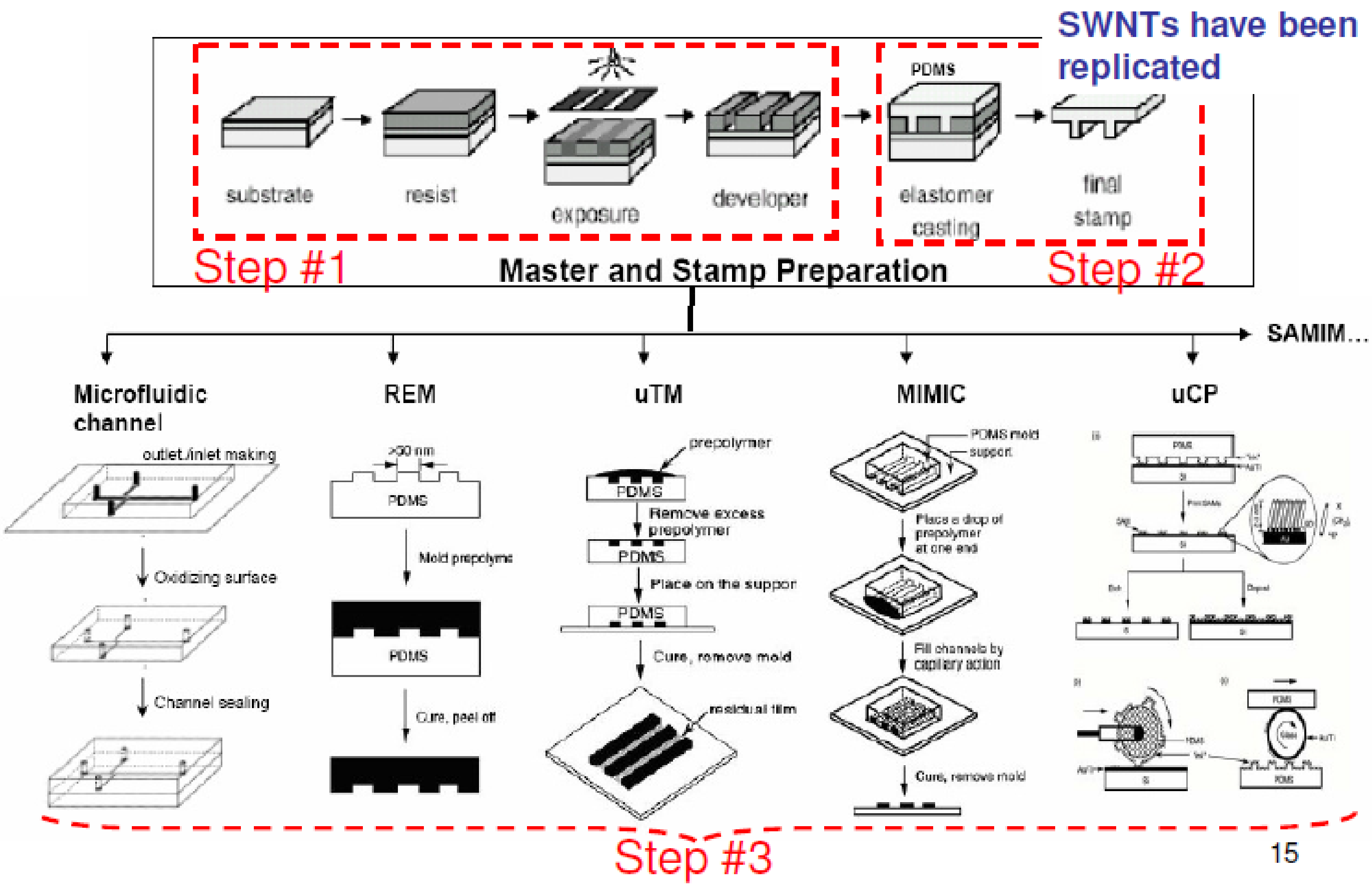
- PDMS

Soft Lithography

There are 3 basic steps in Soft Lithography:

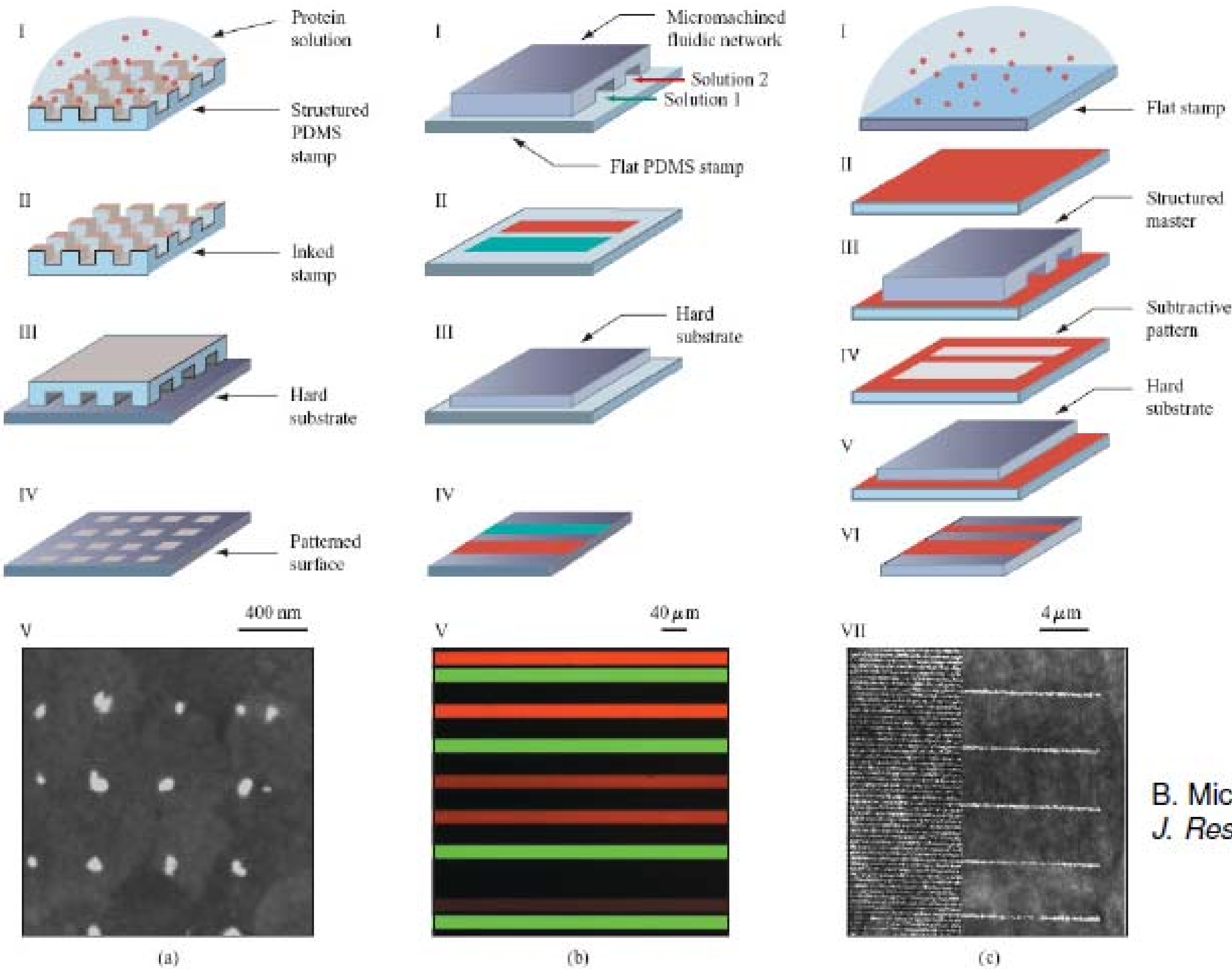
- **Step # 1:**
  - Master fabrication (usually Si wafer with SU-8 pattern) & silanize
- **Step # 2:**
  - Create PDMS micromold from the master
- **Step # 3:** use the PDMS micromold in a number of ways …
  - Microfluidic Device Fabrication
  - Microcontact Printing (μCP)
  - Microtransfer Molding (μTM)
  - Micromolding in Capillaries (MIMIC)
  - Replica Molding (REM)
  - Sub-micron Soft Lithography
  - Etc.

Soft Lithography Techniques



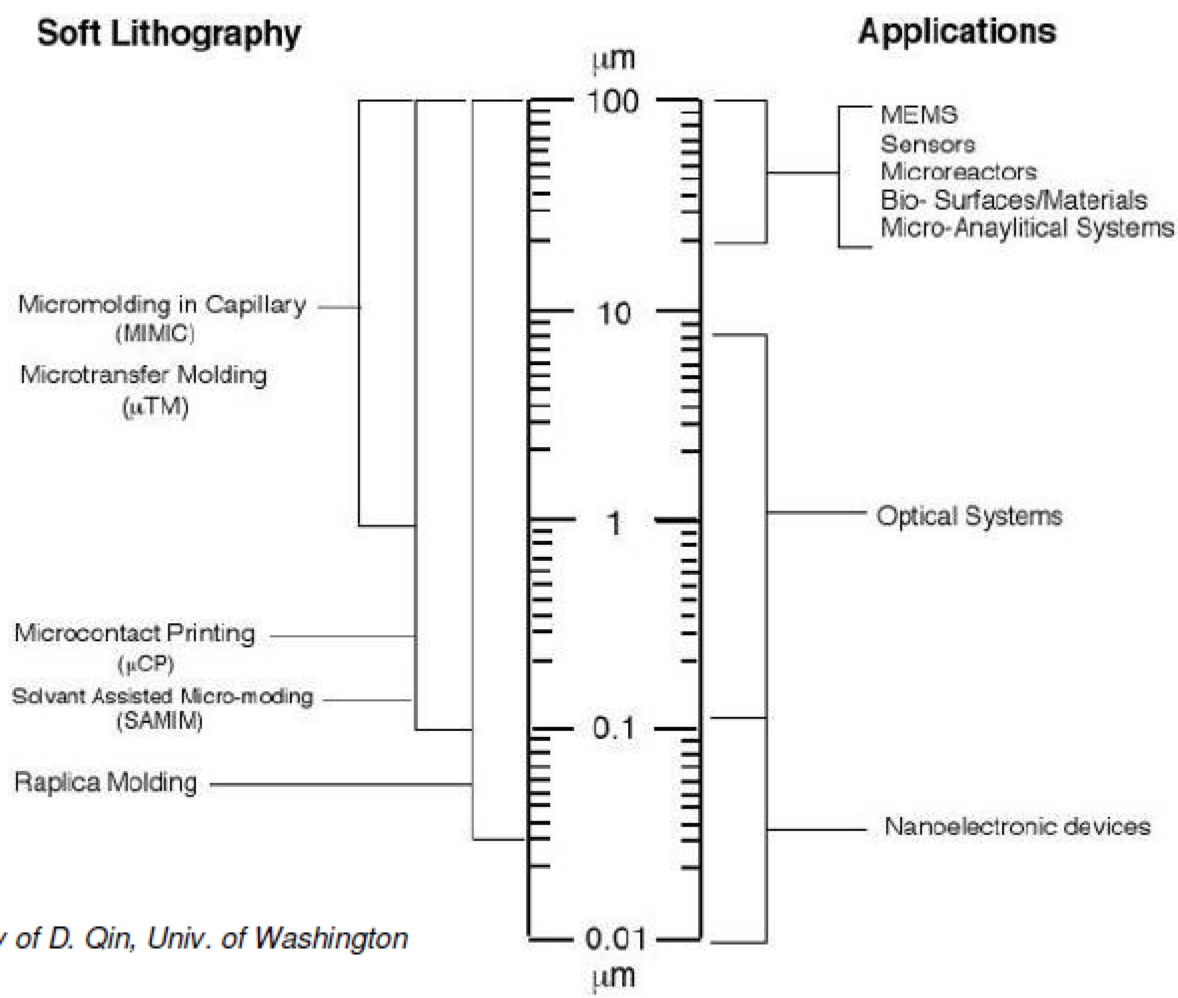
Images courtesy of D. Qin, Univ. of Washington

Printing of Biological Molecules (Proteins)



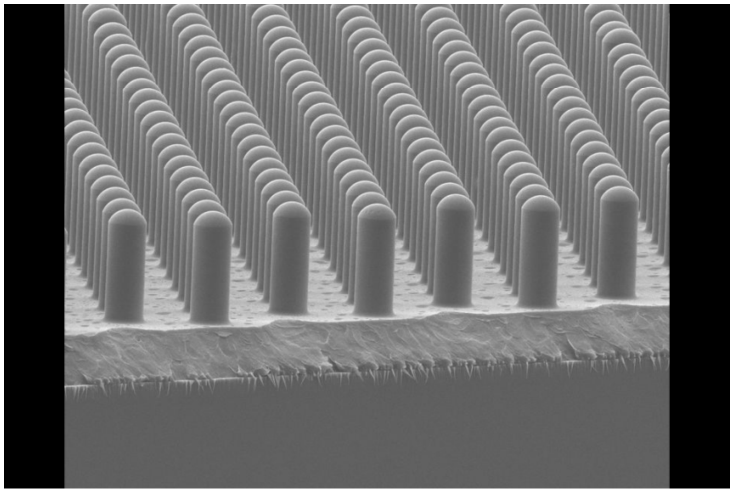
B. Michel *et al.*, *IBM J. Res. & Dev.* 2001

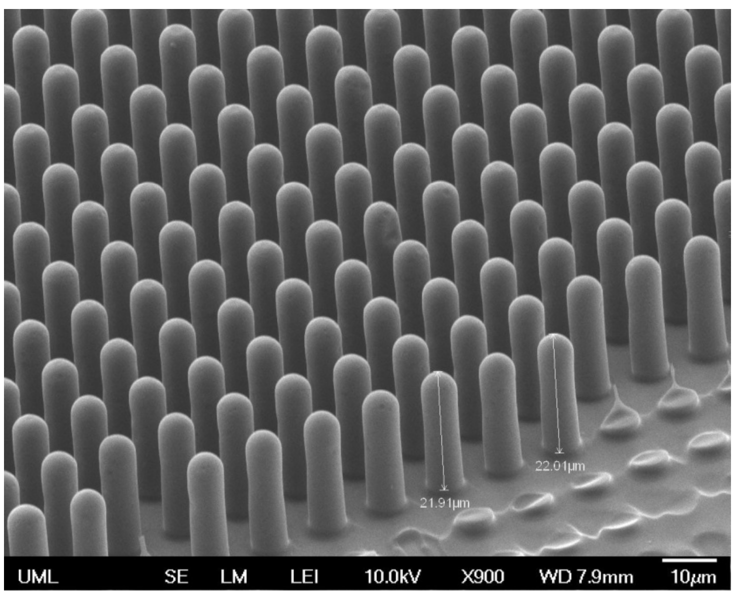
Soft Lithography

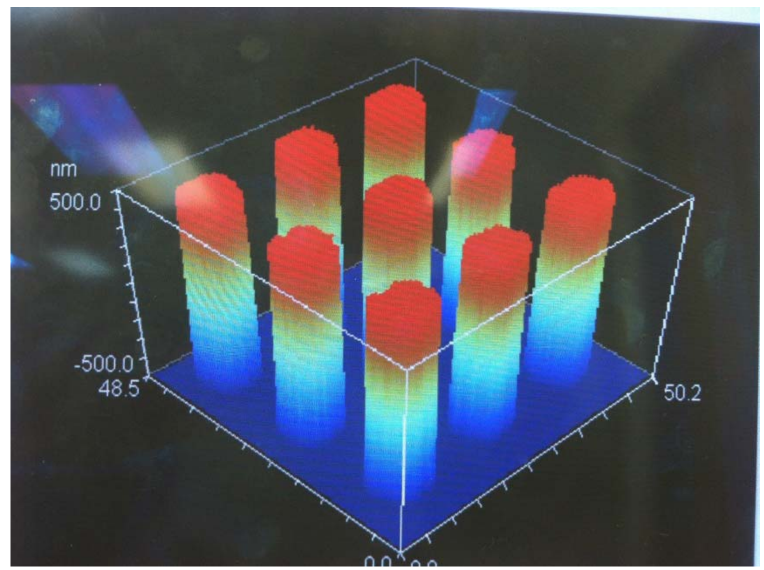


Slide courtesy of D. Qin, Univ. of Washington

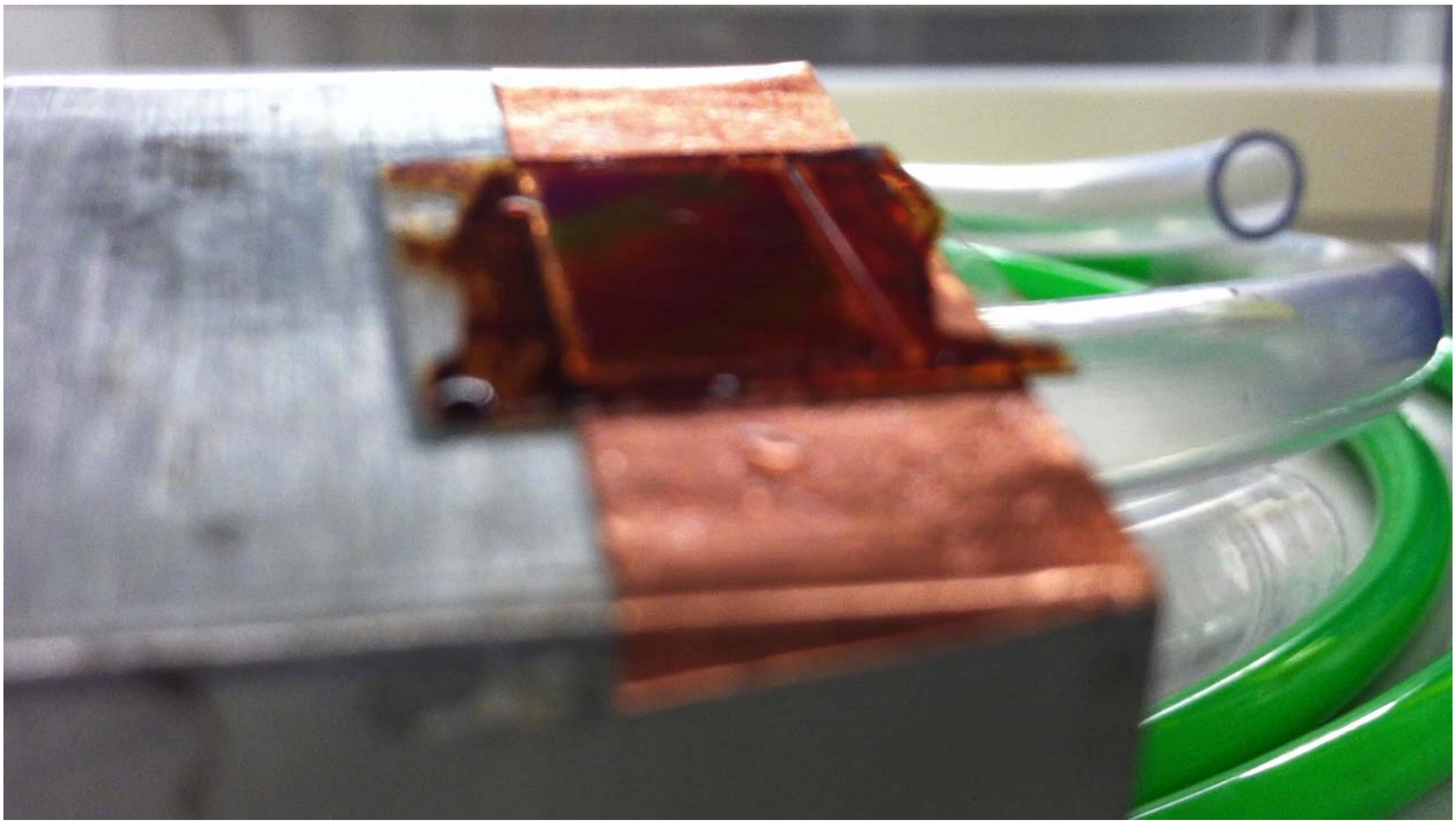
Soft Lithography Application (Superhydrophobic Surface)



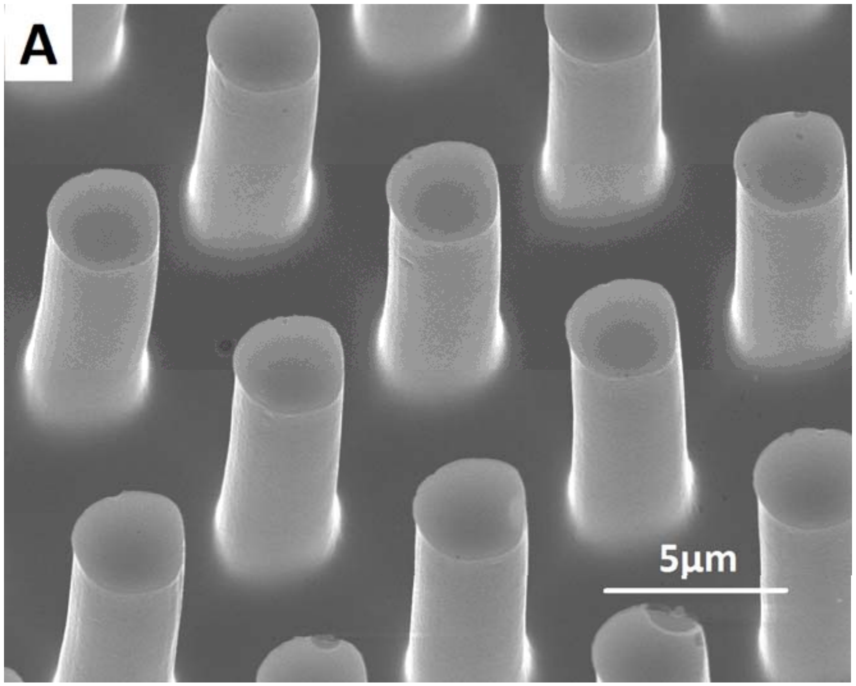




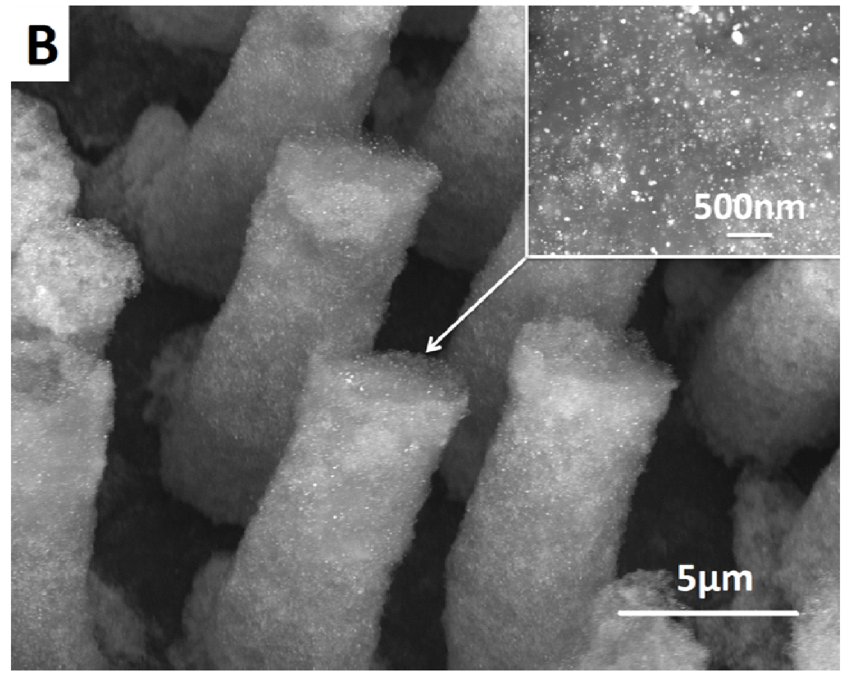
Soft Lithography Application (Superhydrophobic Surface)



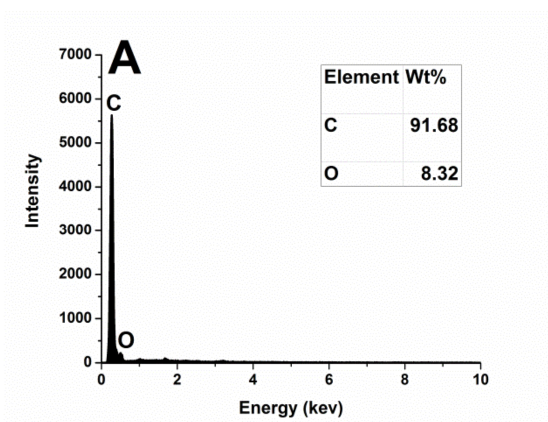
Soft Lithography Application (Carbon based MEMS-Bio Sensor)

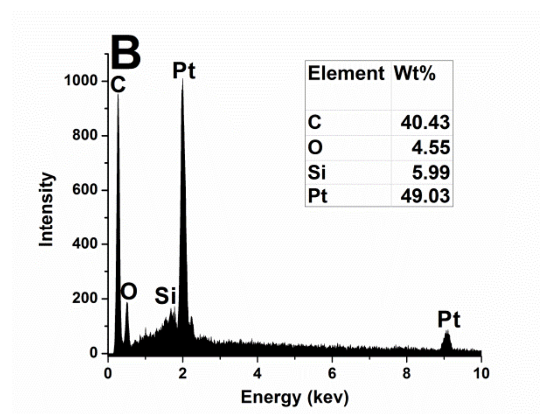


Bare Micro Carbon Pillars

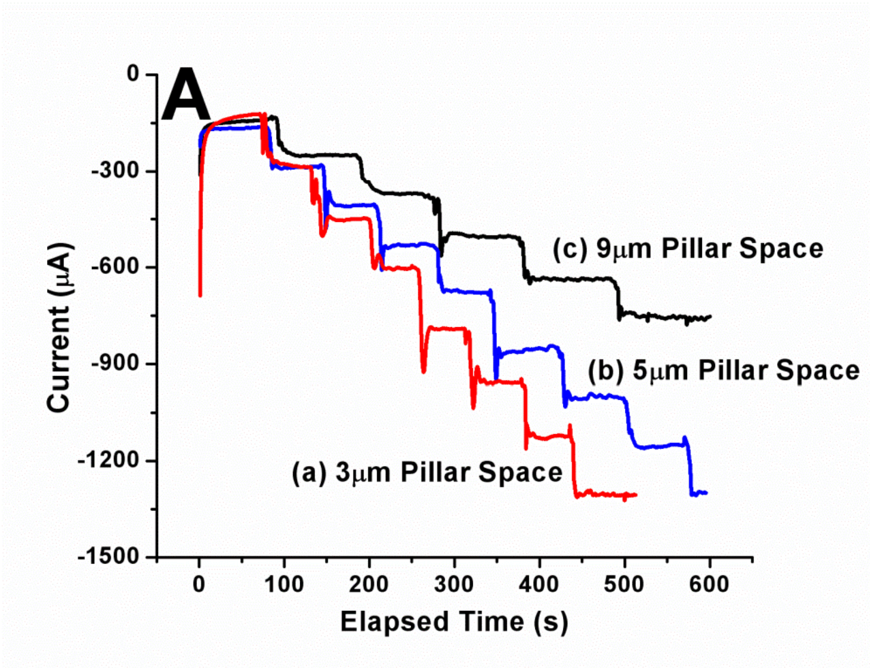


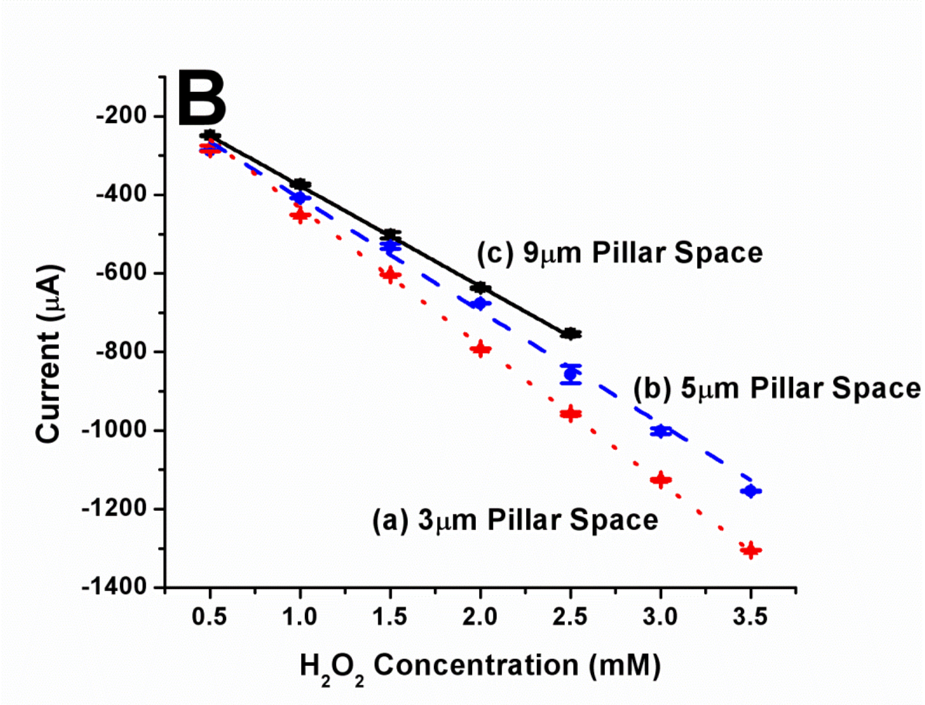
Pt NPs decorated Micro Carbon Pillars





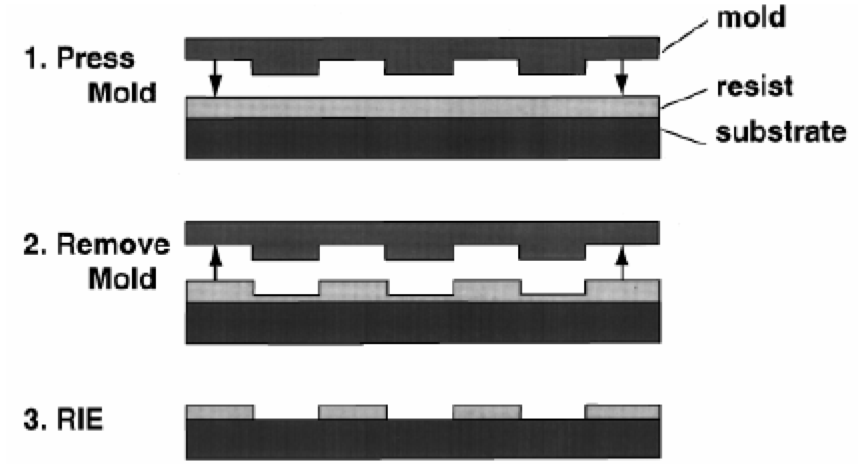
Soft Lithography Application
(Carbon based MEMS-Bio Sensor)





Nanoimprint Lithography (NIL)

- Introduction



Stephen Y. Chou

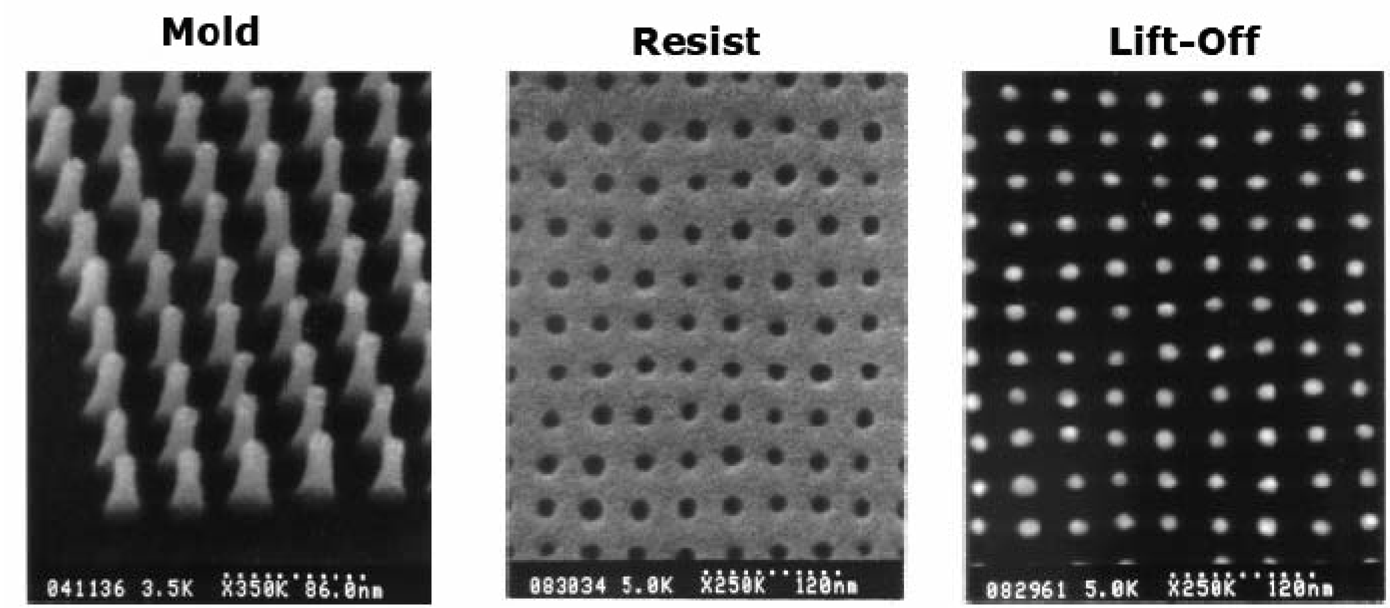
the head of the NanoStructure Laboratory

Princeton University

- *Hard mold ("mask") with surface relief pattern used to emboss resist*
- *Heat and pressure are typically used during imprinting*
- *The mold is removed after imprint*
- *Resist residual layer (dry) etched to leave behind fully patterned resist*

S. Chou et al., "Nanoimprint Lithography," J. Vac. Sci. Technol. B, 14 (6), 1996

Nanoimprint Lithography (NIL)

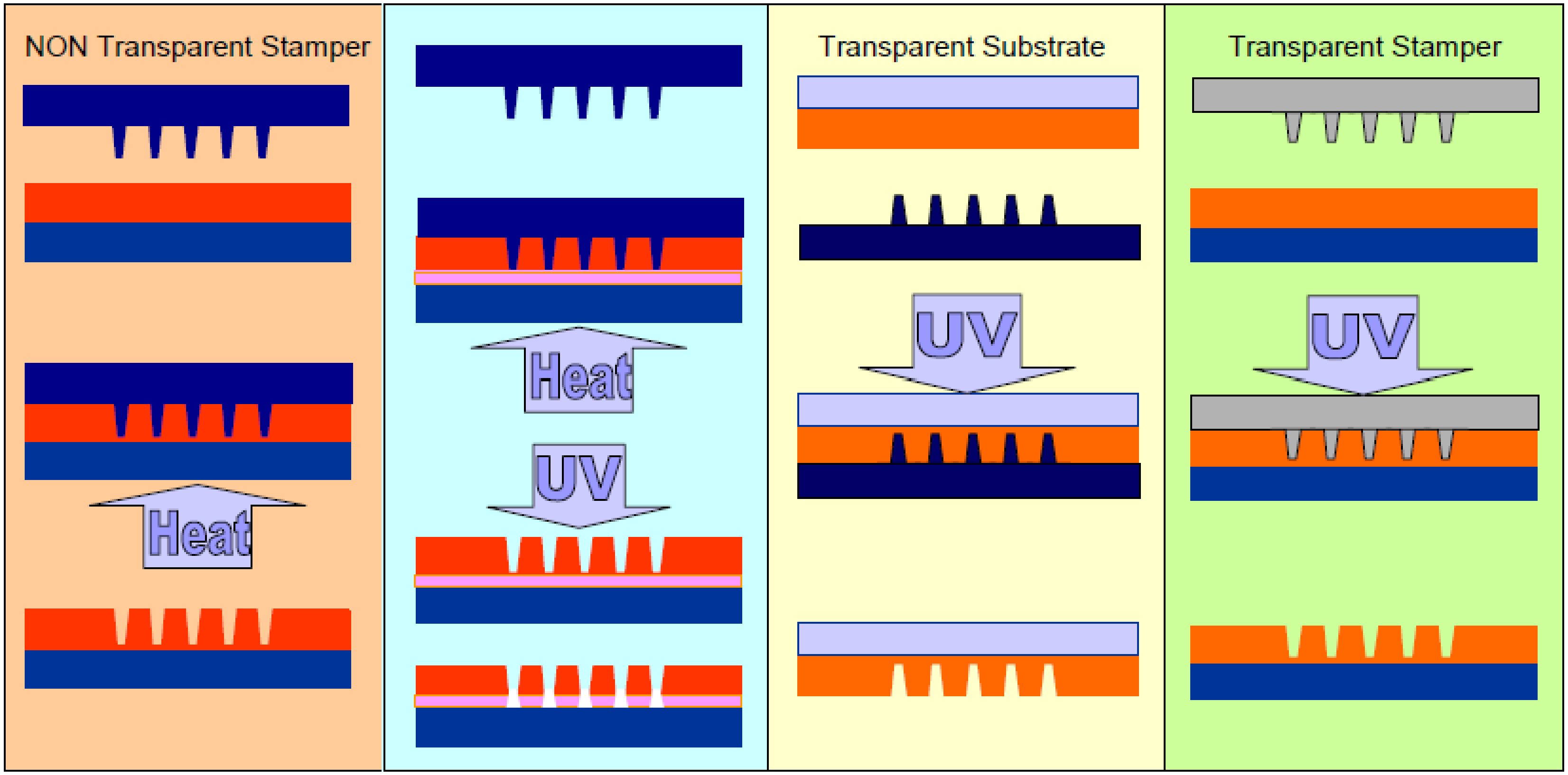


10 nm dia pillar mold

10 nm dia resist holes by imprinting

10 nm dia metal dots by imprint and lift-off

NIL category



Thermal Imprint

(PMMA)

Thermal + UV Imprint

(SU-8)

UV Imprint

(PU)

UV Imprint

(PU)

Thermal Vs. UV NIL

Thermal:

+ Less restrictions on template
  - •Si and Ni are okay
+ Simpler/cleaner process
  - •UV resists are little 'messy'
+ More readily available poly/resists

- Temperature (but, controllable)
  - •May be as high as 200 C
  - •CTE mismatch b/w template/wfr
  - •distortion of alignment: function of substrate size
- May require large force
  - •Another source of distortion
  - •Breakage

UV:

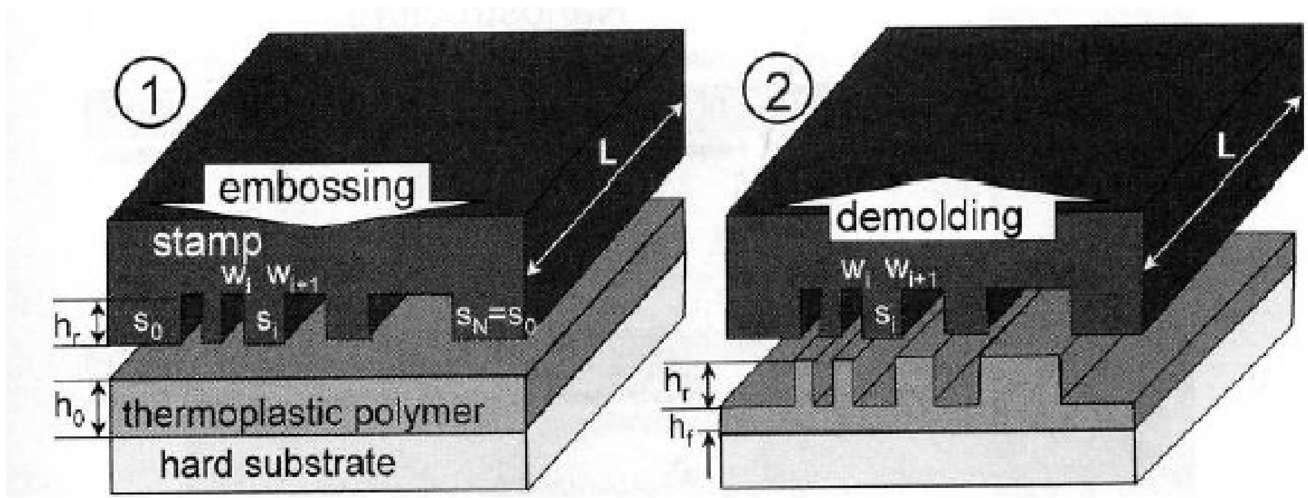
+ No thermal cycling
  - •No CTE mismatch issues
+ Fast (few seconds – not including dispensing for S&F)
+ Usually minimal force needed

- volume shrinkage due to phase transition
- Uniform layers from spin coating
- Must use transparent template

Resist Polymer Available in Umass Lowell

- PMMA: Tg=100C, Low etch selectivity over SiO2
- SU-8
- PU (Polyurethane)

How Much Initial Material (Resist) is Needed?



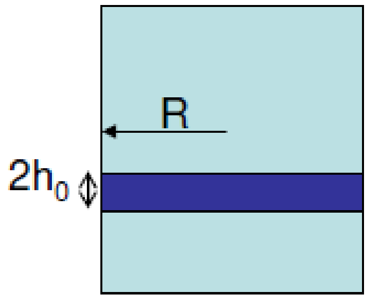
$$h_0 \sum_{i=1}^{N} (s_i + w_i) = h_f \sum_{i=1}^{N} (s_i + w_i) + h_r \sum_{i=1}^{N} w_i$$

$$h_0 = h_f + \frac{h_r}{\sum_{i=1}^{N} (s_i + w_i)} \sum_{i=1}^{N} w_i$$

*C. Torres, Editor, *Alternative Lithography: Unleashing the Potentials of Nanotechnology*, Kluwer, 2003

Newtonian Liquid between Two Parallel Disks

Steady-state solution to the Stefan eq:



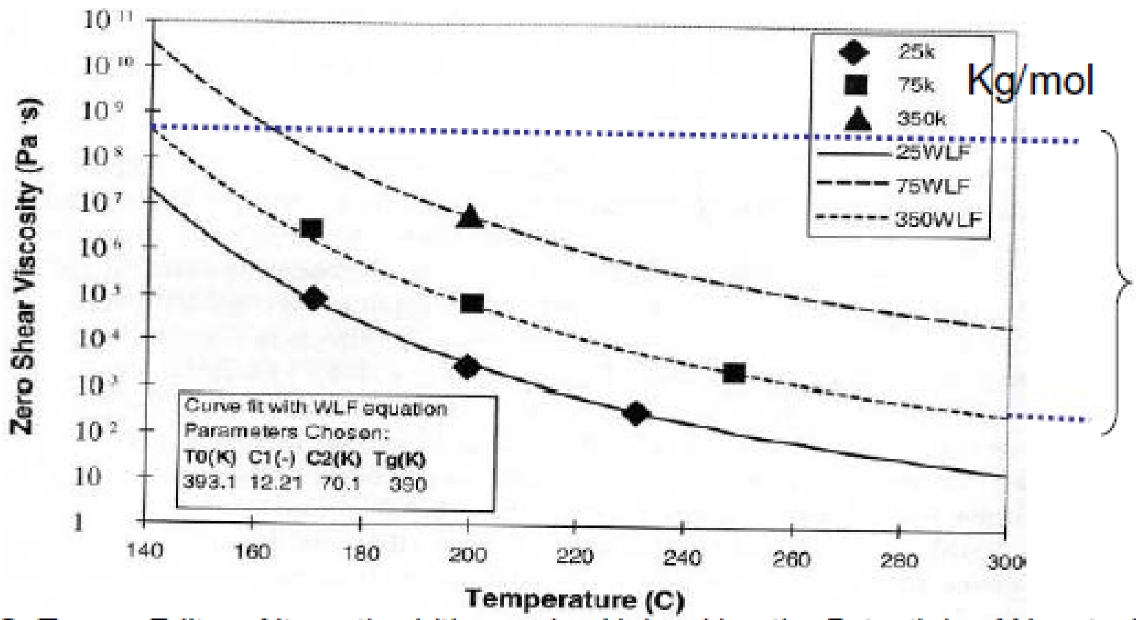
$$F = -\frac{3\pi R^4}{4h_0^{\,3}}\frac{dh}{dt}\eta_0$$

$$F \propto R^4$$

$$F \propto \frac{1}{h_0^{\,3}}$$

$$F \propto \eta_0$$

Changes by *orders* of magnitude with temp

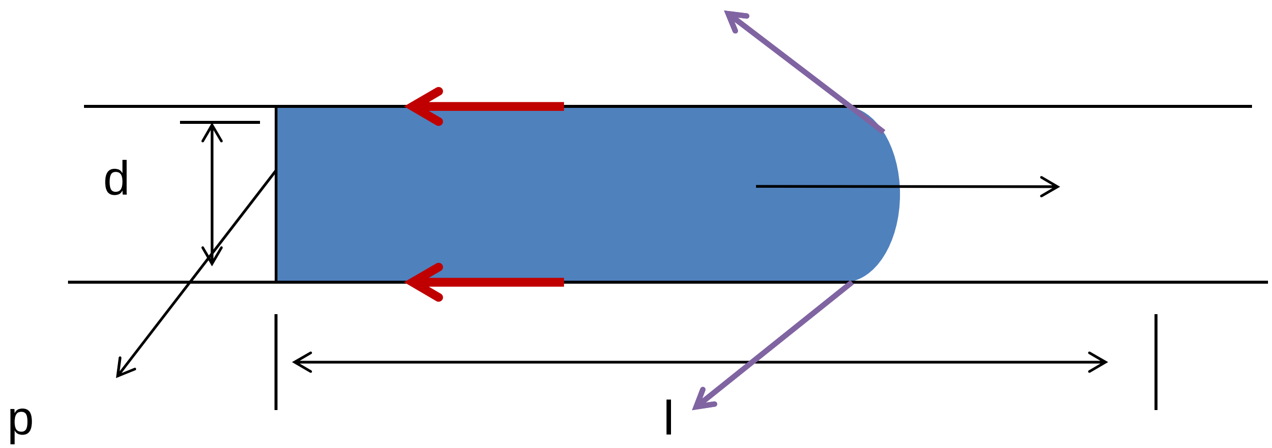


x10^5

Shear viscosity also function of shear velocity in (realist) materials of interest (PMMA)

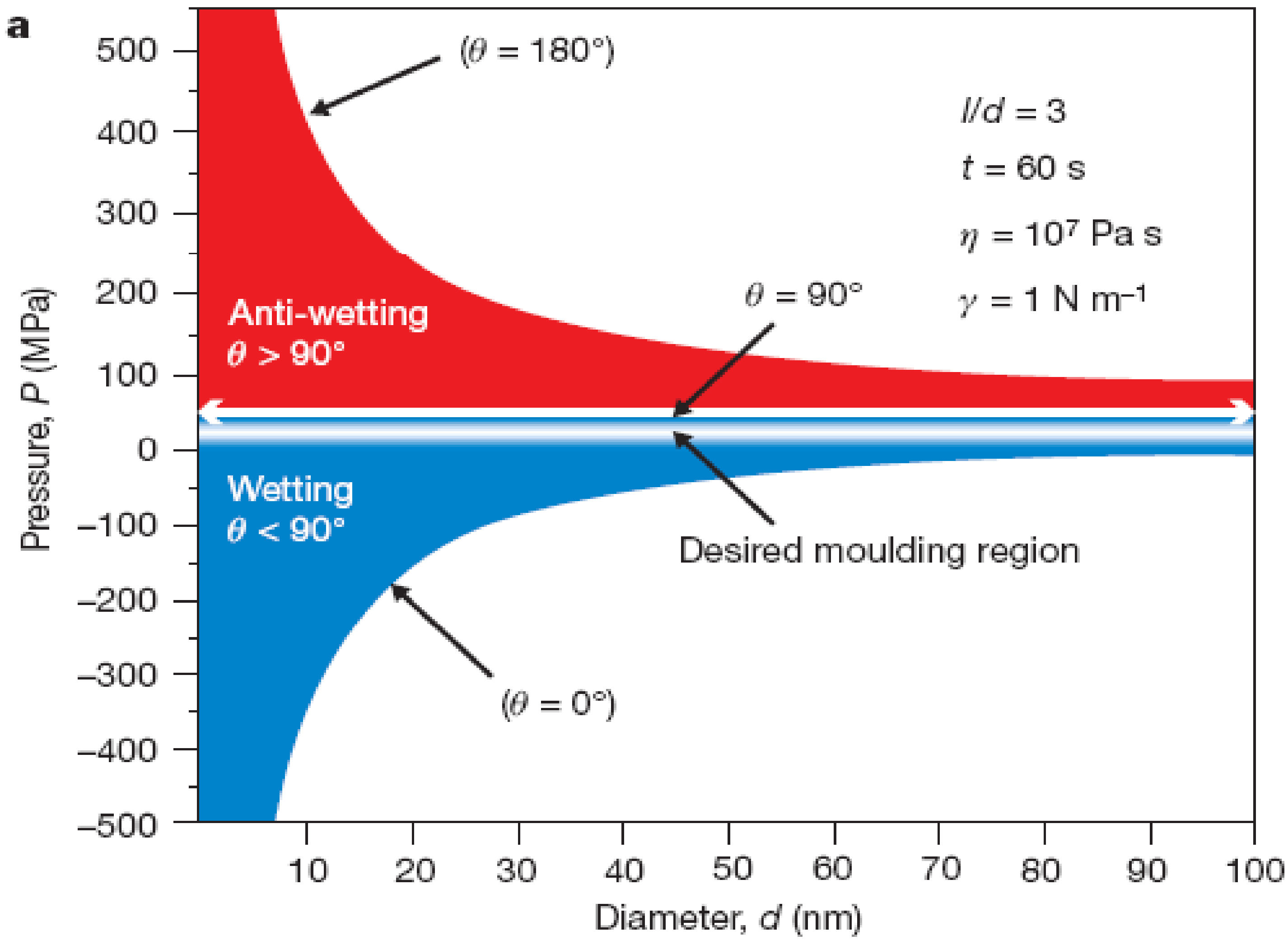
*C. Torres, Editor, *Alternative Lithography: Unleashing the Potentials of Nanotechnology*, Kluwer, 2003

Flow in a channel

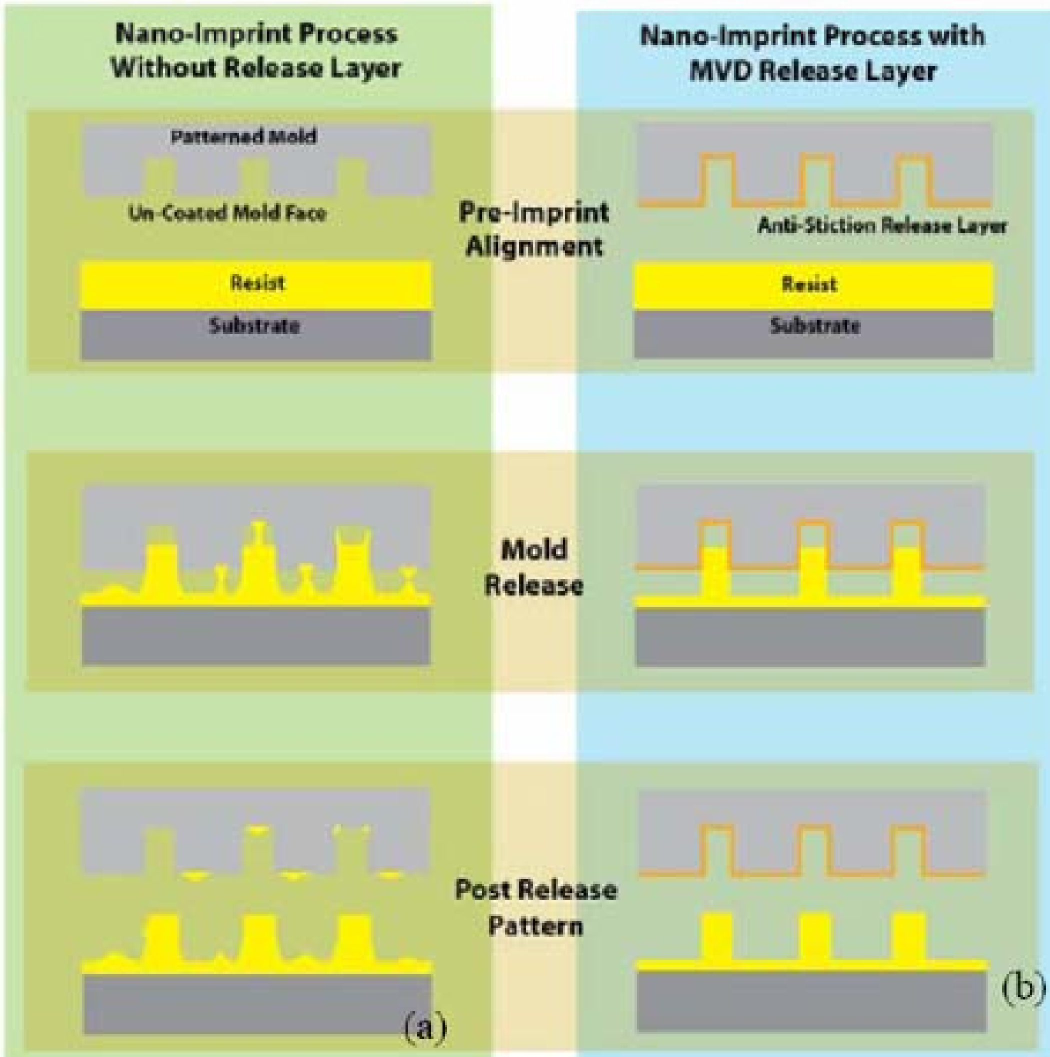


$$P = \frac{32\eta}{t}\left(\frac{l}{d}\right)^2 - \frac{4\gamma\cos\theta}{d}$$

Molding pressure for filling a channels

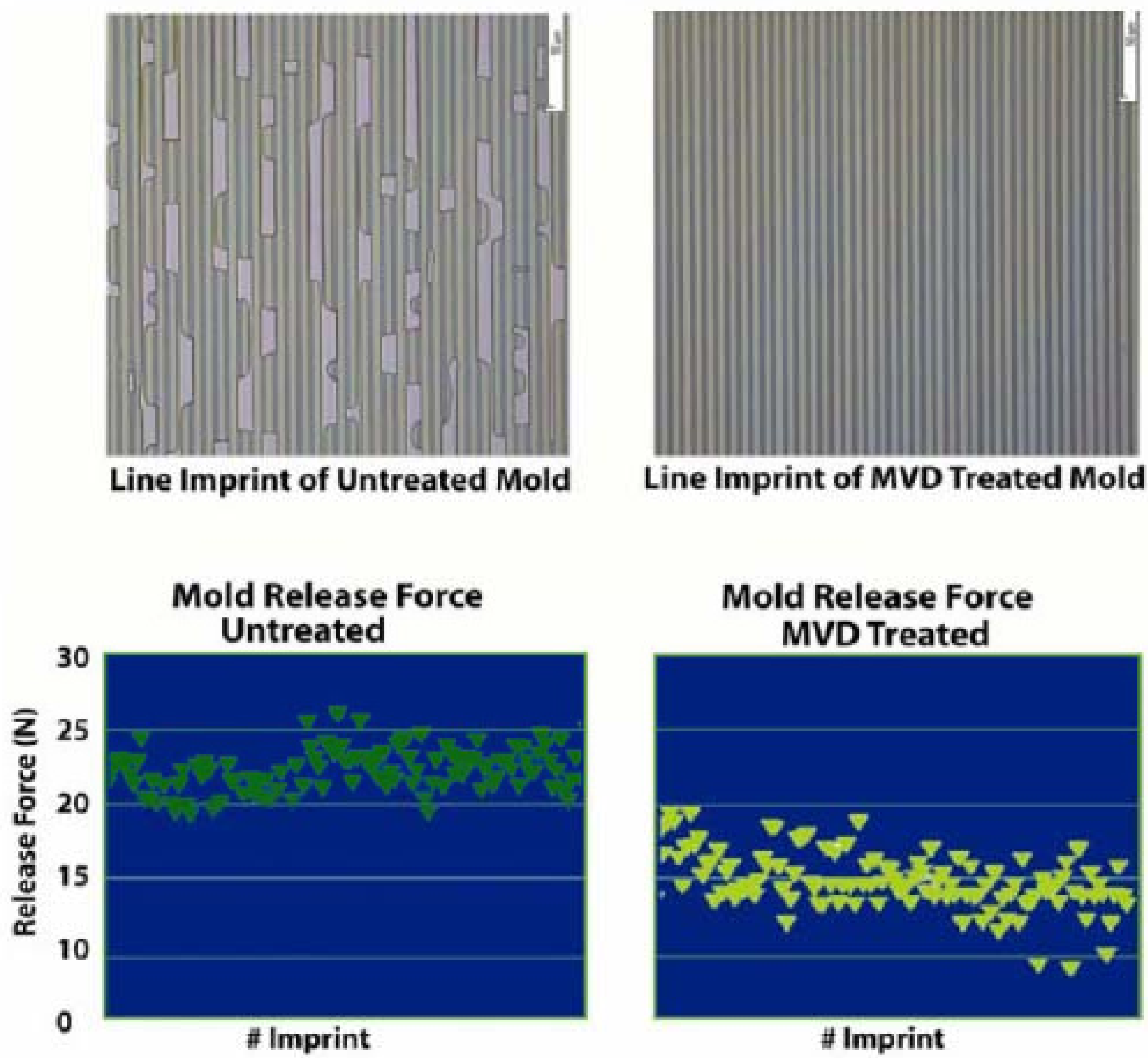


Importance of Antistick



T. Zhang et al., SPIE 2006

NIL with and without Antistick

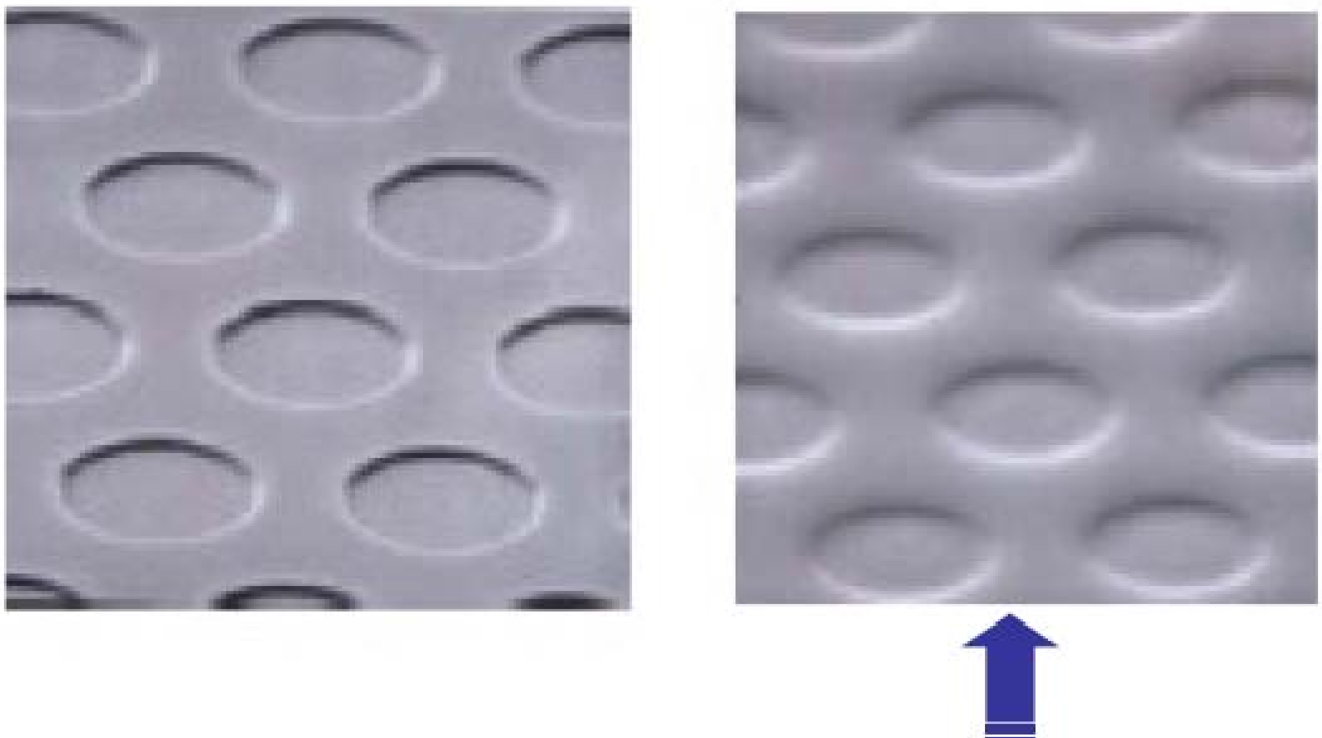


T. Zhang et al., SPIE 2006

Resist Issues

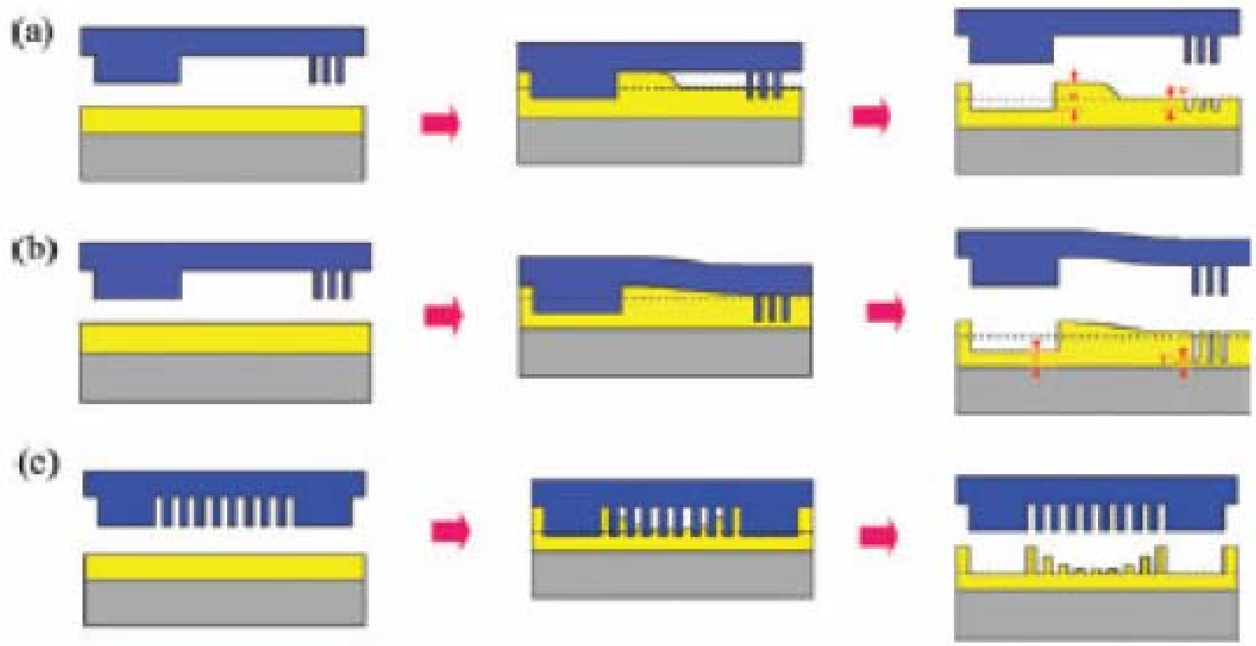
- Proper glass transitional temperature
- Minimal shrinkage
- Mechanical strength
- Mold fill
- Viscosity

If glass transitional temperature is too low, what will happen?



10 days after imprinting a low Tg resist

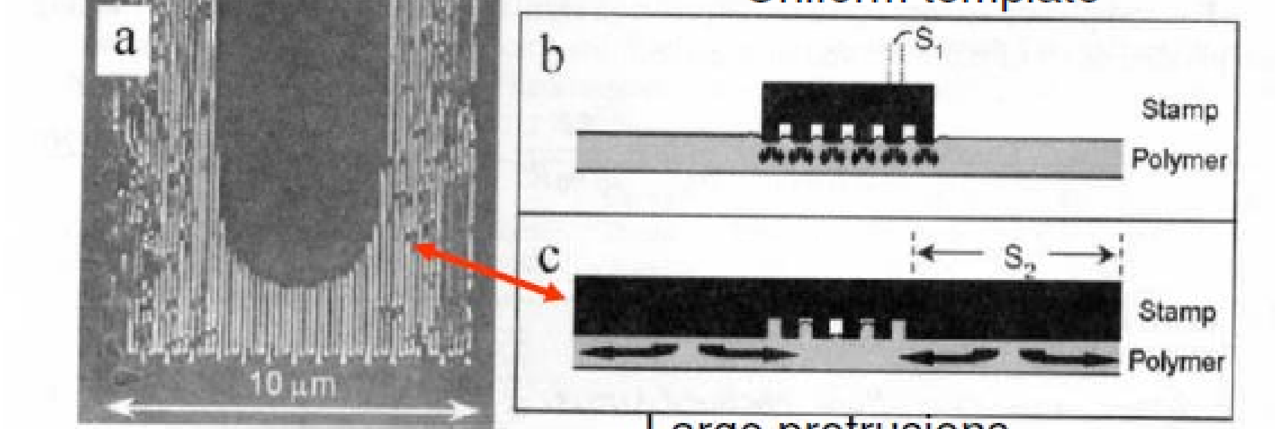
Issues with Imprinting Micro & Nano Features



L. Guo, "Recent Progress in nanoimprint technology and its applications," J. Phys. D, 37, 2004

Issues with Imprinting Micro & Nano Features

Uniform template

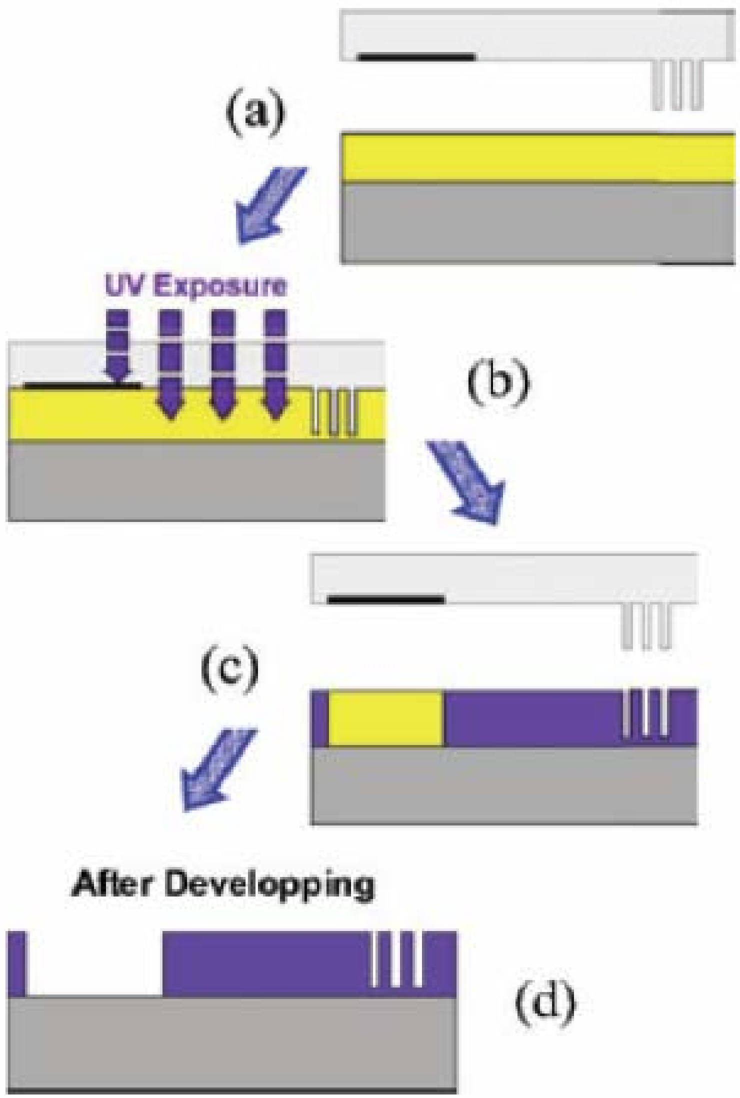


Large protrusions dominate (large s_i)

- The fill factor should be kept constant: better flow and shorter imprint time
    - Fabricate dummy cavities/protrusions
- Different fill factor across template leads to different sinking rates
    - template bending → non-uniform residual layer on substrate

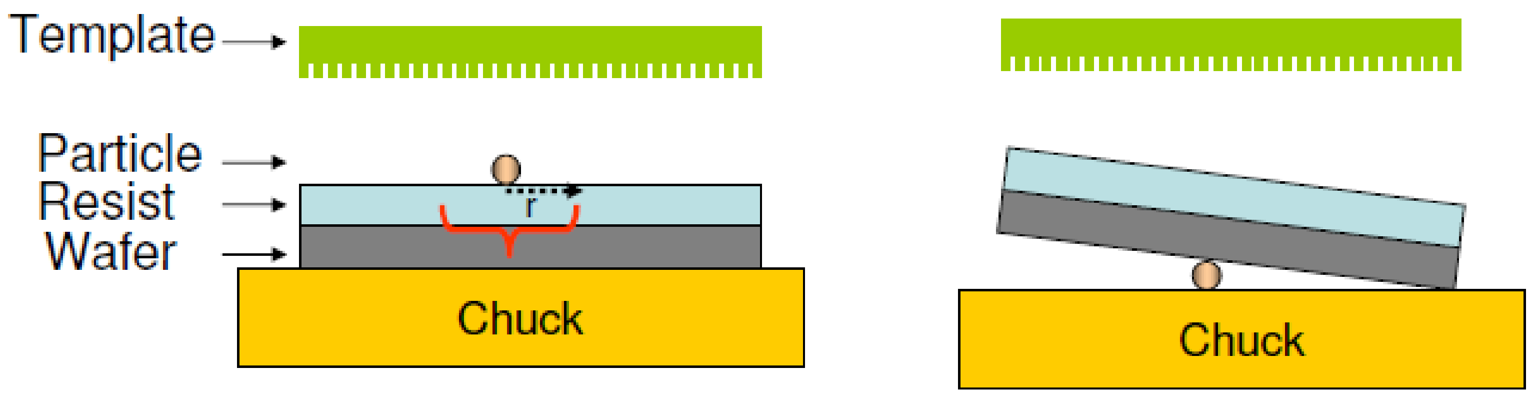
*C. Torres, Editor, *Alternative Lithography: Unleashing the Potentials of Nanotechnology*, Kluwer, 2003

Combined UV {for Micro} and Imprint {for Nano}



L. Guo, "Recent Progress in nanoimprint technology and its applications," J. Phys. D, 37, 2004

Imprinting in Presence of a Particle (Contamination)

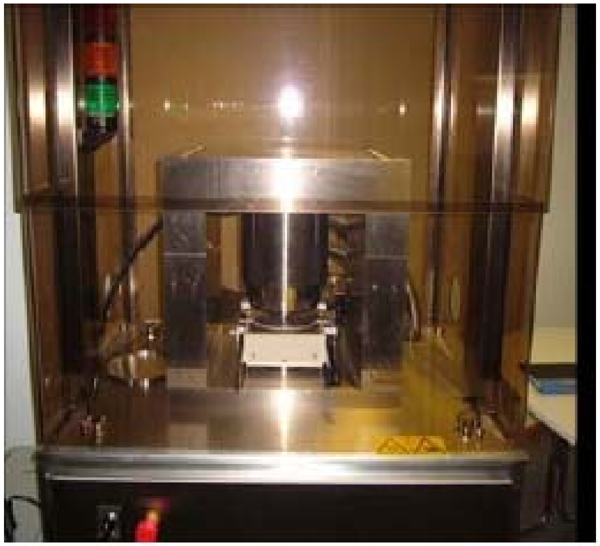


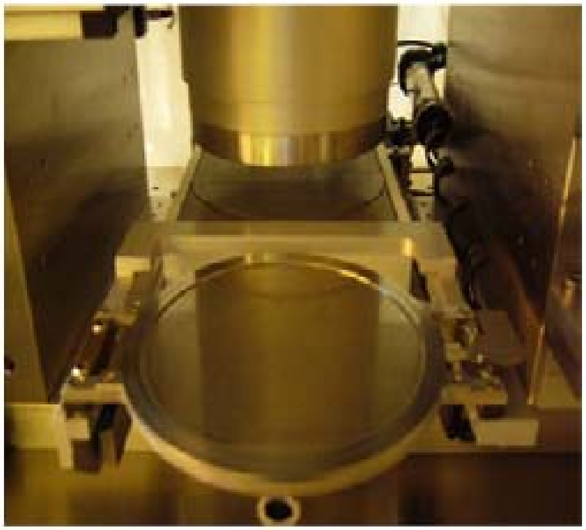
- VERY important to perform imprint in clean environment

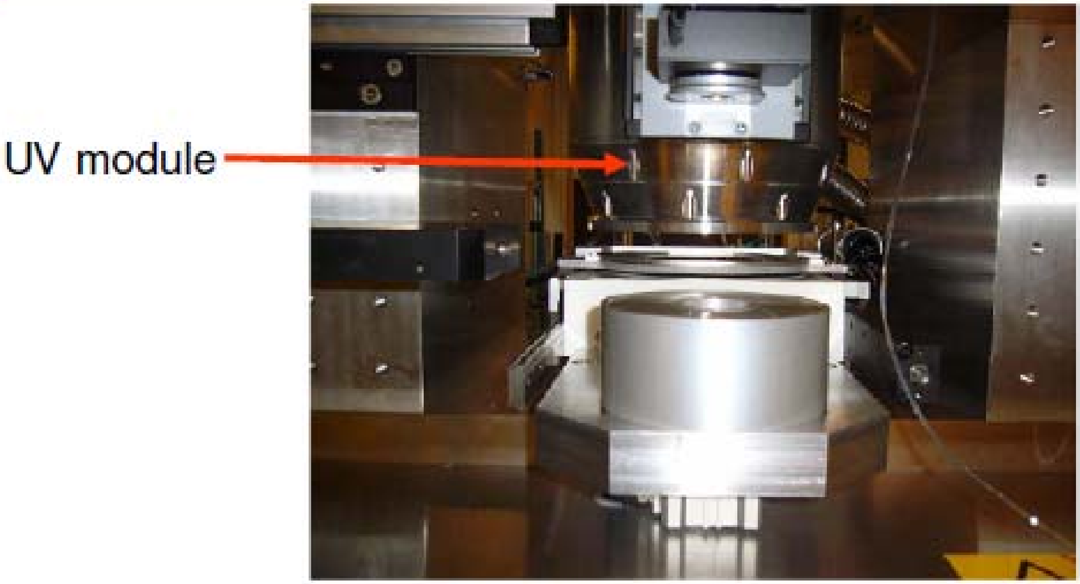
NIL System Overview

- Obducat (Sweden based)
- 6” max wafer size
- Max temp: 300˚C
- Max pressure: 70 bar
- UV module: 365 nm (filter)
- Integrated alignment: ~1um (~0.5um @ tool demo)
- Automatic demolding
- Easy software interface
- *Start-to-finish:* fully automatic or semiautomatic (up to user)

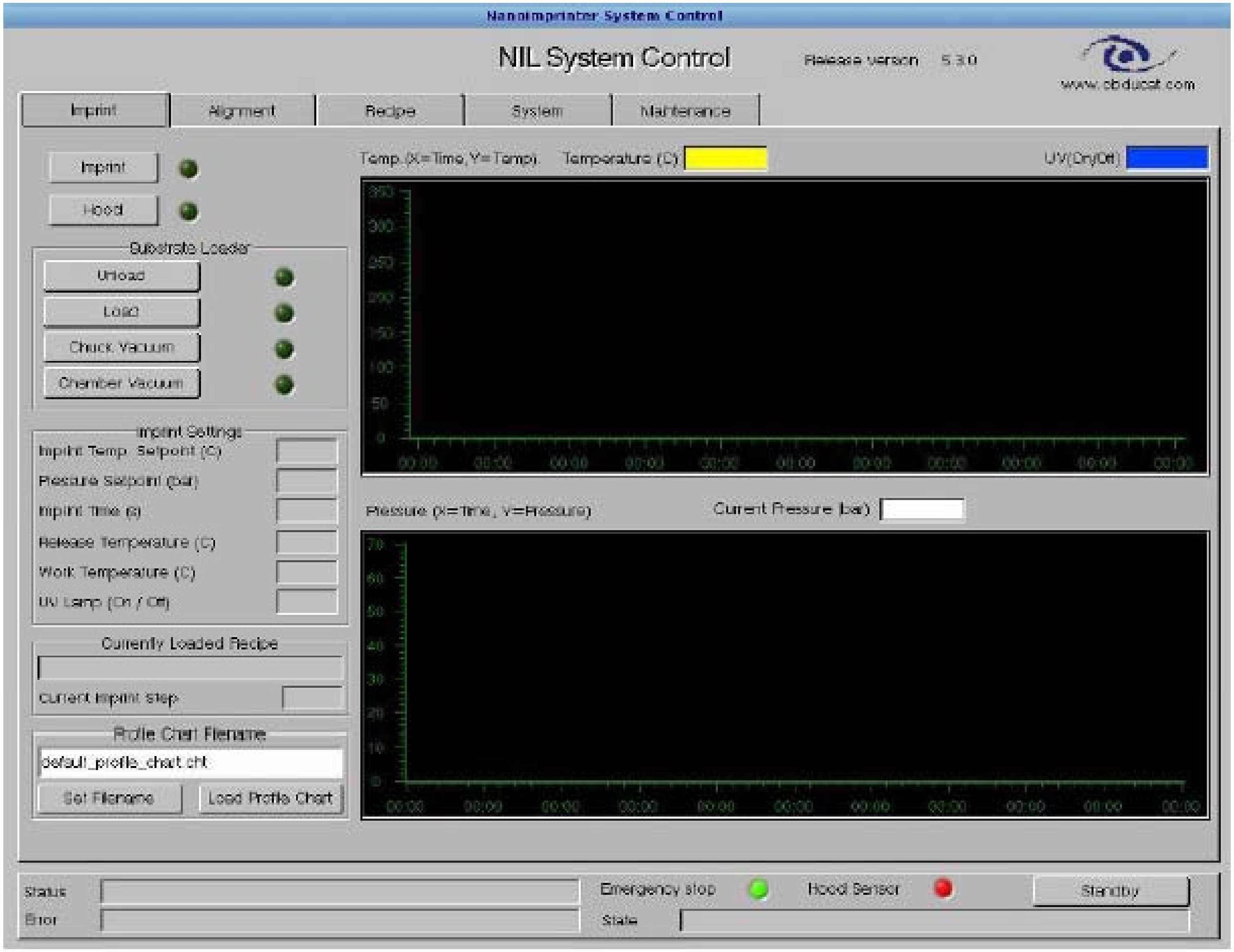
Loader & Front View of System



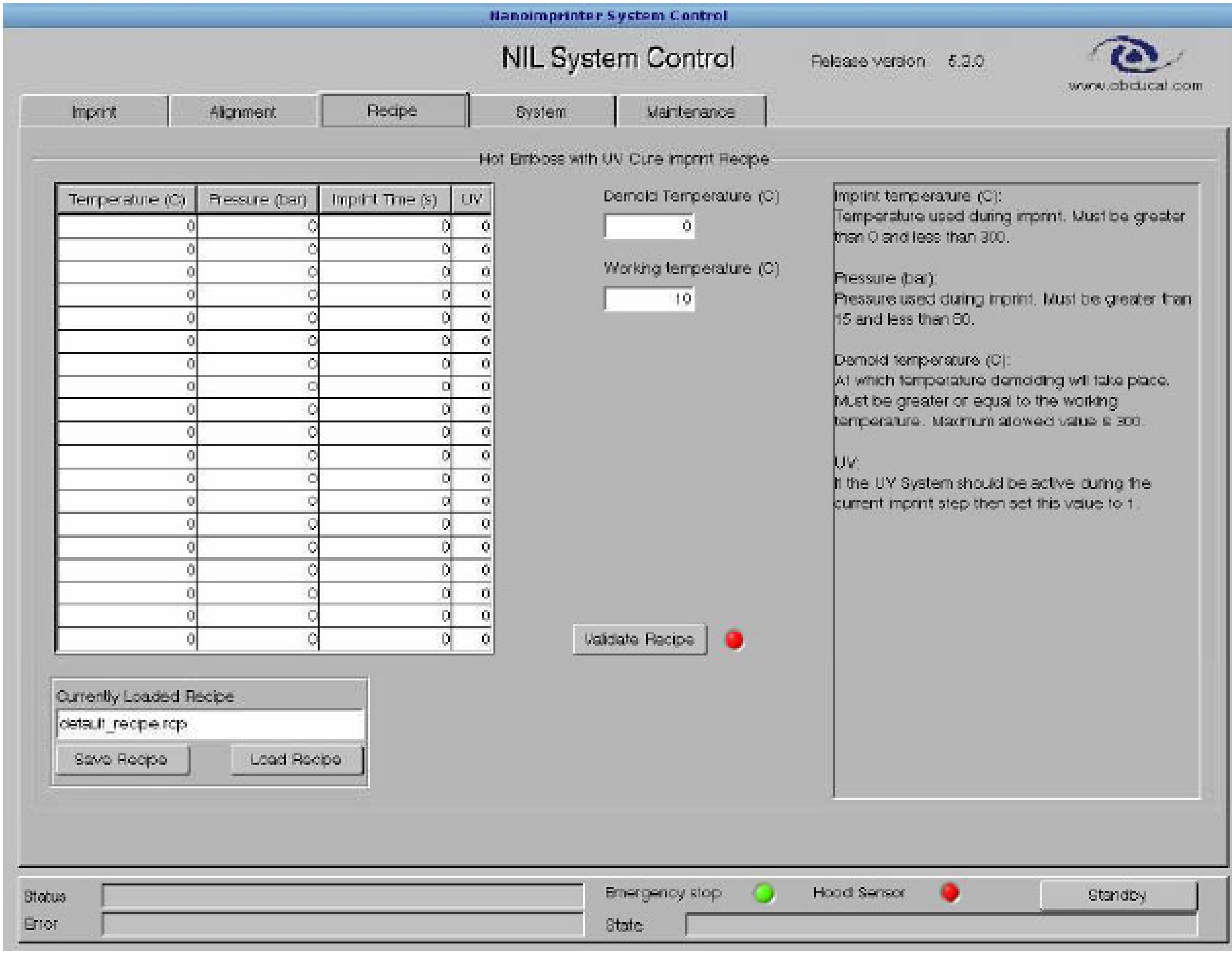




Main Operating Window in Software

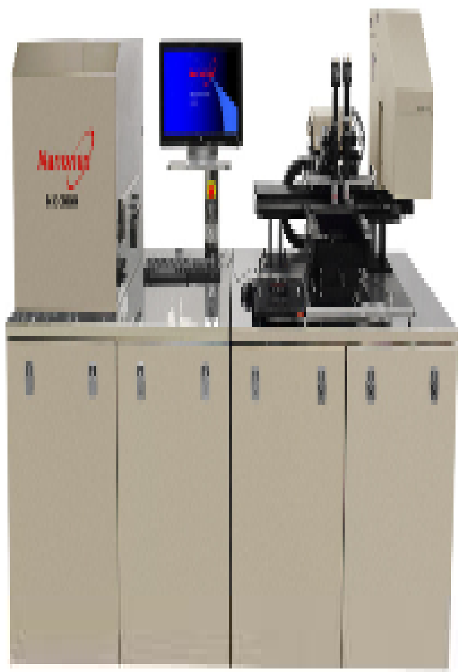


Recipe Definition in Software



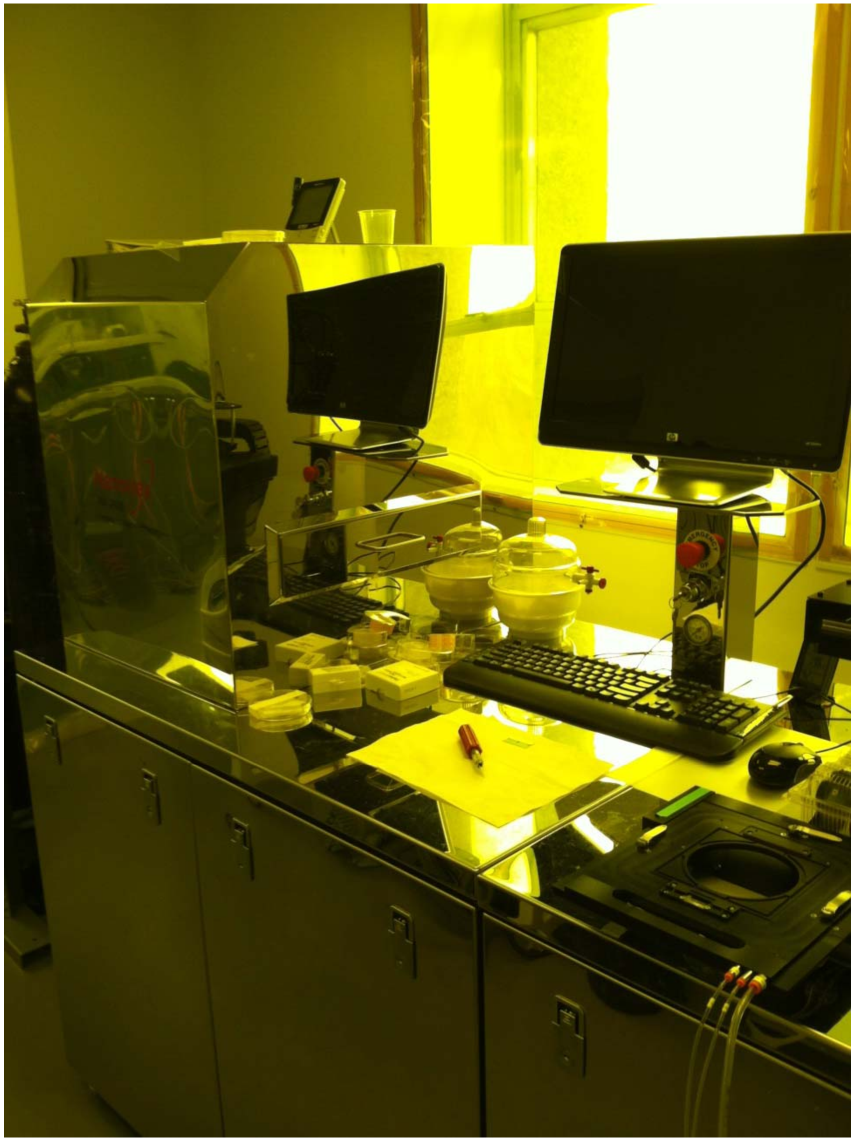
NIL System Overview

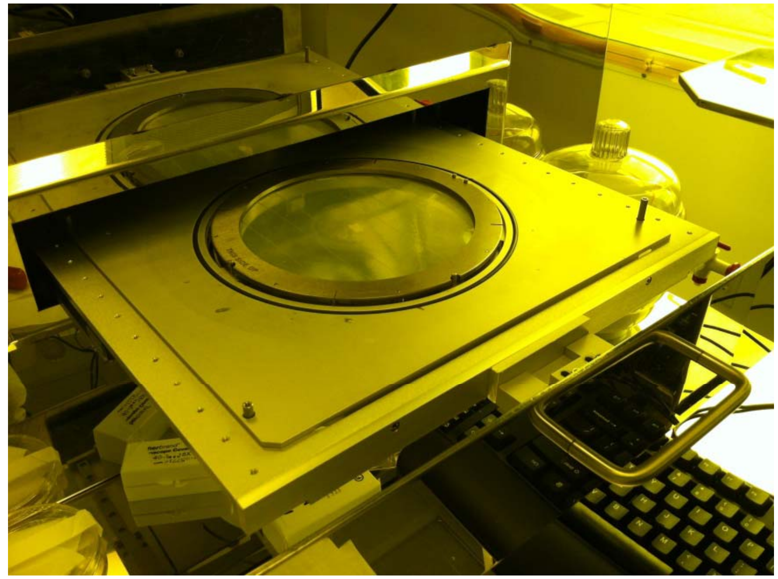
NX-2600/2600BA, Full-Wafer Imprintor with Alignment and Photolithography

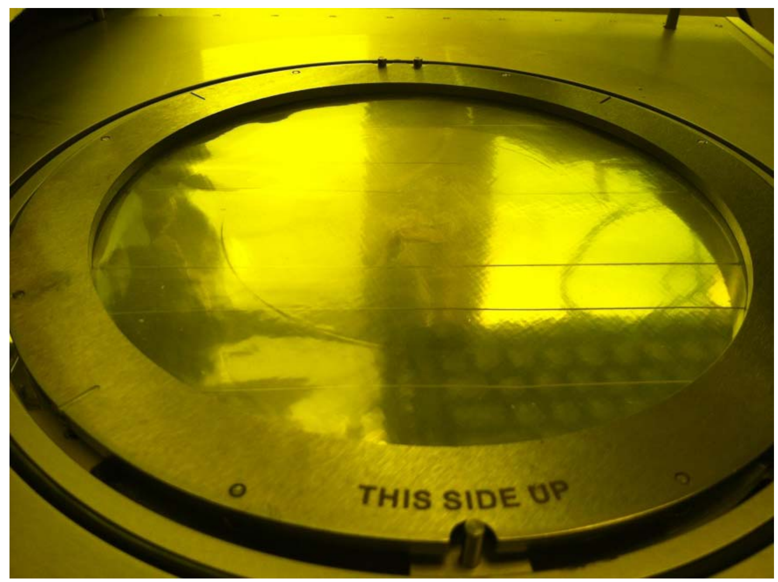


- Full-wafer (up to 8") nanoimprinting tool
- All forms of nanoimprint and high resolution photolithography
- Patented Air Cushion Press^{TM} (ACP) for ultimate nanoimprint uniformity
- Sub-micron overlay alignment accuracy and optical backside alignment (NX-2600BA)
- User friendly alignment scheme
- Smart Sample Holder for handling different sizes and irregular shapes
- Applications in opto, displays, biotechnologies, data storage, materials, ..., etc

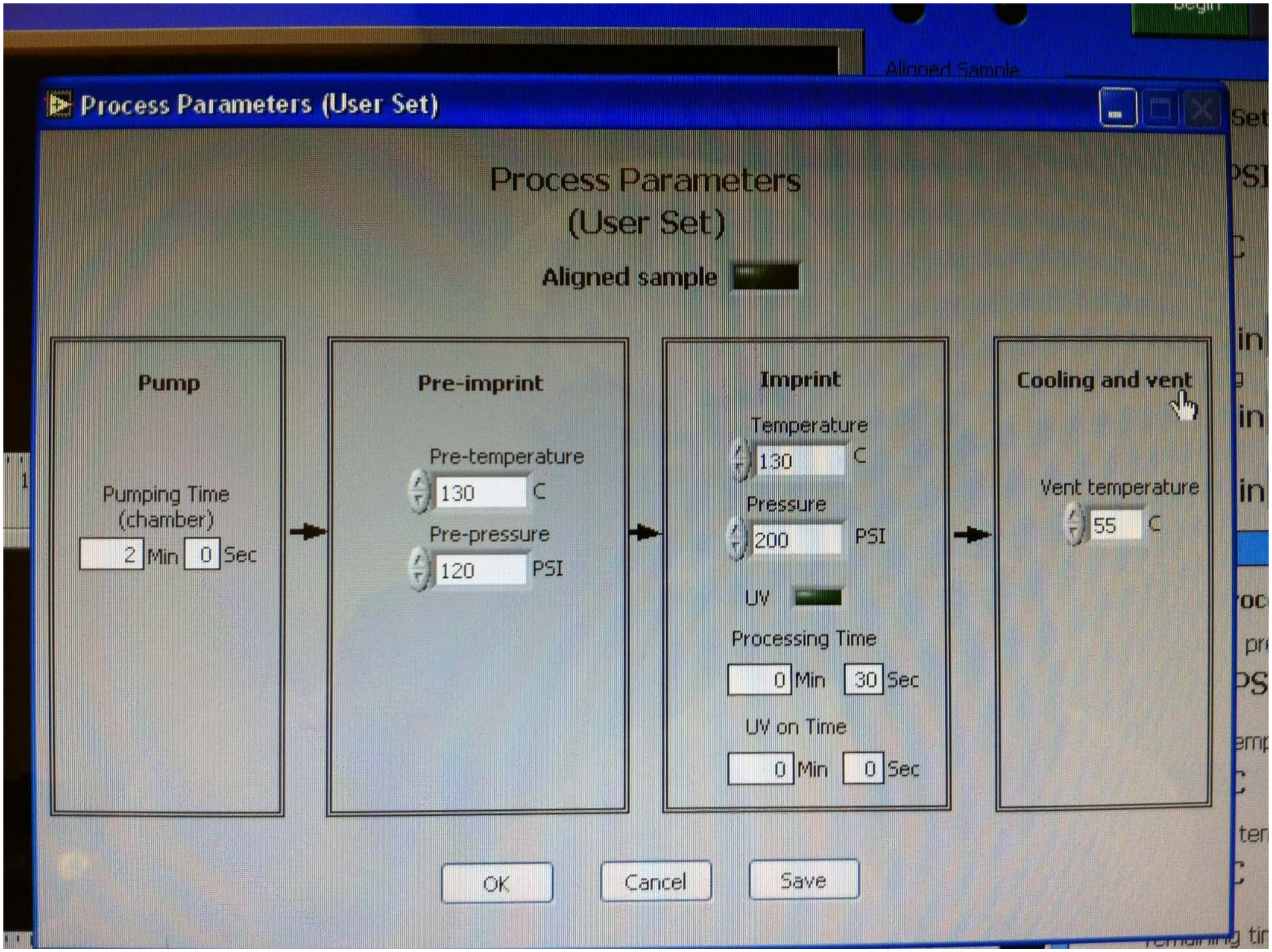
Nanonex 2600



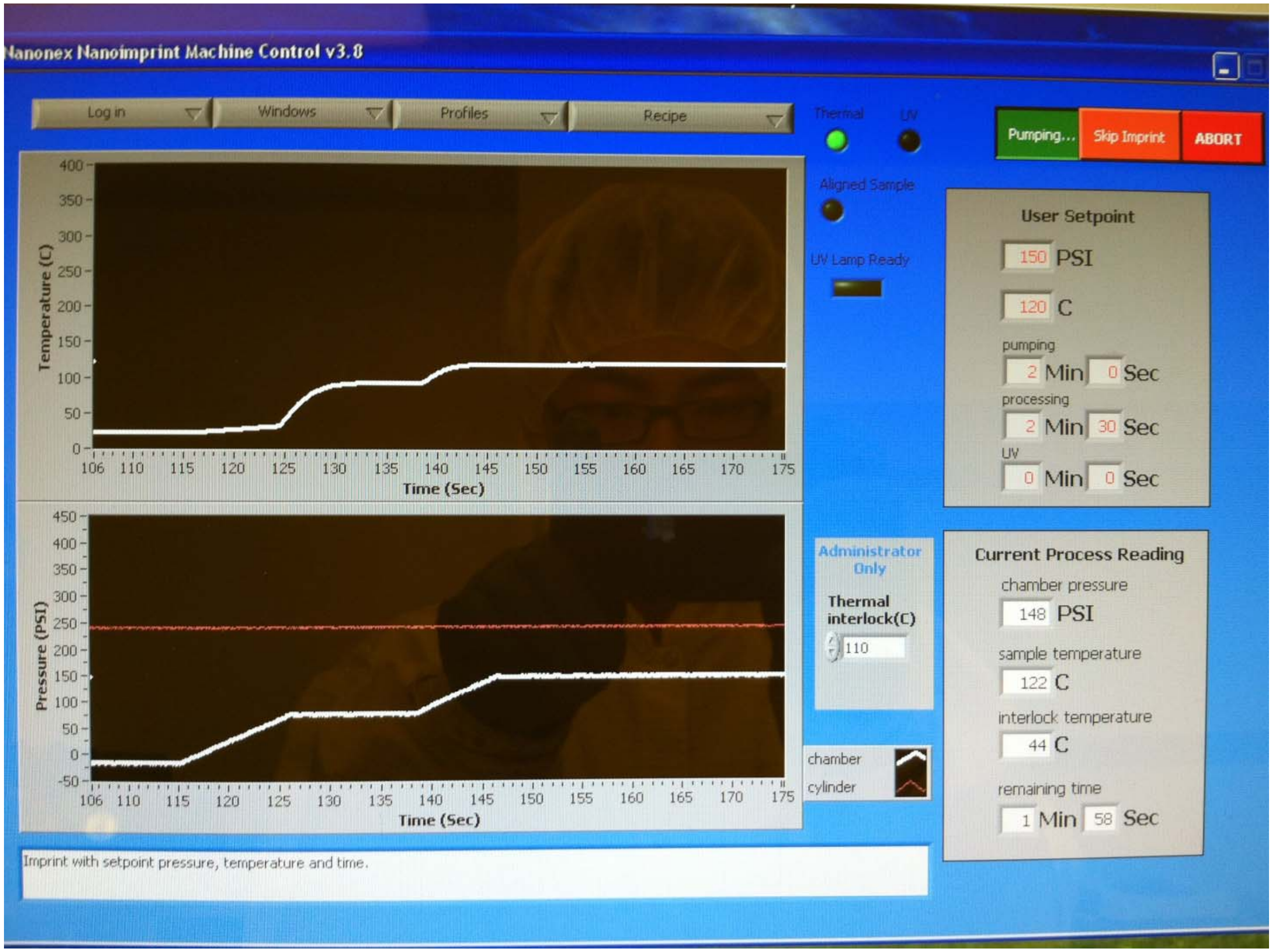




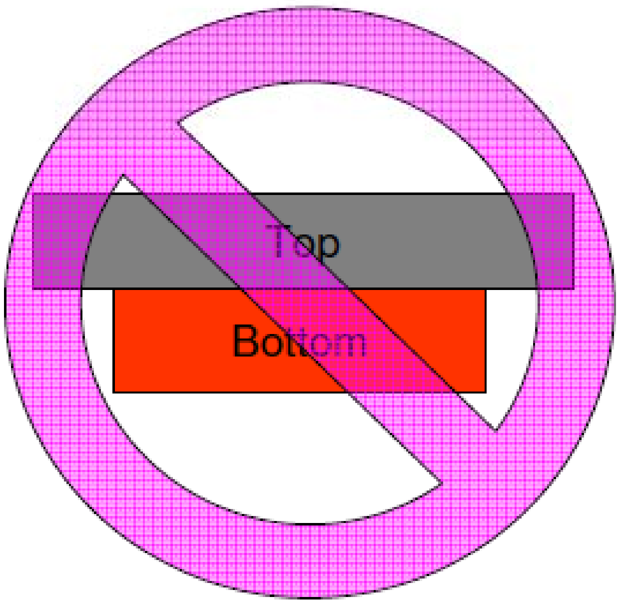
Nanonex 2600 software

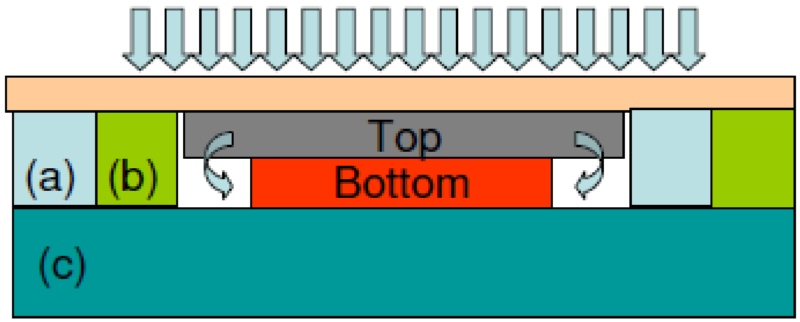


Nanonex 2600



Relative Size of Top & Bottom Substrates





Conclusion

There are major differences between soft-litho & nanoimprint-litho & photolithography:

- Soft template vs. hard template
- The resist used
- Resolution and application

Umass Lowell offer:

- Soft-litho
- Photolithography
- Nanoimprint-litho: Thermal & UV