Introduction to Soft & Nanoimprint Lithography

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Outline

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

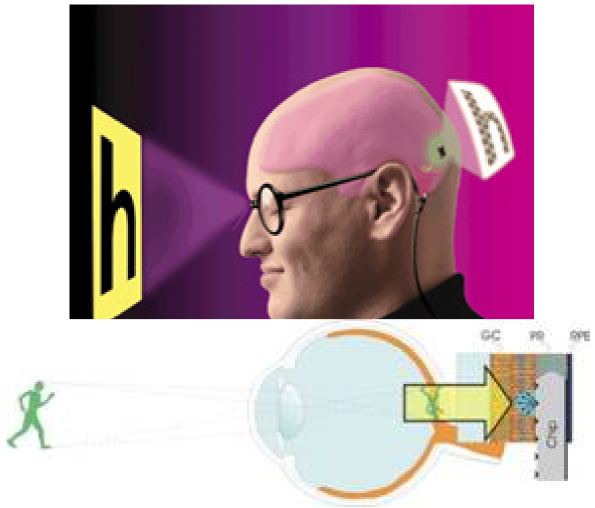
Microelectronics – Pervasive Force In Shaping Our Life

Communication

Entertainment

Productivity

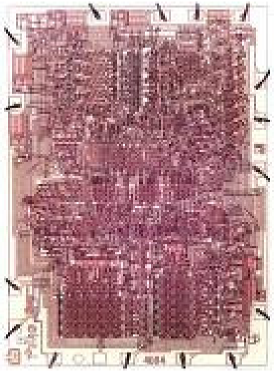
Medical



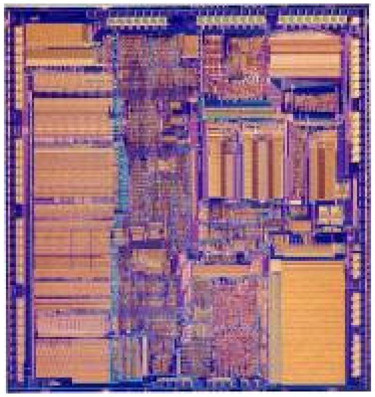
Transportation

Military

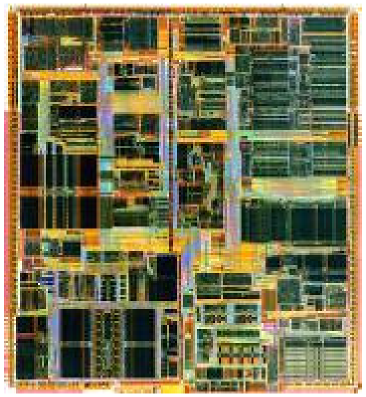
Intel Microprocessors – Brief History



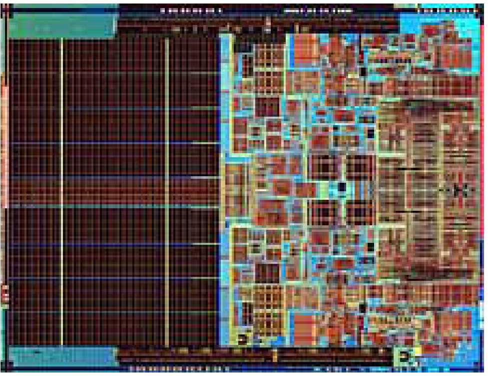
1971
Intel 4004 µP
2,300 transistors
108 KHz
10 µm linewidth



1985
Intel 386 µP
275K transistors
33 MHz
1.5 µm



1997
Intel PII µP
7.5 M-transistor
300 MHz
0.25 µm



2006
Intel Core 2 Duo
291 M-transistor
2.4 GHz
0.065 µm

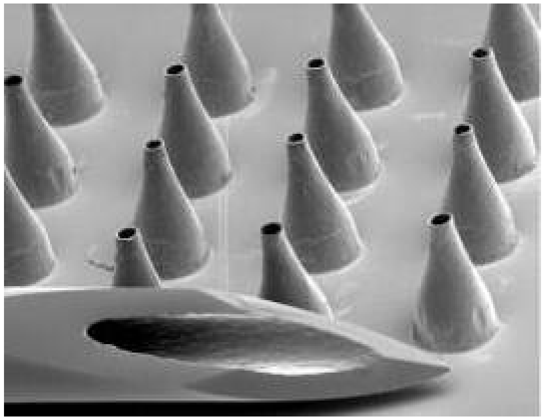
Historically, advances in microelectronics have been due to ability to making smaller and denser patterns.

→Photolithography has been the workhorse of the semiconductor industry.

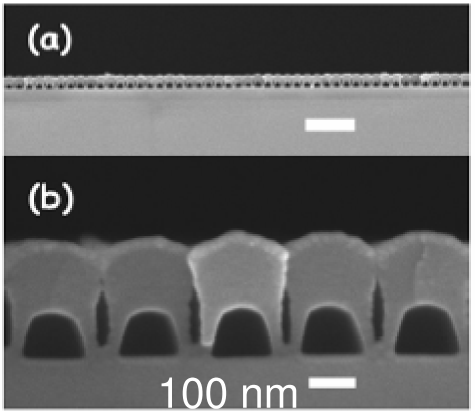
→ Lithography is key technology pacing Moore’s Law

Also, Many Exciting "Non-Microprocessor" Technologies Enabled

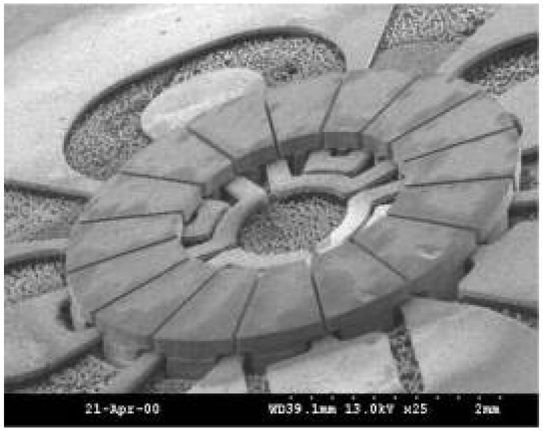
Examples of such at the MiRC



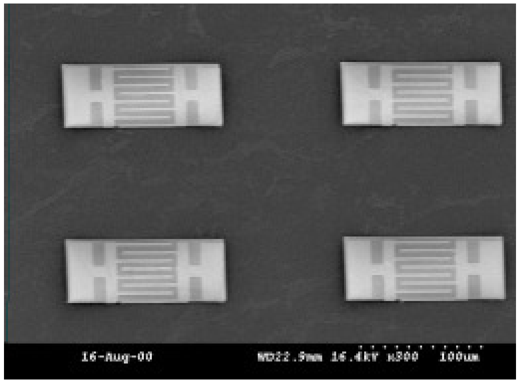
Bio-MEMS



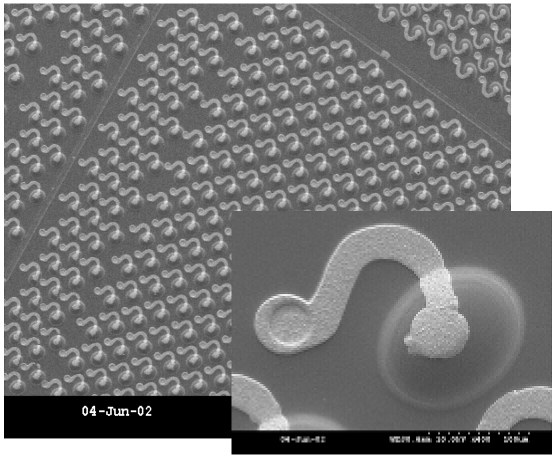
Nano-Fluidics



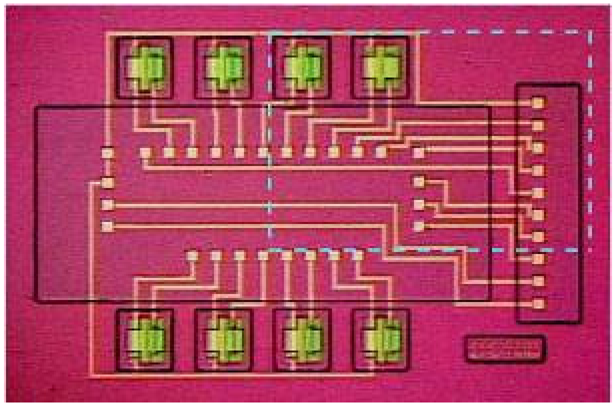
MEMS



Compound Semiconductors

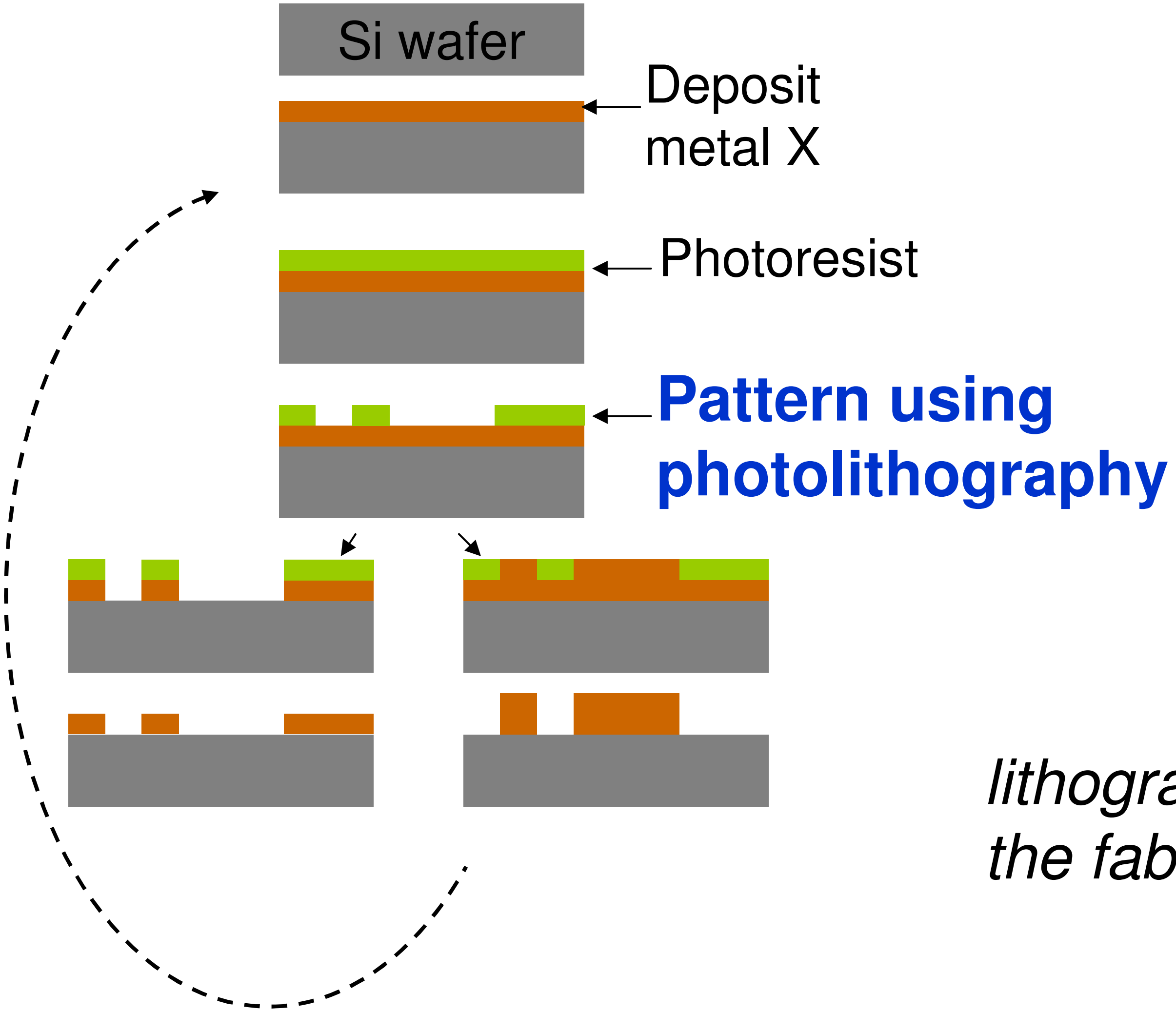


Electronic Packaging



Chemical Sensitive Transistor "Electronic Nose"

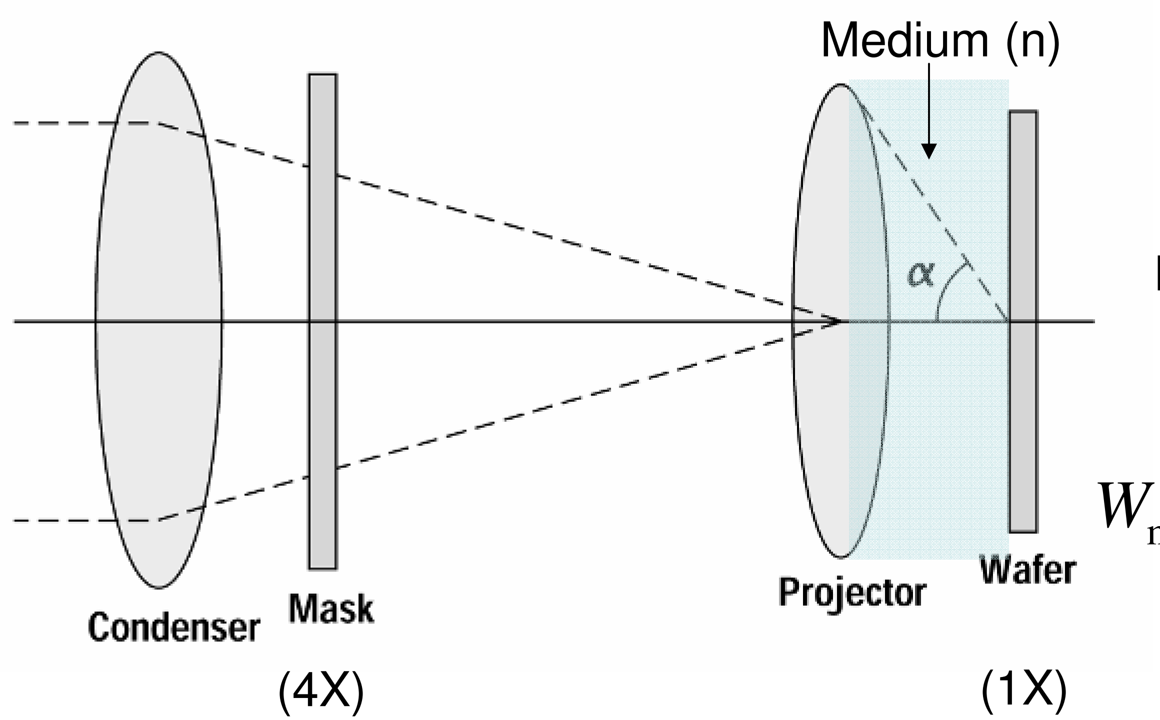
A Common Fabrication Sequence



lithography is the heart of the fabrication process

Optical Projection Printers

- Most widely used litho for IC manufacturing



NA=n sinα
typically {0.16-0.8}

Rayleigh's equation

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

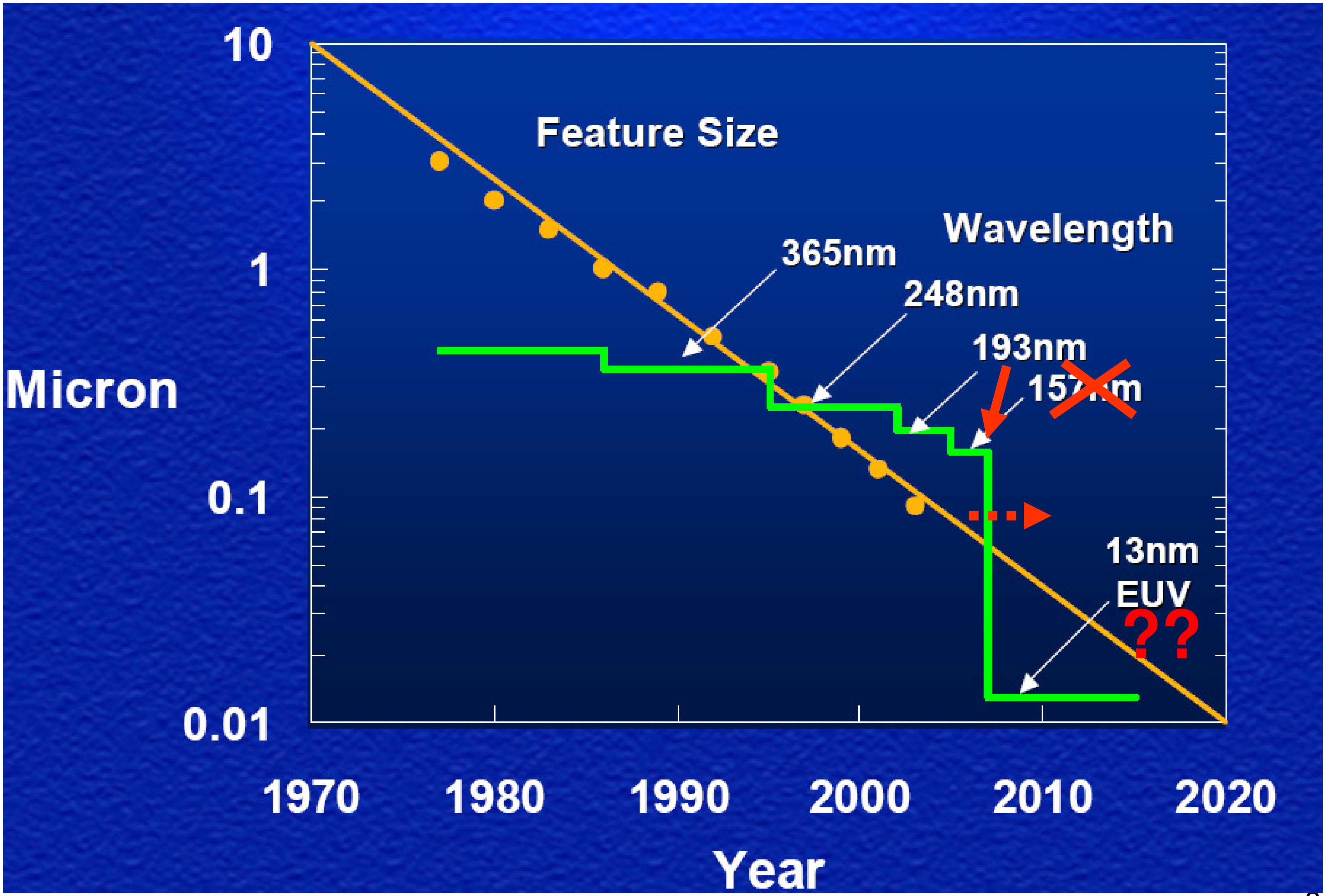
$$W_{\min} \downarrow : \lambda \downarrow, \underbrace{NA \uparrow}, k \downarrow$$

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

- 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

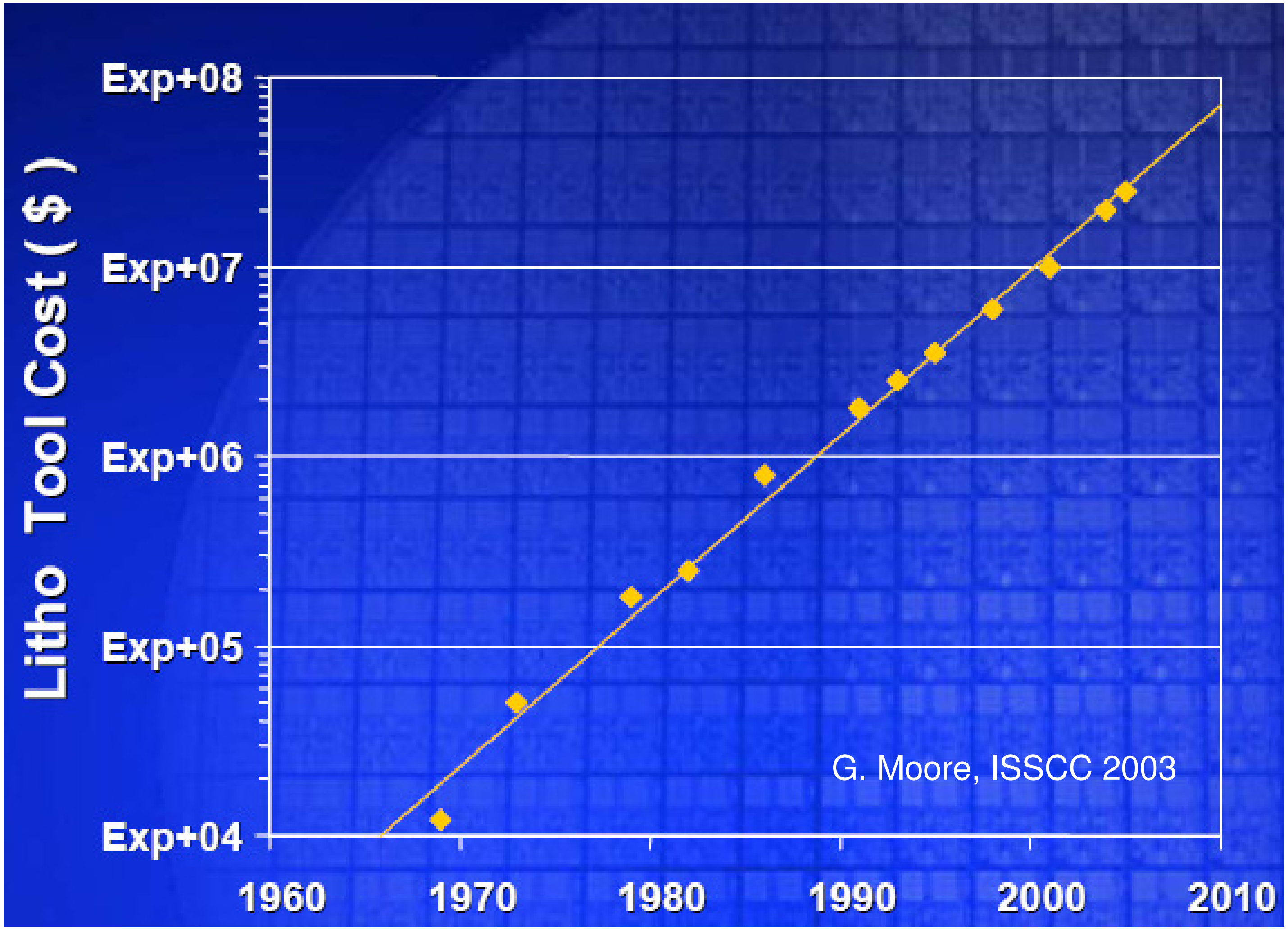
Nominal Feature Size Trend & Lithography λ



A. Grove, IEDM 2002

Cost of Lithography Systems !!!!!!

Approaching $100M+ litho systems



mask set cost few M$

Are there any cheaper/better alternatives to optical litho???

Key Requirements of Lithography for Manufacturing ICs*

- Critical Dimension Control
  - Size of features must be controlled within wafer and wafer-to-wafer
- Overlay
  - For high yield, alignment must be precisely controlled
- Defect Control
  - Other than designed pattern, no additional patterns must be imaged
- Low Cost
  - Tool, resist, mask; fast step-and-repeat

→30-40% of total semiconductor manufacturing cost is due to lithography (Masks, resists, metrology)

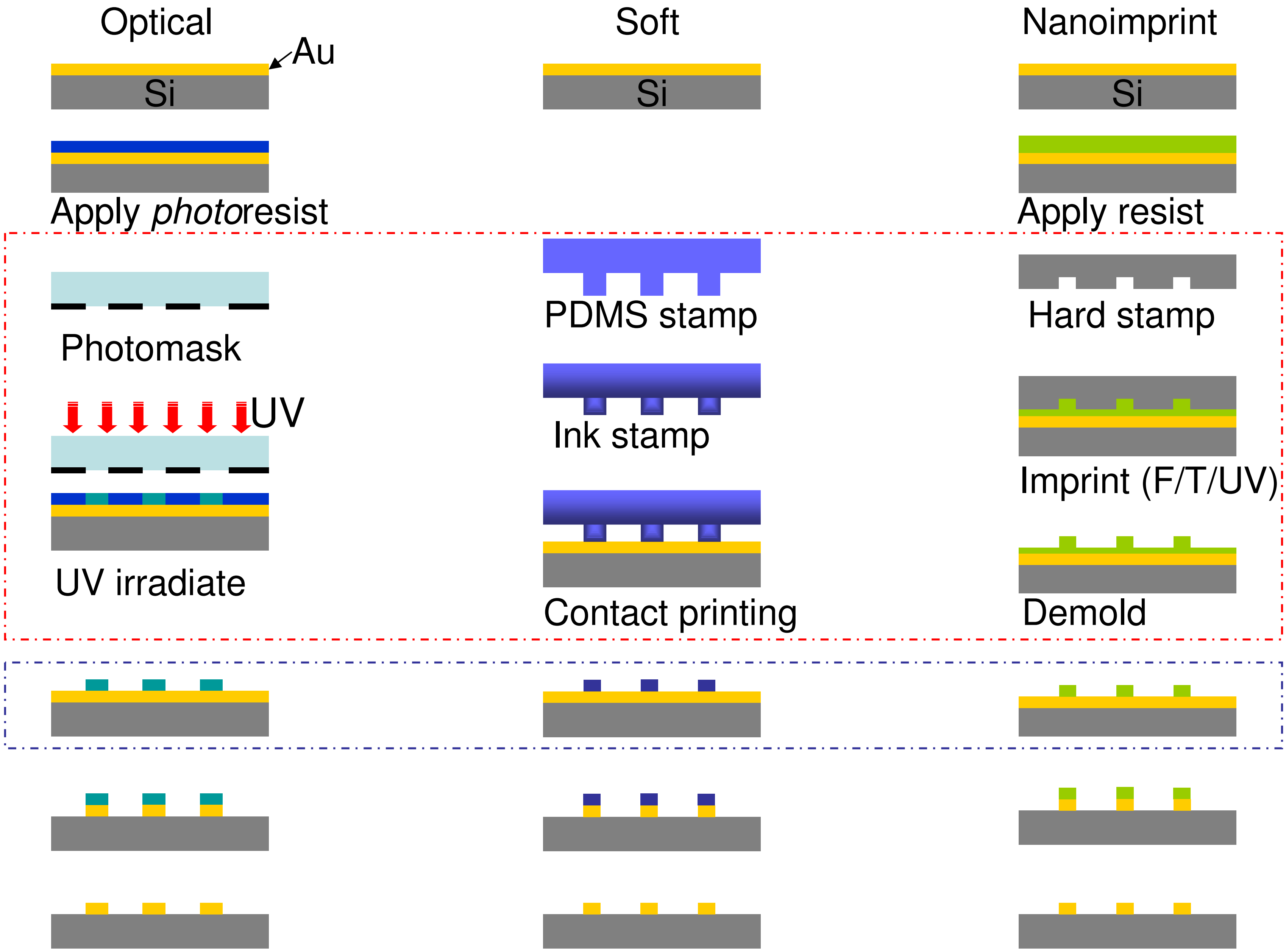
→At the end of the roadmap, μP will require **39** mask levels

**ITRS 2005/6, Lithography*

Objectives of This Presentation

1. To introduce soft & nanoimprint lithography
2. Compare and contrast the different lithography technologies
3. Describe the nanoimprint lithography capability at the MiRC
4. Cultivate interest by highlighting unique opportunities from nanoimprint lithography

Optical Vs. Soft Vs. Nanoimprint Lithography



Apply *photo*resist

Apply resist

Photomask

PDMS stamp

Hard stamp

Ink stamp

UV irradiate

Imprint (F/T/UV)

Contact printing

Demold

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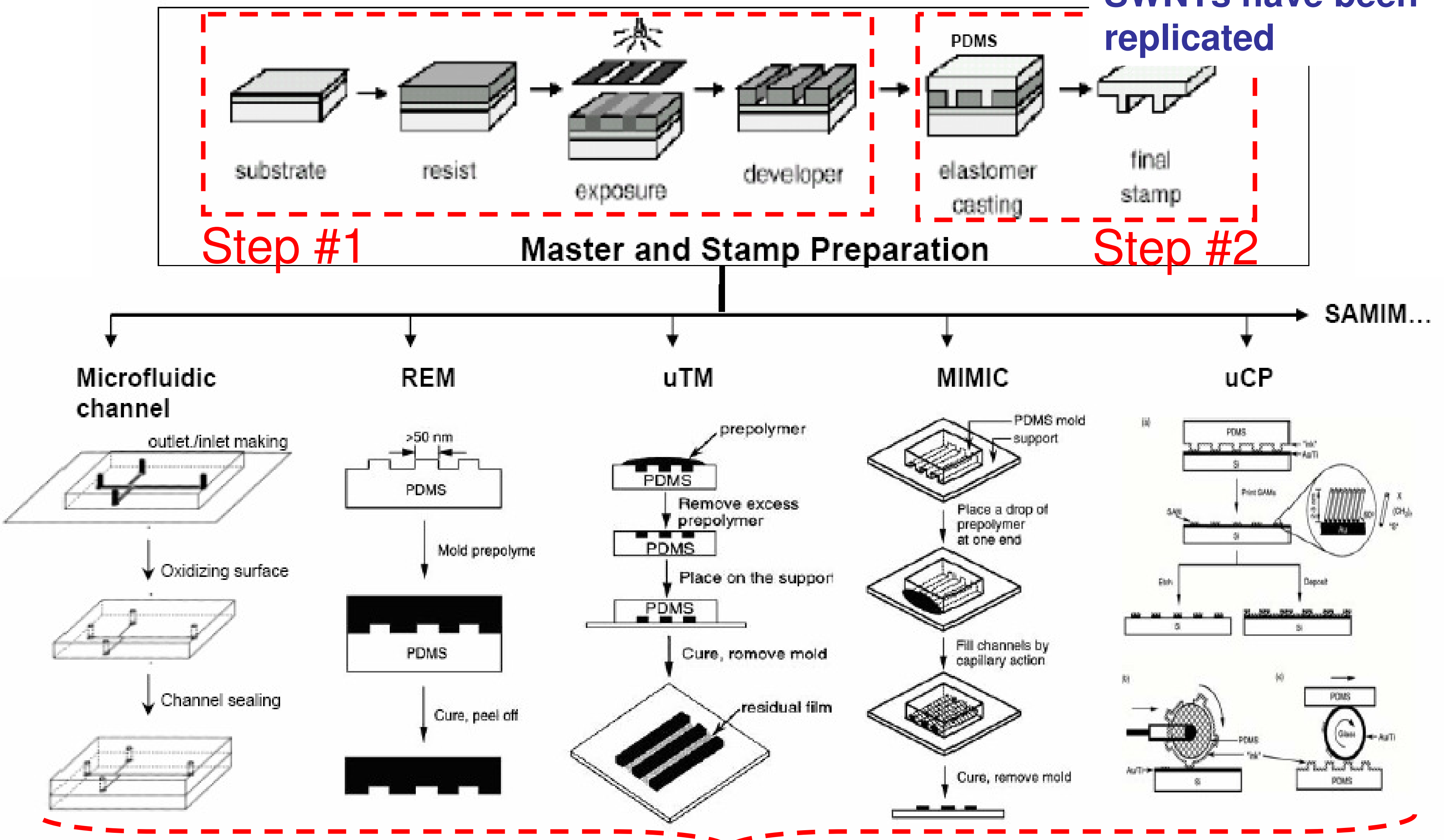
Soft Lithography Implementation

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



SWNTs have been replicated

Step #1

Step #2

Step #3

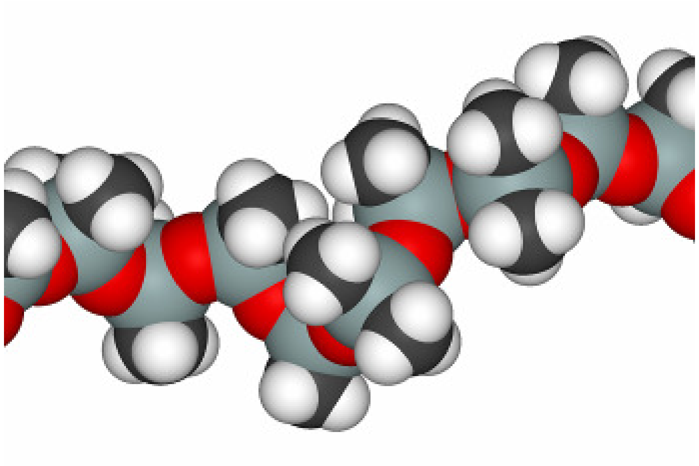
Images courtesy of D. Qin, Univ. of Washington

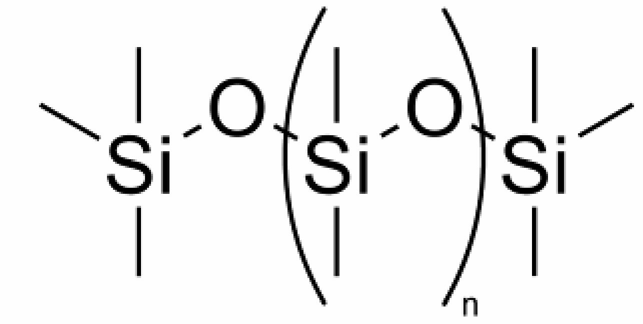
PDMS Properties

PDMS: Poly(dimethylsiloxane)

- Silicone elastomer
- Range of viscosities
- Transparent
- Flexible (1 MPa Young's modulus)
- Very easy to mold
- Replicates features faithfully
- Biocompatible (even food additive)
- Seals to flat and clean surfaces
- Sylgard 184 (Dow Corning brand)

→Silanization of master mold needed

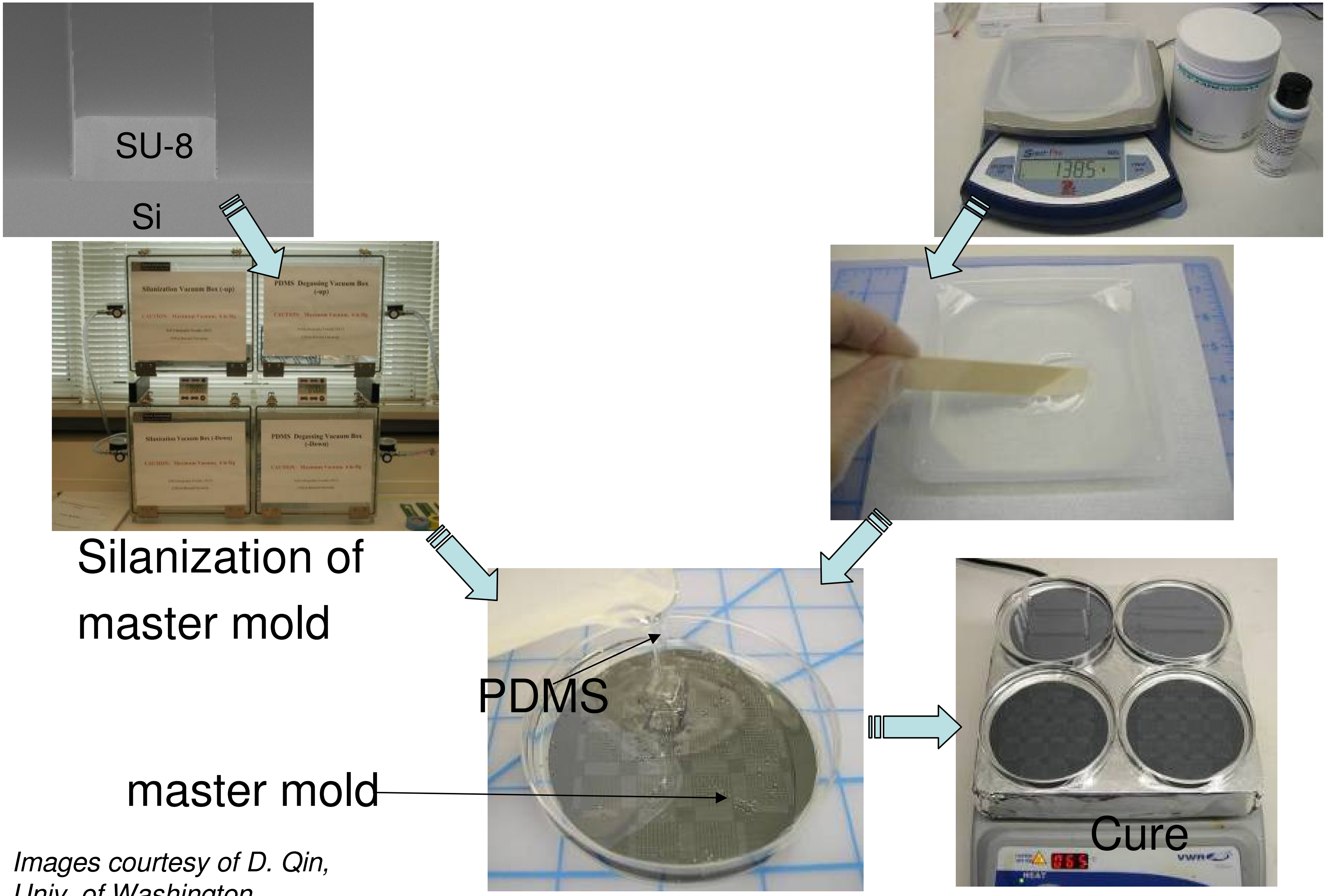




(Source: Wikipedia)

Slide courtesy of D. Qin, Univ. of Washington

The Three Fabrication Steps



SU-8

Si

Silanization of master mold

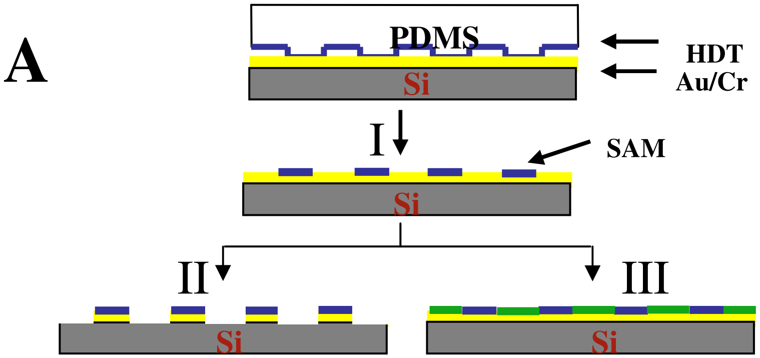
PDMS

master mold

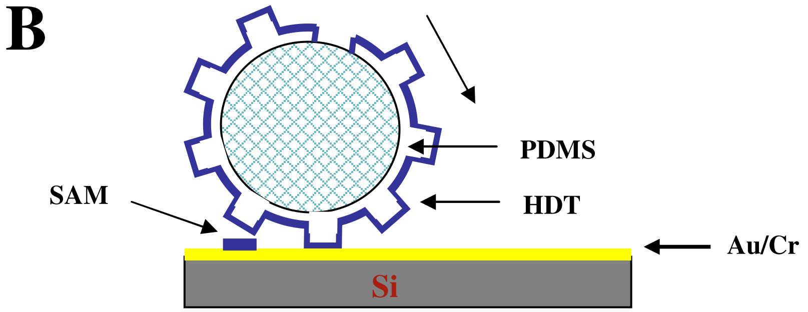
Cure

Images courtesy of D. Qin,
Univ. of Washington

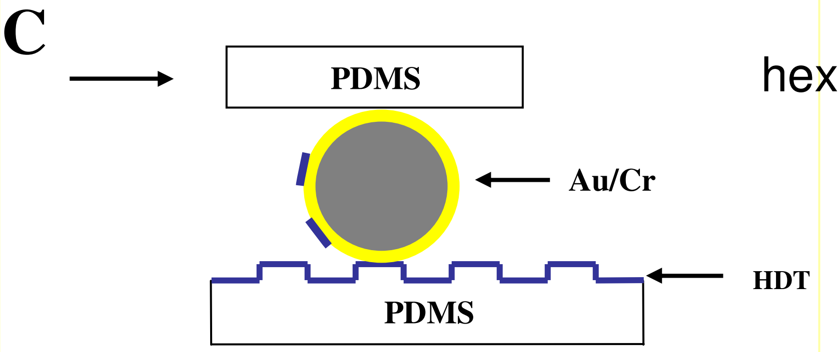
Microcontact Printing (uCP)



Printing on a planar surface with a planar stamp



Printing on a planar surface with a rolling stamp



Printing on a nonplanar surface with a planar stamp

hexadecanethiol (HDT)

A. Kumar & G. Whitesides,
Applied Physics Lett. 1993

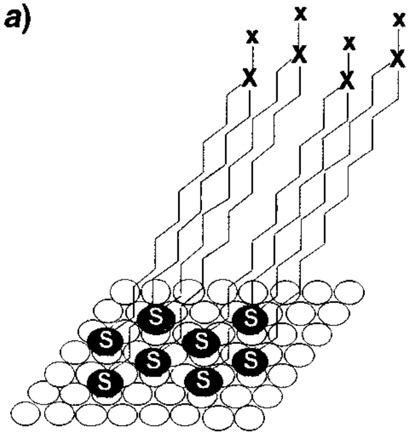
Slide courtesy of D. Qin, Univ. of Washington

Methods of Applying Alkanethiols (Resist) on Stamp

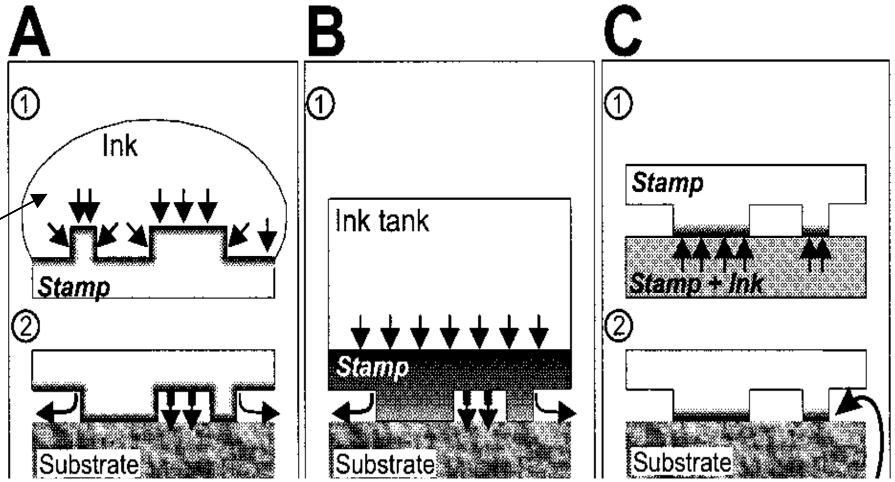
- Alkanethiol molecules form self-assembled monolayer (SAM) on surface of noble metals (Au, Ag)
- These monolayers allow control over wettability, adhesion, chemical reactivity, electrical conduction, and mass transport to underlying metal
- Linear alkanethiols with various molecular weights

158 g mol^{-1} (dodecanethiol, DDT)
258 g mol^{-1} (hexadecanethiol, HDT)
314 g mol^{-1} (eicosanethiol, ECT)

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



G. Whitesides *et al.*, Ann. Rev. Biomed. Eng., 2001



Ethanolic
solution
of a thiol

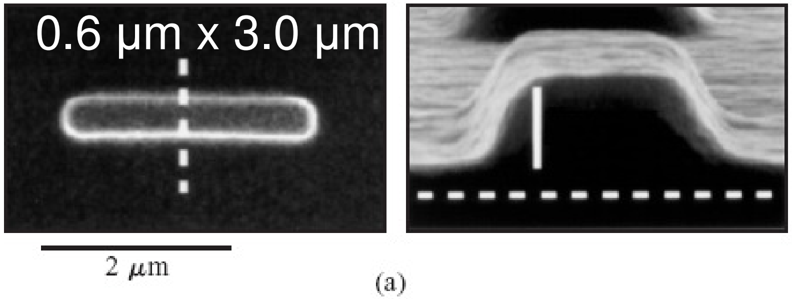
L. Libioulle et al, *Langmuir (ACS)* 1999

Transport Mech. of Alkanethiols during uCP on Au

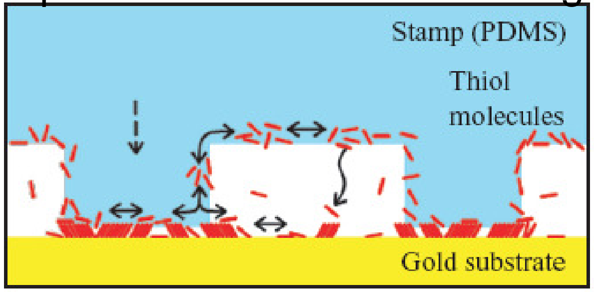
- Template features limited to low aspect ratio (b/c low modulus)

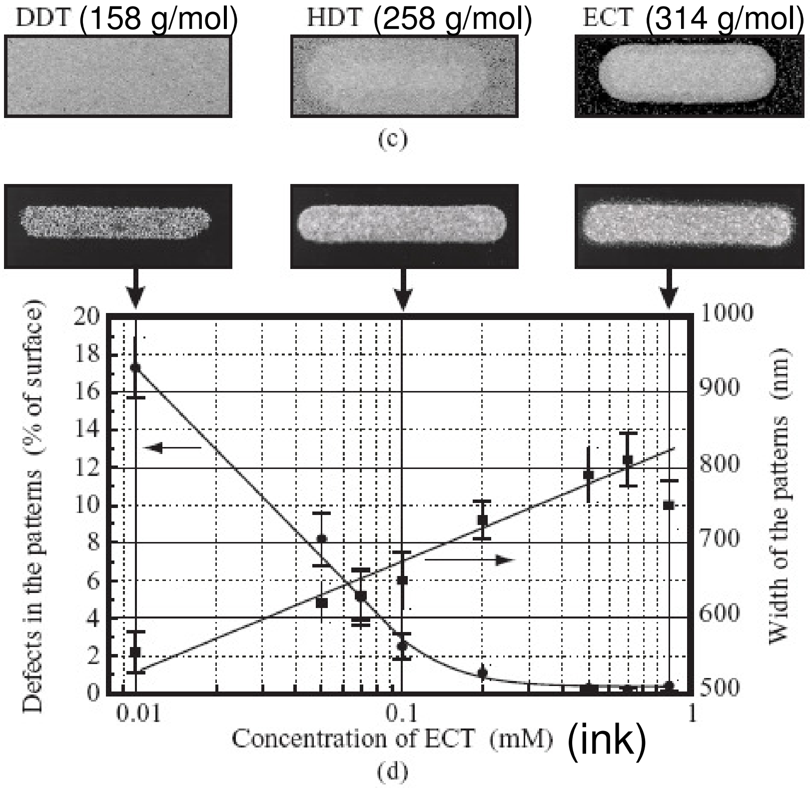
Transport mechanism into no-print area Include:

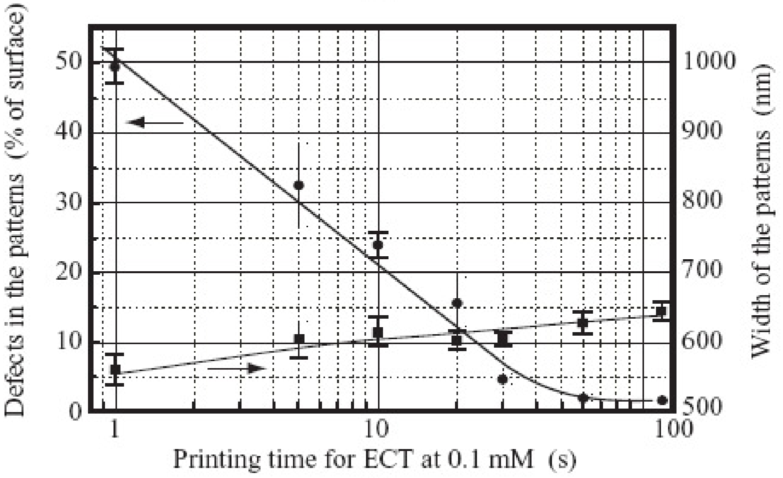
1) Gas-phase diffusion (surface/ambient)
    - As MW ↑, vapor pressure ↓
2) Diffusion of molecules along surface



diffusion paths of molecular ink during printing



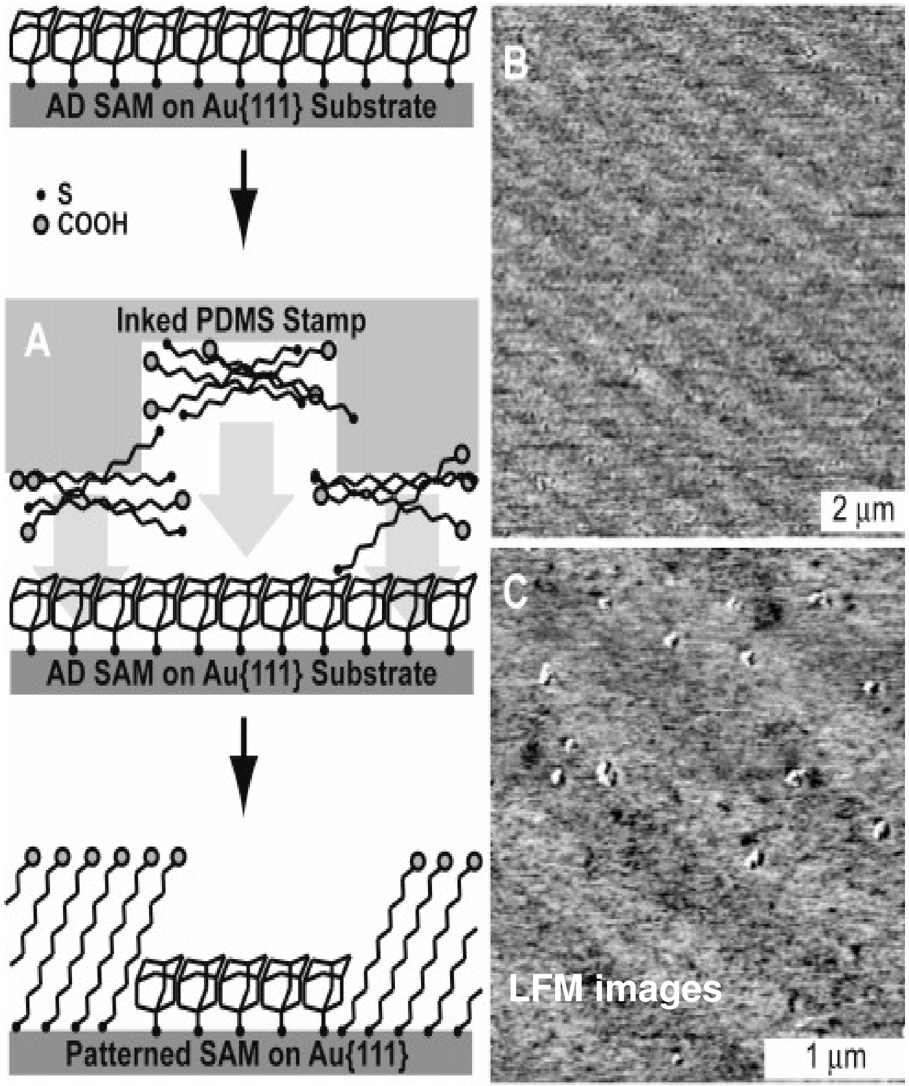




B. Michel *et al.*, *IBM J. Res. & Dev.* 2001

E. Delamarche *et al.*, *J. Phys. Chem. B*, 1998

MicroDisplacement Printing (µDP)



Lateral diffusion rate of ink on surface ↑ as alkyl chain length↓. Low molecular weight molecules highly susceptible to diffusion

If no backfilling, lateral mobility ↑

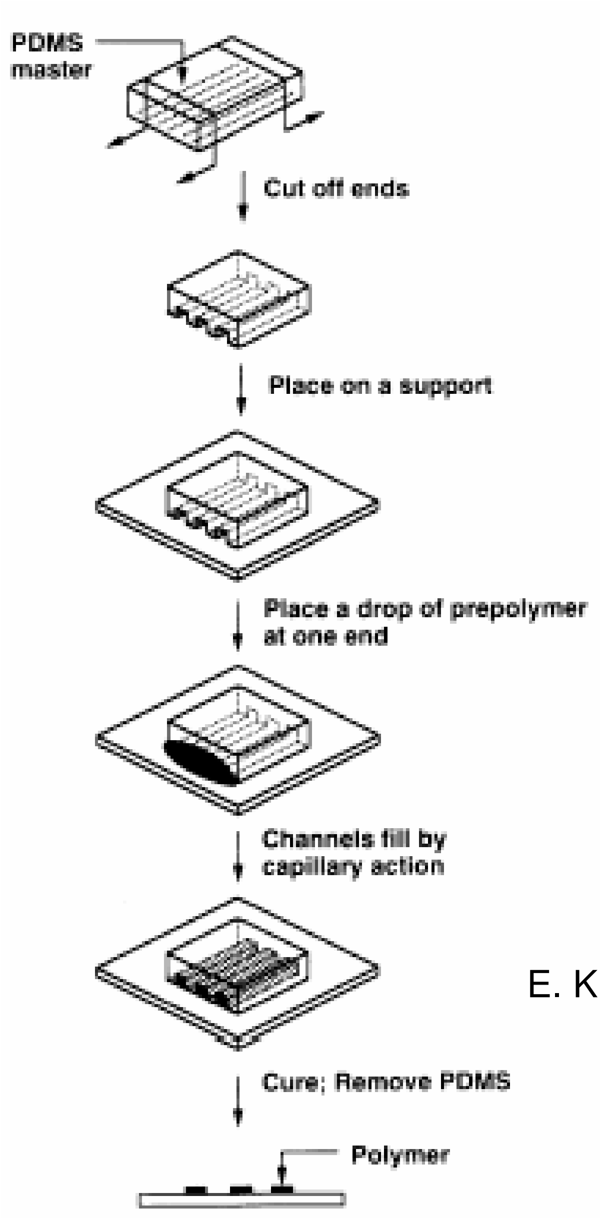
AD: 1-adamantanethiolate; form close-packed one-molecule thick film

AD films are labile (weakly bound - possible to displace AD molecule from surface with another thiolated molecule (n-alkanethiol))

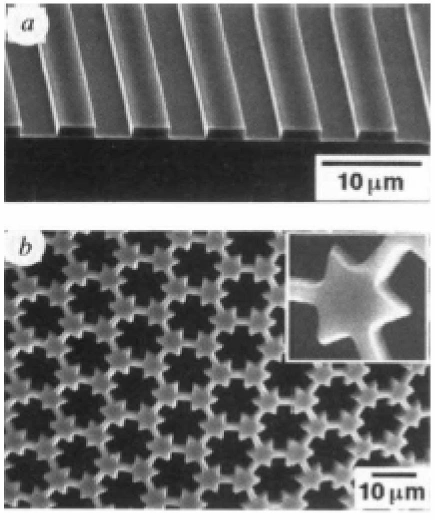
AD SAM minimize lateral surface diffusion and molecular exchange of ink during printing

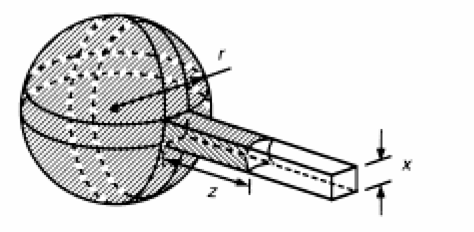
A. Dameron et al., *Nano Letters*, Aug. 2005

Micro/Nanomolding in Capillaries



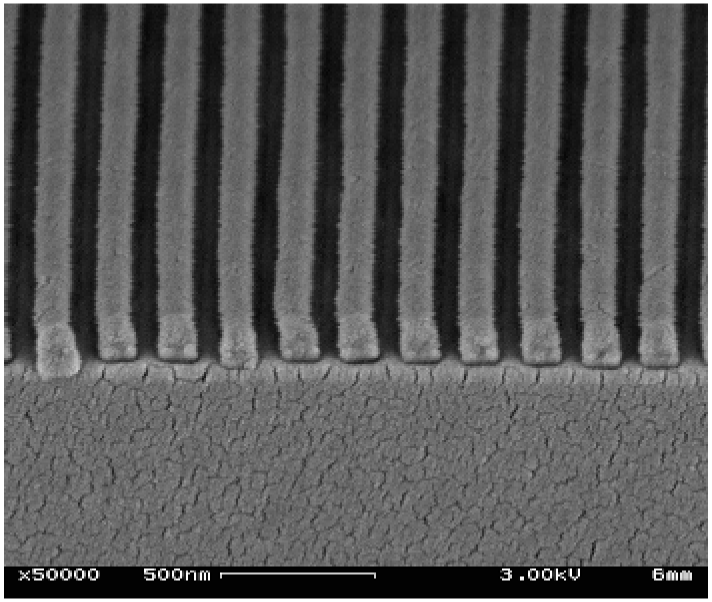
Micro-



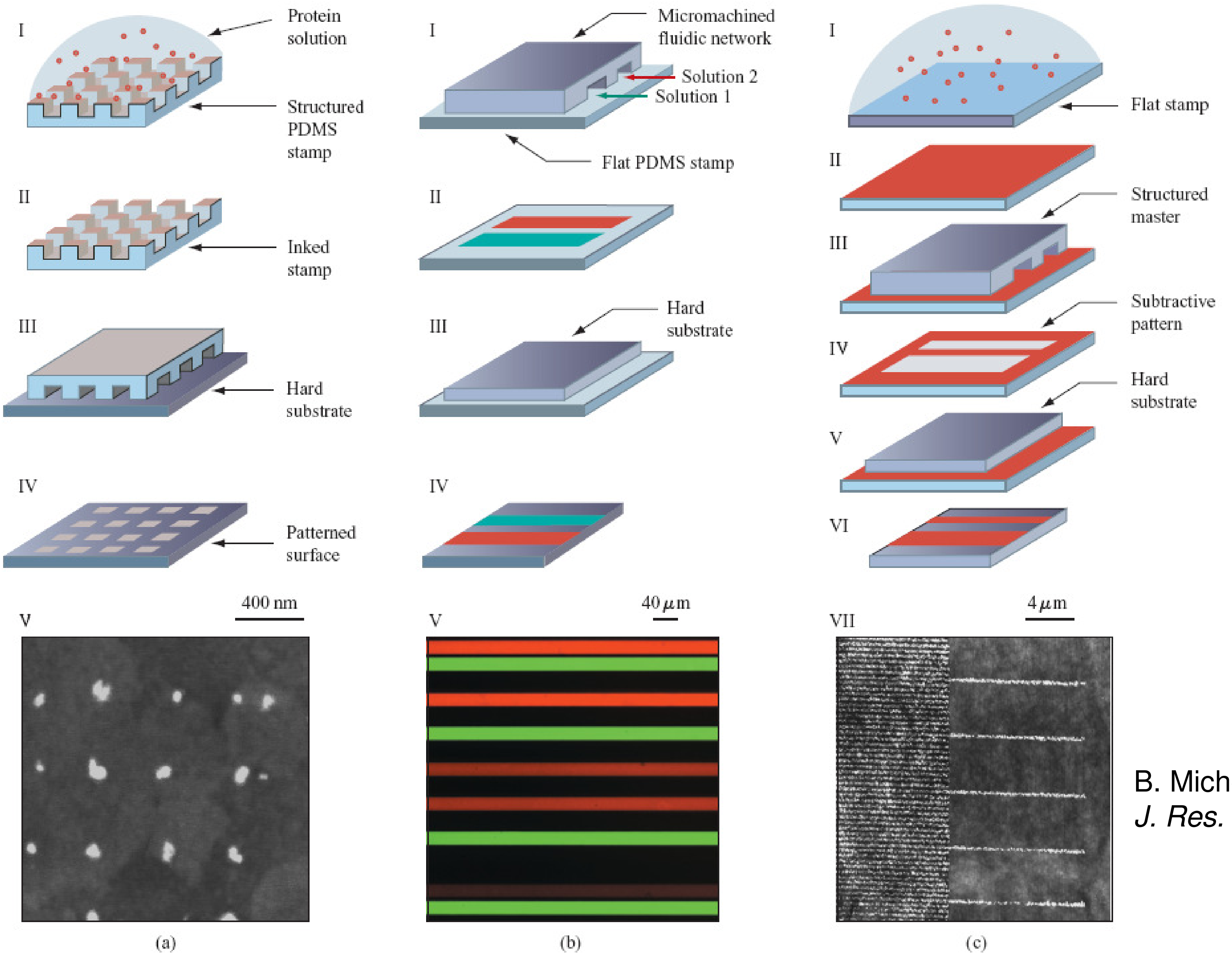


E. Kim et al., *Nature* Aug. 1995

Nano-

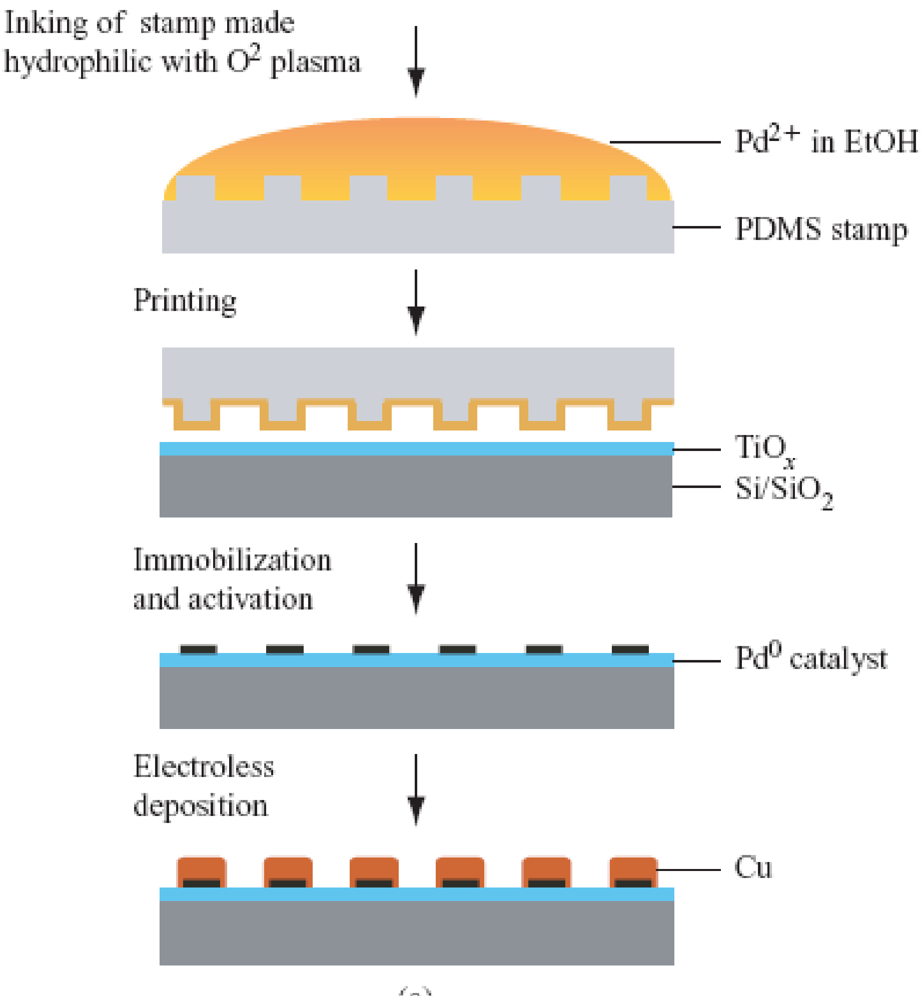


Printing of Biological Molecules (Proteins)



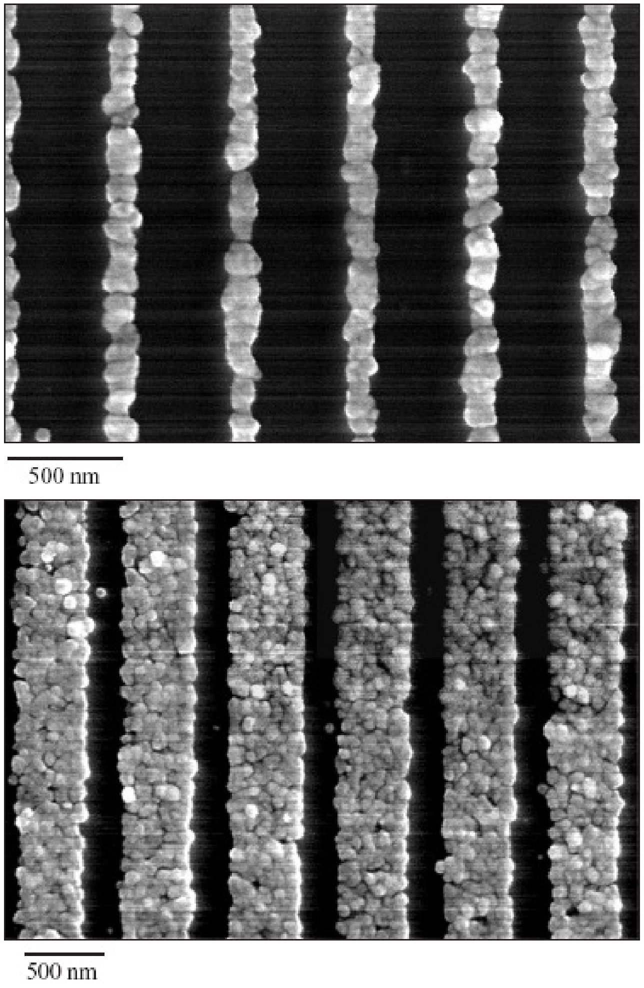
B. Michel *et al.*, *IBM J. Res. & Dev*. 2001

Patterning of Palladium for Electroless Cu plating

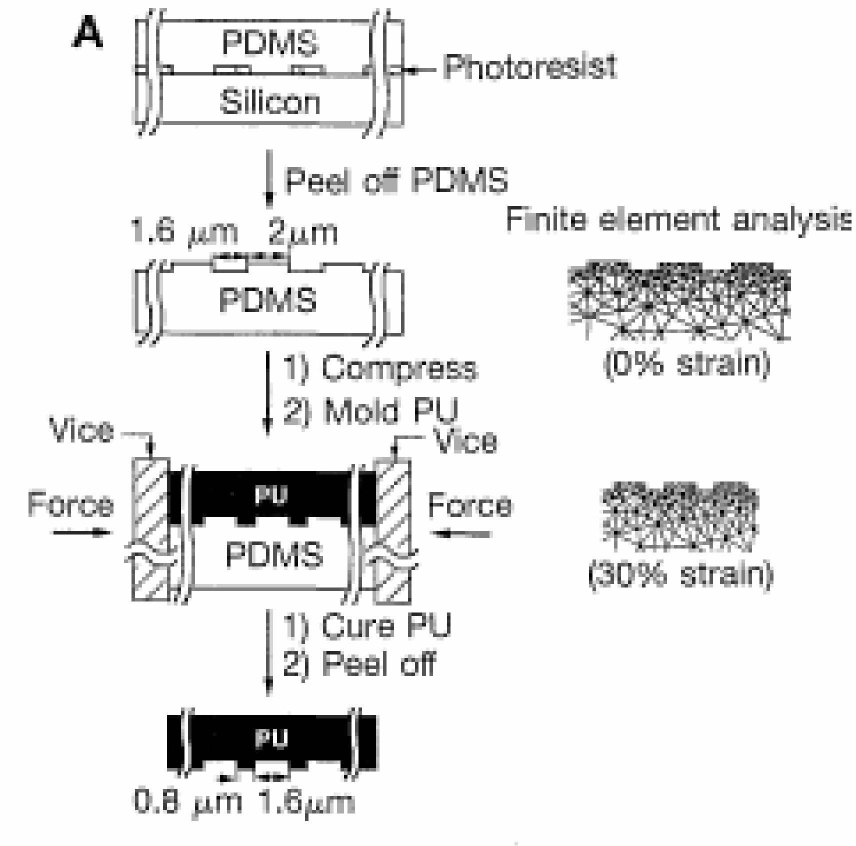


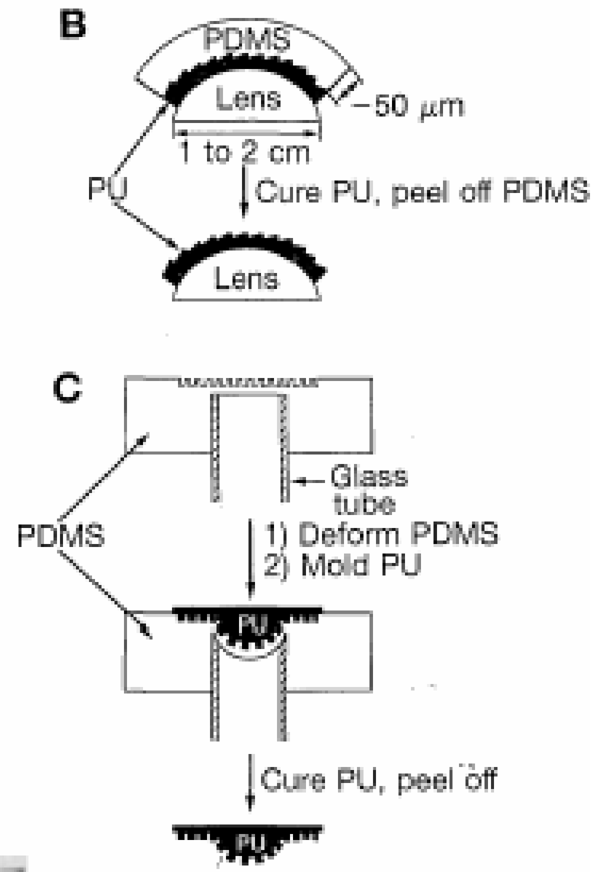
B. Michel *et al*., *IBM J. Res. & Dev*. 2001

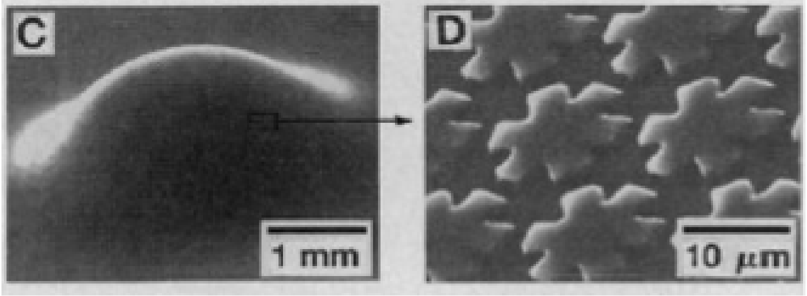
SEM images of Cu deposited onto catalytic Pd lines



3D Soft Litho



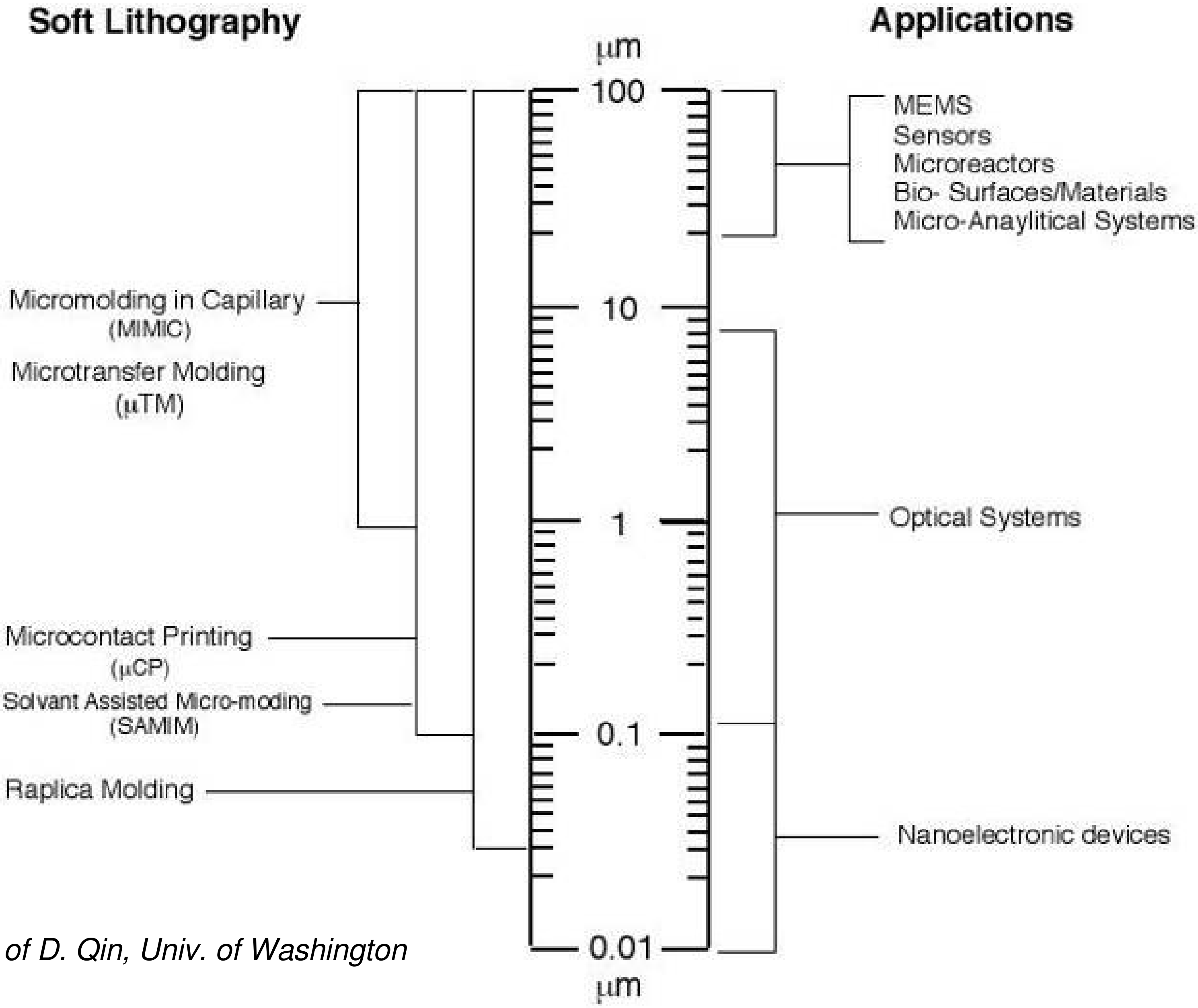




PU: polyurethane

Y. Xia et al., *Science* 1996

Soft Lithography Opportunity Assessment



Slide courtesy of D. Qin, Univ. of Washington

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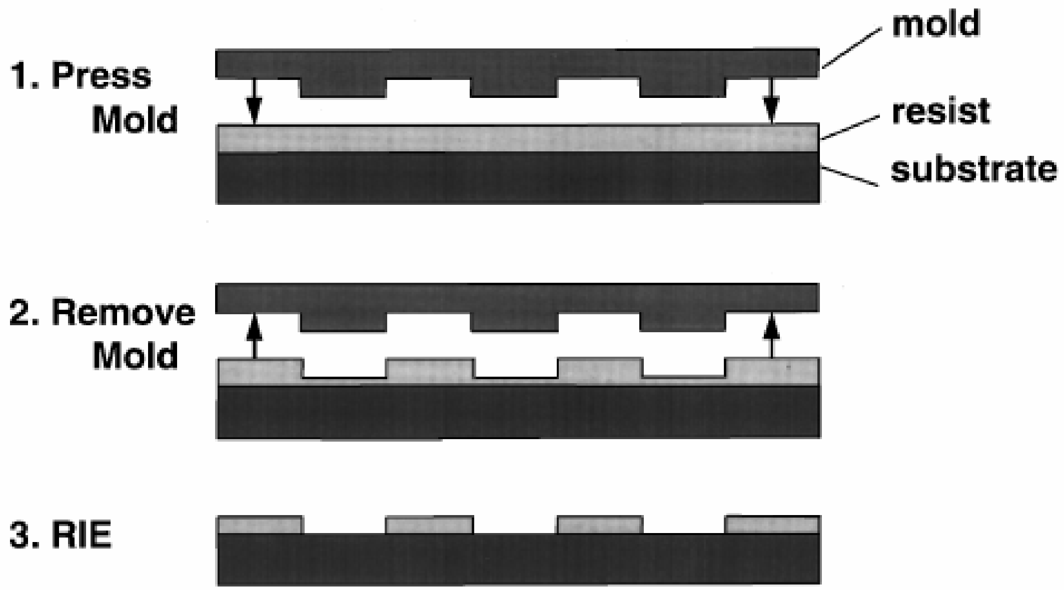
Basics of Nanoimprint –*Themoplastic Resist*

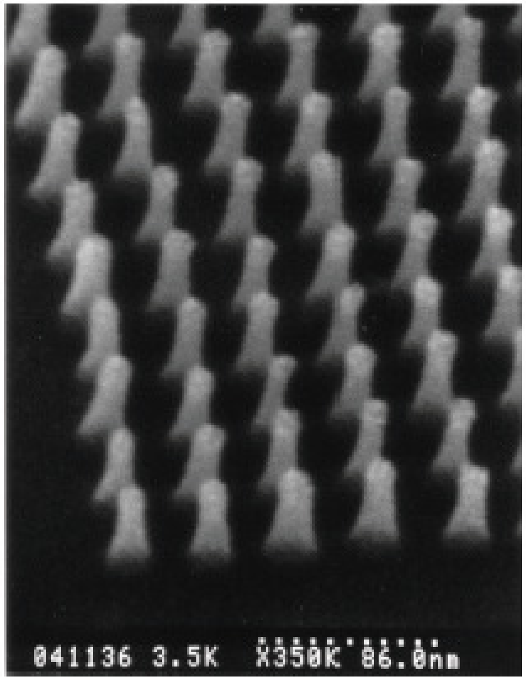


- Hard mold (“mask”) with surface relief pattern used to emboss resist
- Heat and pressure are typically used during imprinting
- The mold is removed after imprint
- Resist residual layer (dry) etched to leave behind fully patterned resist

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

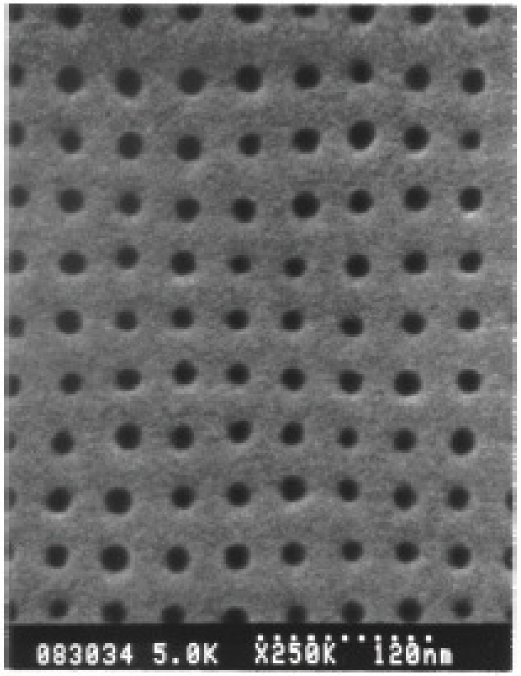
Nanoimprint

Mold



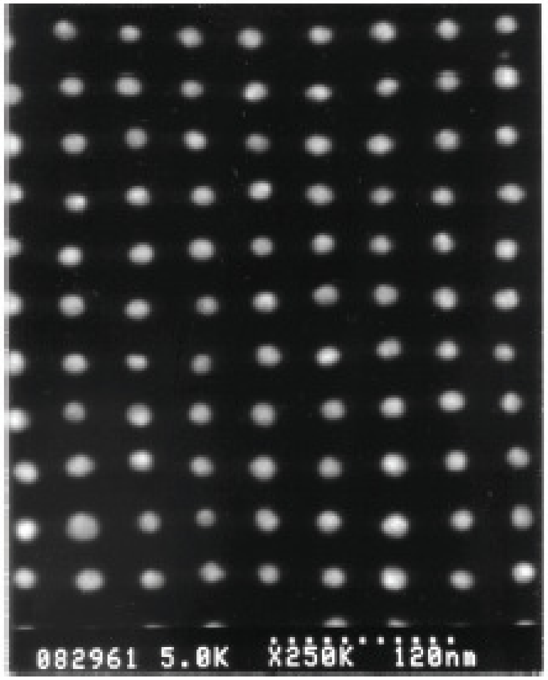
10 nm dia pillar mold

Resist



10 nm dia resist holes
by imprinting

Lift-Off



10 nm dia metal dots
by imprint and lift-off

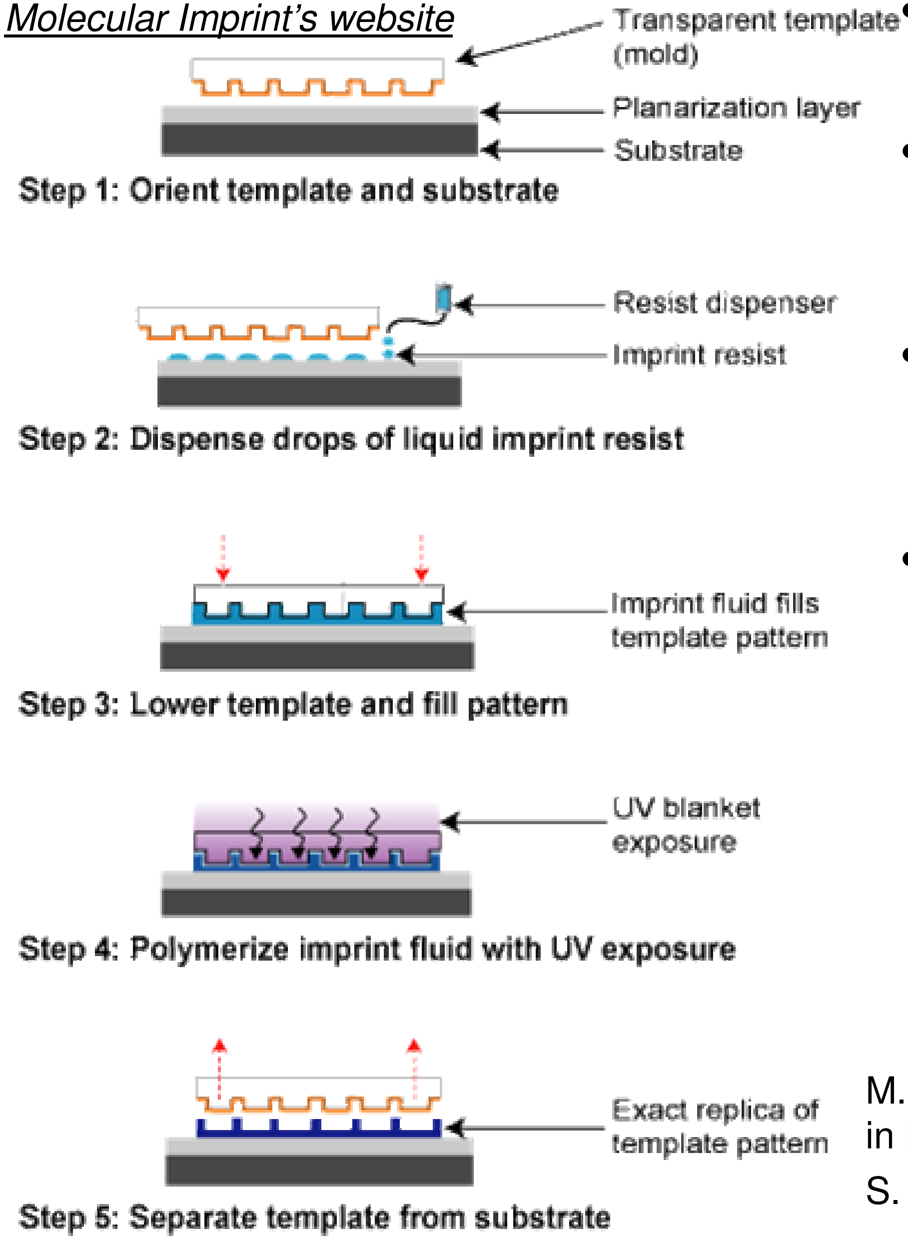
NanoStructure Laboratory

PRINCETON UNIVERSITY

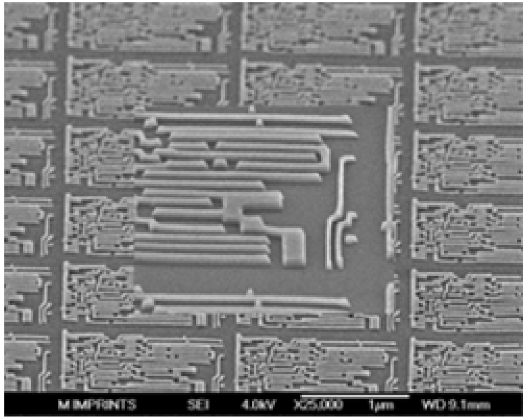
F. Pease, Stanford Univ.

Basics of Nanoimprint – *UV Curable Resist* (S&F)

Molecular Imprint's website



- Again, hard mold with surface relief pattern
- This time, resist is low viscosity, photopolymerizable organosilicon solution
- Mold is pressed on solution and ***blanket*** UV exposure is used to cure solution
- Dry etch to remove residual and transfer into layer underneath



M. Dickey et al, “Advanced Lithography: Imprint Lithography” in NNIN Open Book 2005

S. C. Johnson,. *Proceedings of SPIE*, 2003.

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

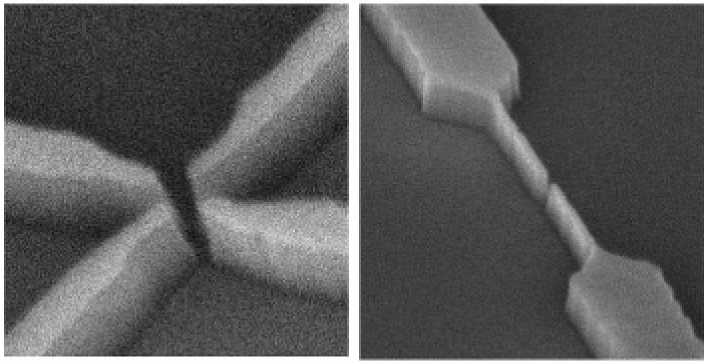
- Temperature (but, controllable)
  - May be as high as 200 C
  - CTE mismatch b/w template/wfr
  - distortion of alignment: function of substrate size
- May require large force
  - Another source of distortion
  - Breakage

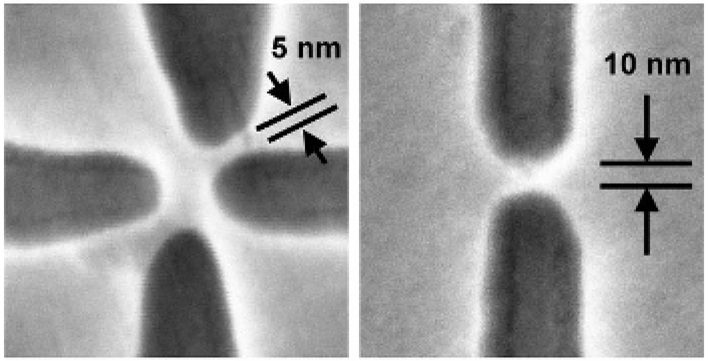
UV:

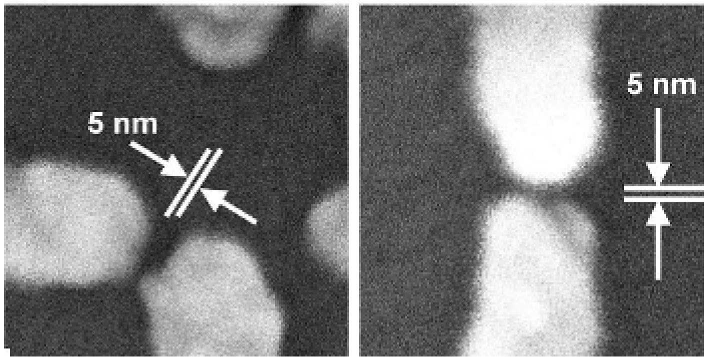
+ No thermal cycling
  - No CTE mismatch issues
+ Fast (few seconds – not including dispensing for S&F)
+ Usually minimal force needed

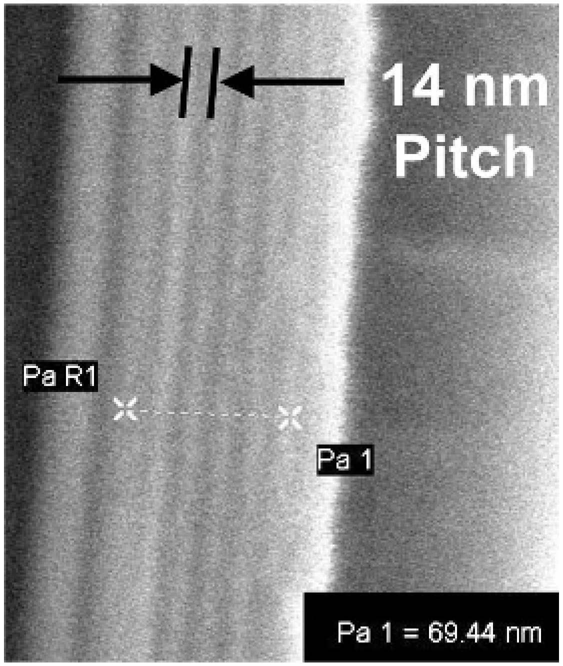
- volume shrinkage due to phase transition
- Uniform layers from spin coating
- Must use transparent template

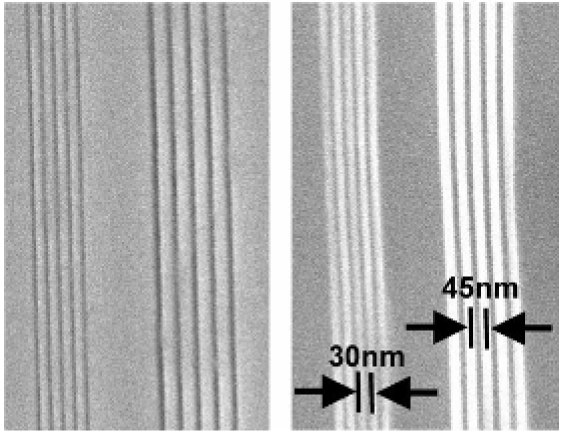
5 nm Linewidth & 14 nm Pitch Features


(a) SiO_2 NIL Mold


(b) NIL Polymer Imprint


(c) Au 5 nm Contacts

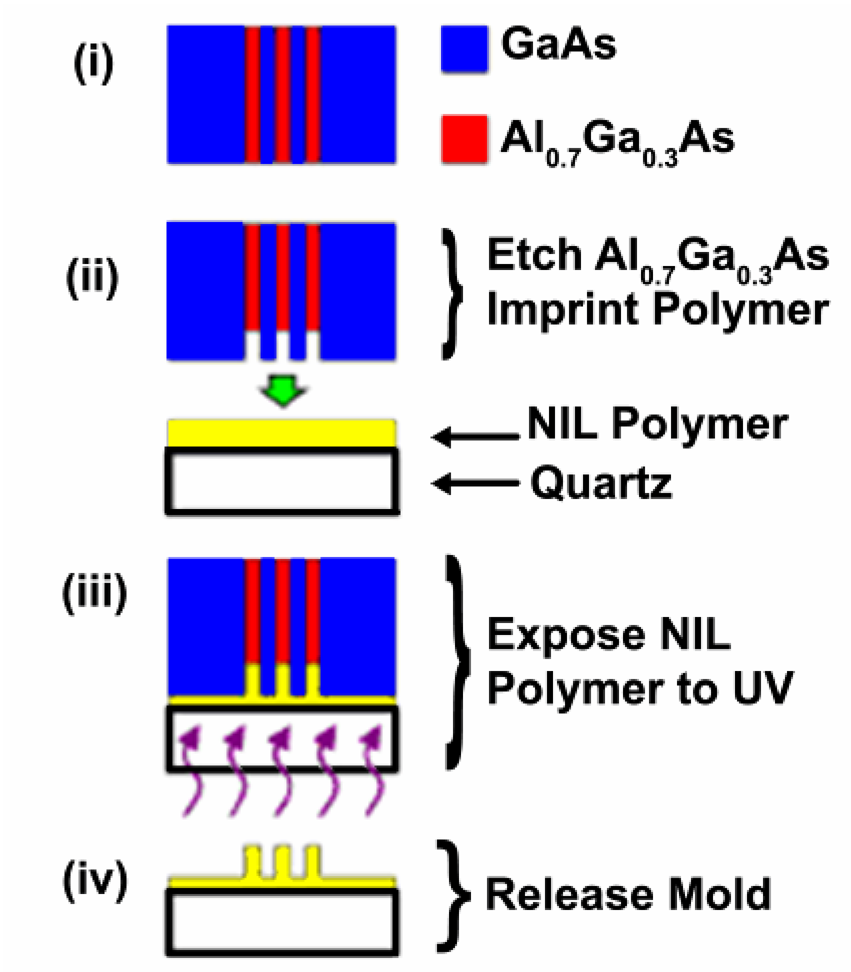

(a) 14 nm Pitch Imprint

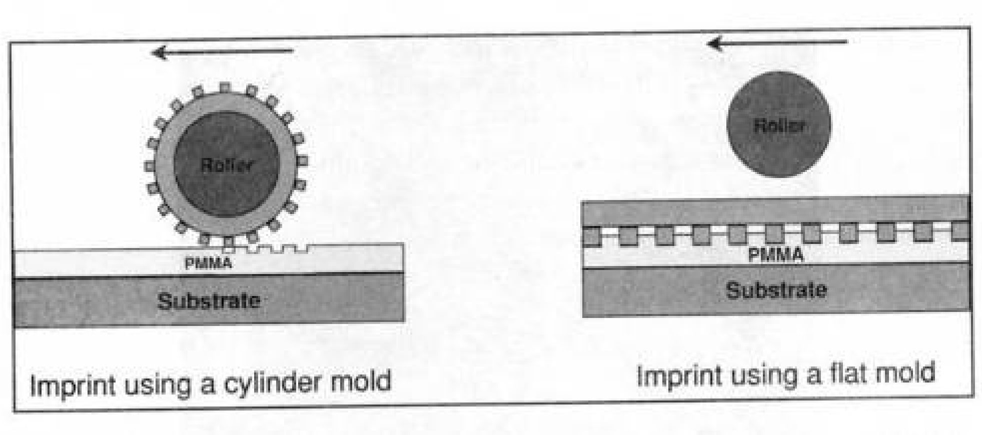

(b) 30/45 nm Pitch Mold

(c) 30/45 nm Pitch Imprint

M. Austin *et al.*, *Appl. Phy. Lett.*, 2004

Two Examples of ‘Exotic’ Templates

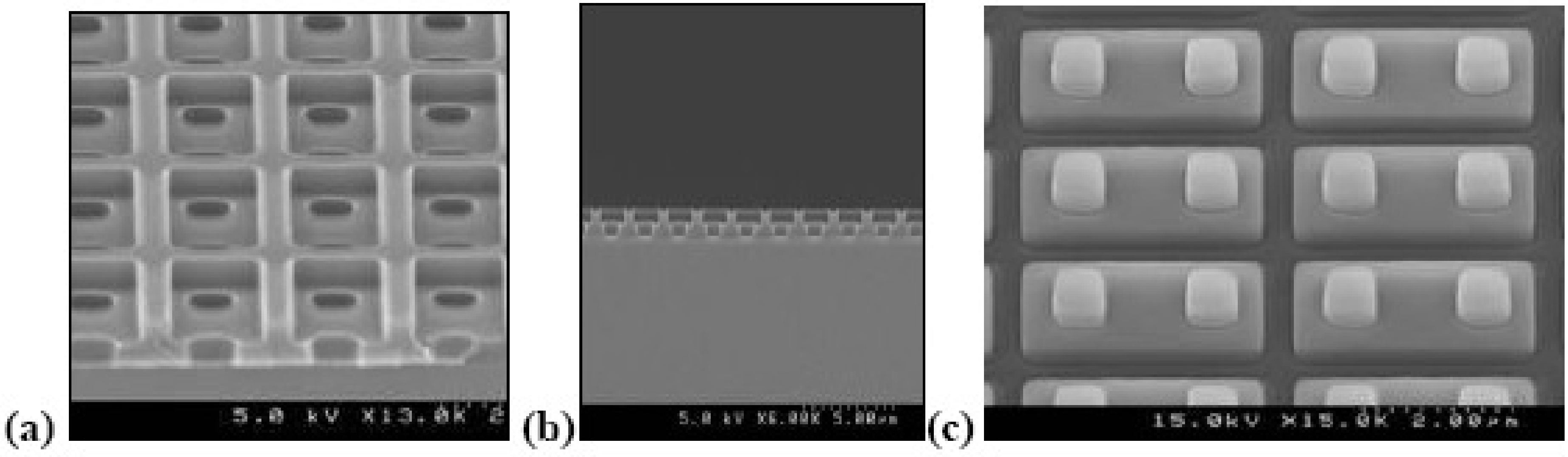




*C. Torres, Editor, Alternative Lithography

M. Austin et al., *Nanotechnology* 2005
M. Dickey et al, “Advanced Lithography: Imprint Lithography” in NNIN Open Book 2005

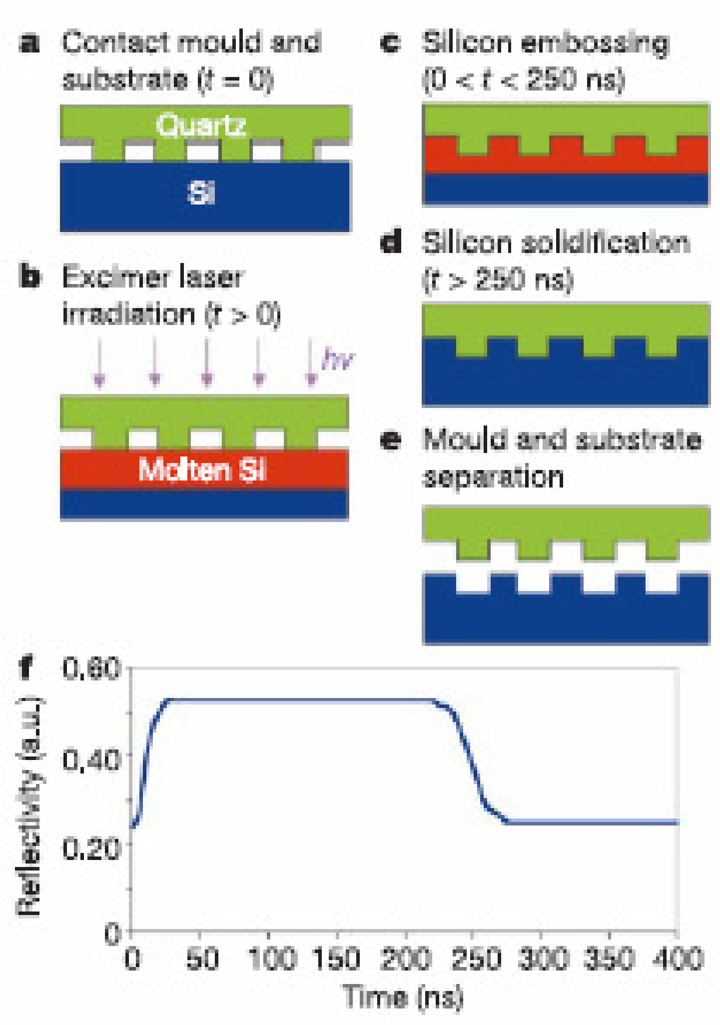
Imprinting of 3D Structures: A Key Advantage of NIL

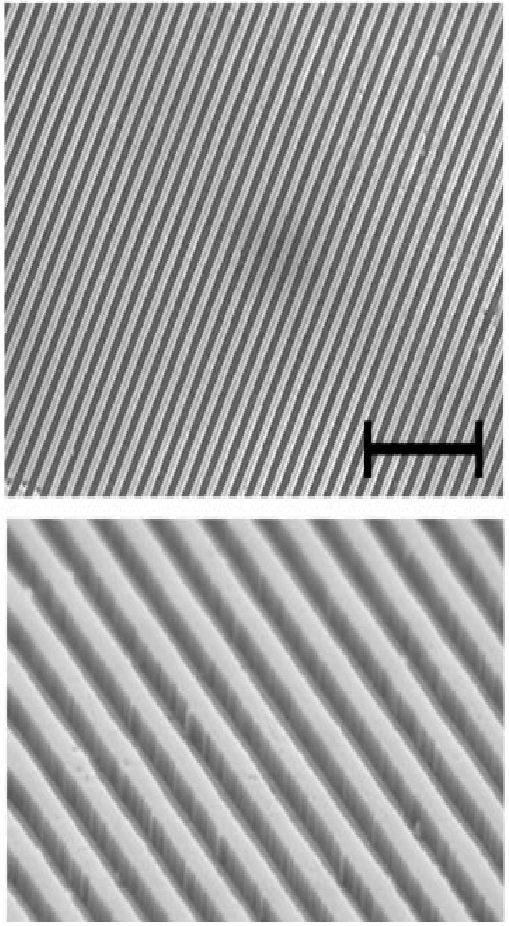


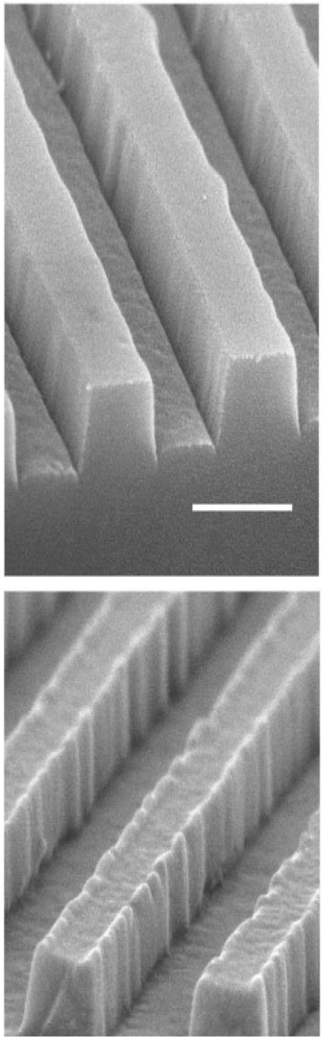
- Patterning of the via and interconnect layers, simultaneously, in CMOS BEOL
- Potentially reduces the number of masking levels needed in BEOL

J. Wang, *SPIE Optoelectronic Dev.*, 2005

Direct Si Nanoimprinting

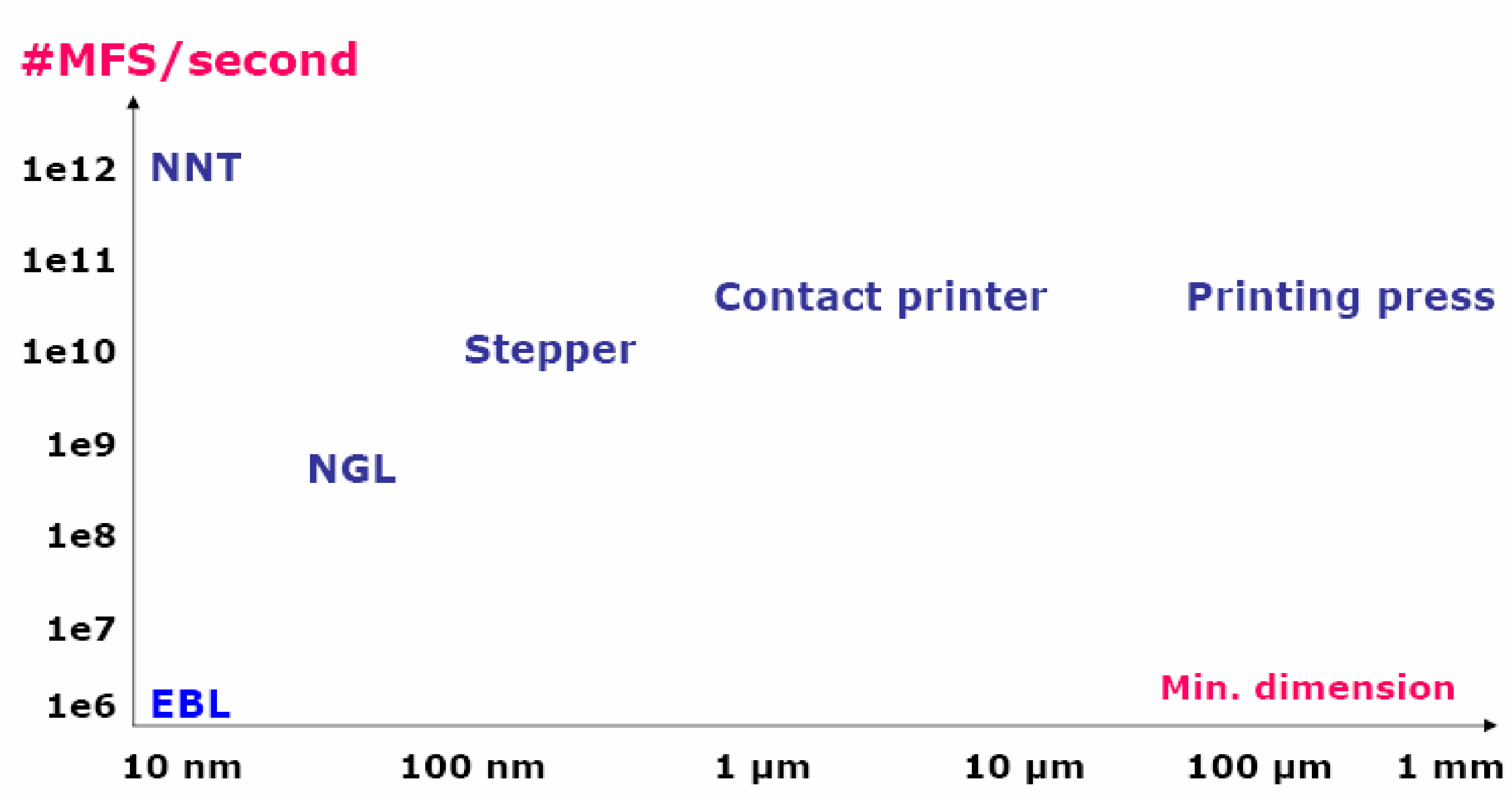






S. Chou et al., Nature, Jun 2002

Manufacturing Throughput



NNT: nanoimprint & nanoprint technology

First Int’l Conf. on NNT, 2002

R. F. Pease, Stanford Univ.

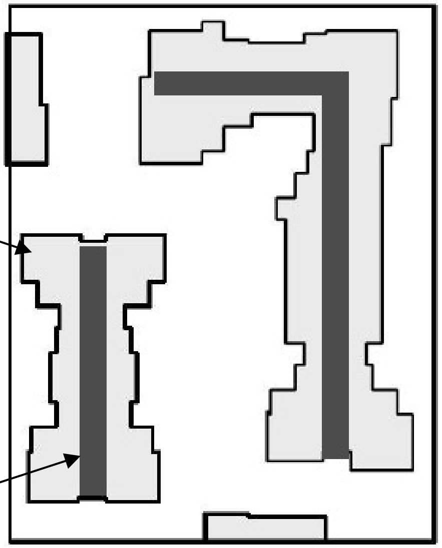
NIL Issues and Complications

- Template
- Resists
- Overlay accuracy
- Defect control

Template Issues

- Usually fabricated from Si, quartz, or nickel
- Feature fabrication at 1x vs 4-5x for optical litho
- Critical dimension control at 1x
  - Photomask needs ~250 nm resolution to print 65 nm features … J. Wang, SPIE Optoelectronic Dev., 2005
- Defect free fabrication & Inspection
- Adhesion and use of antistick coating on template (more later)
- Cleaning & reuse
- CTE mismatch with substrate
- Imprint uniformity
  - Uniform residual layer

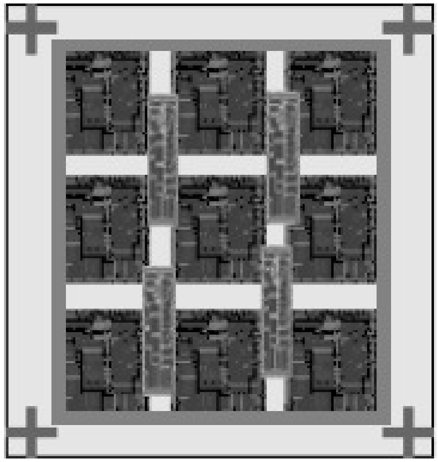
Optical Projection Litho Mask with OPC & Equiv. NIL Template

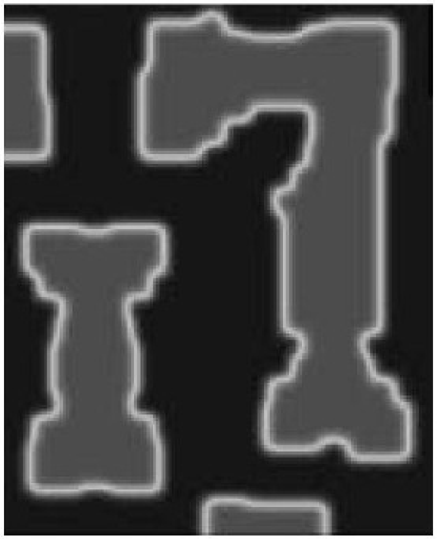


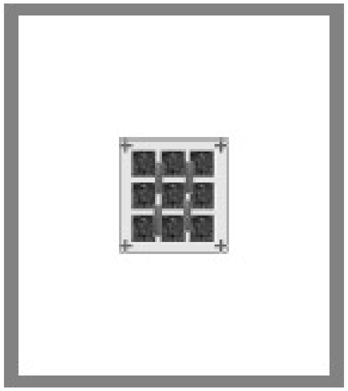
Photolitho mask pattern with OPC

Equivalent NIL pattern

Photomask (4X)



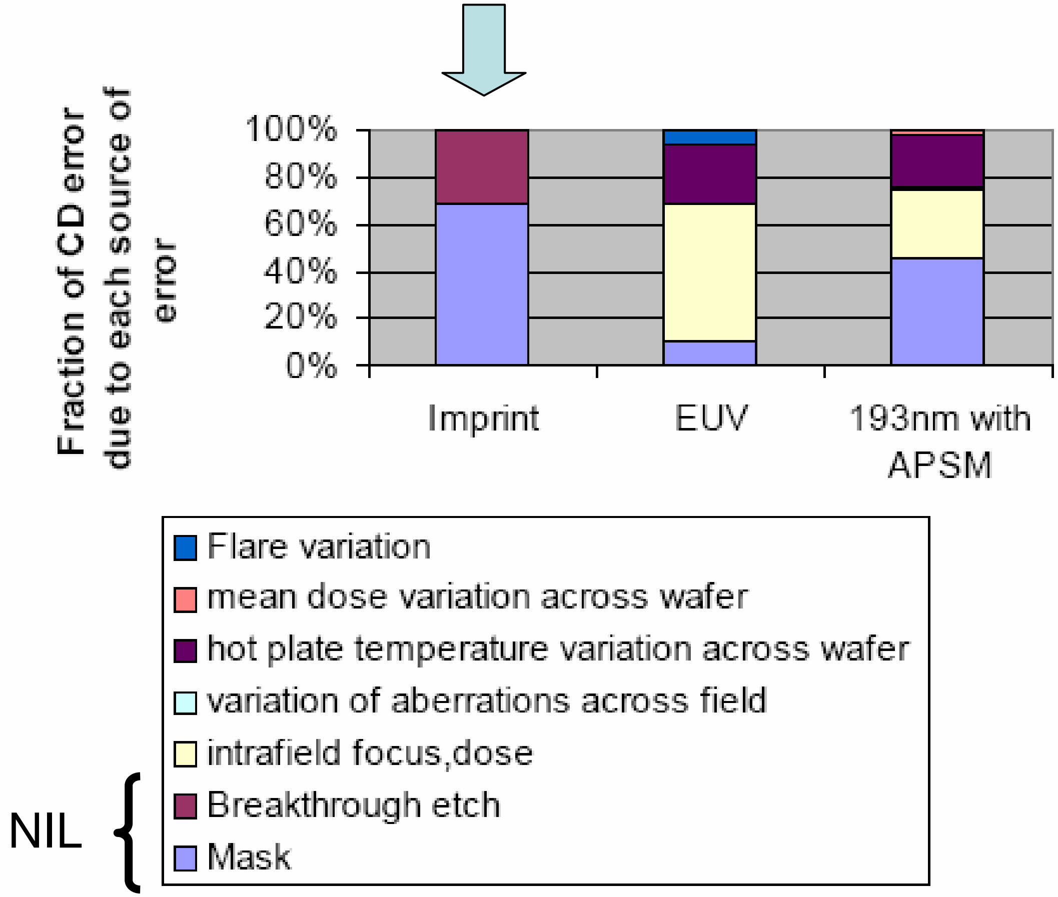




NIL Template (1X)

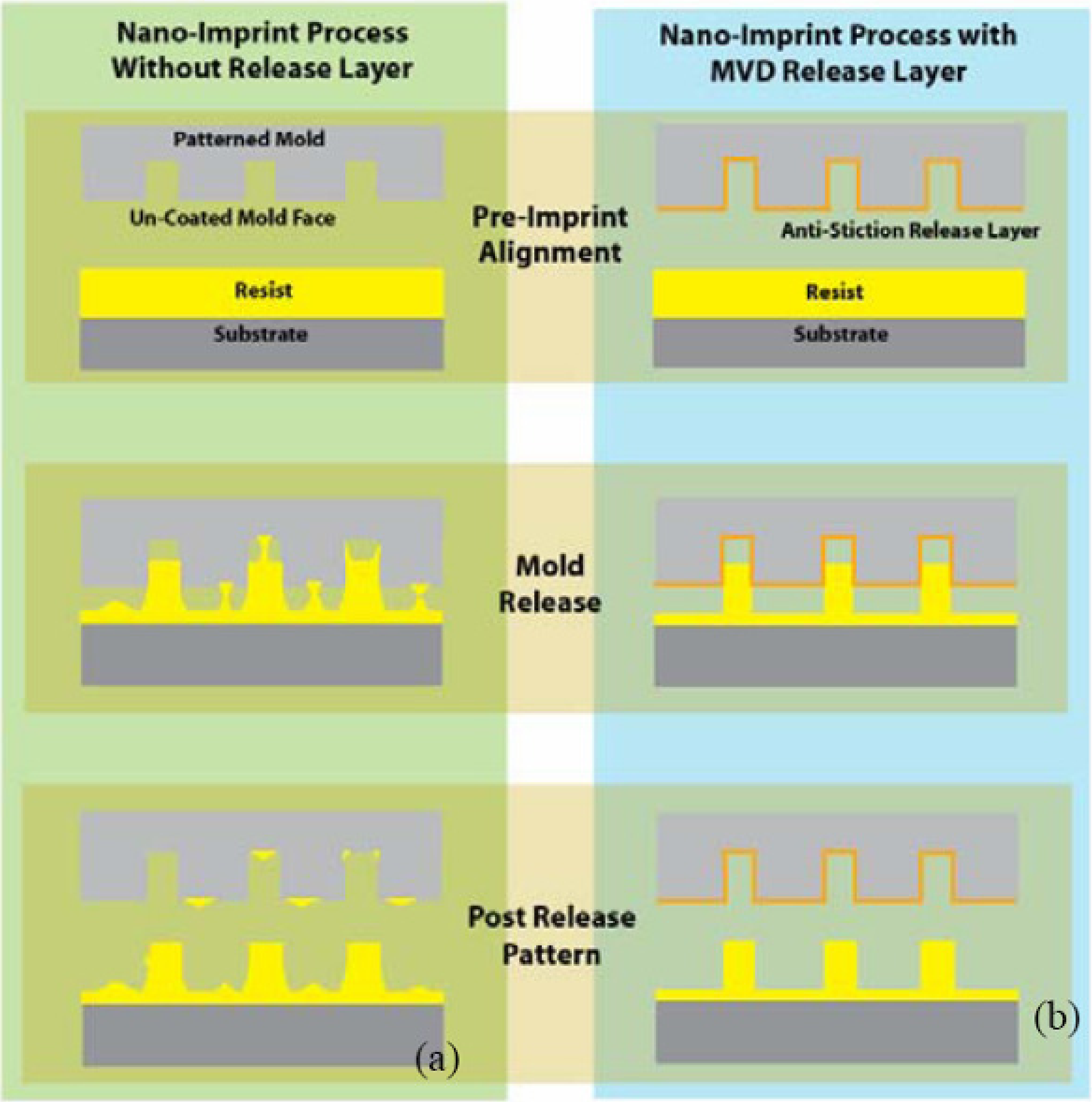
W. Tong *et al.*, *SPIE Emerging Litho Technol.*, 2005

CD Control Error Budget Comparison



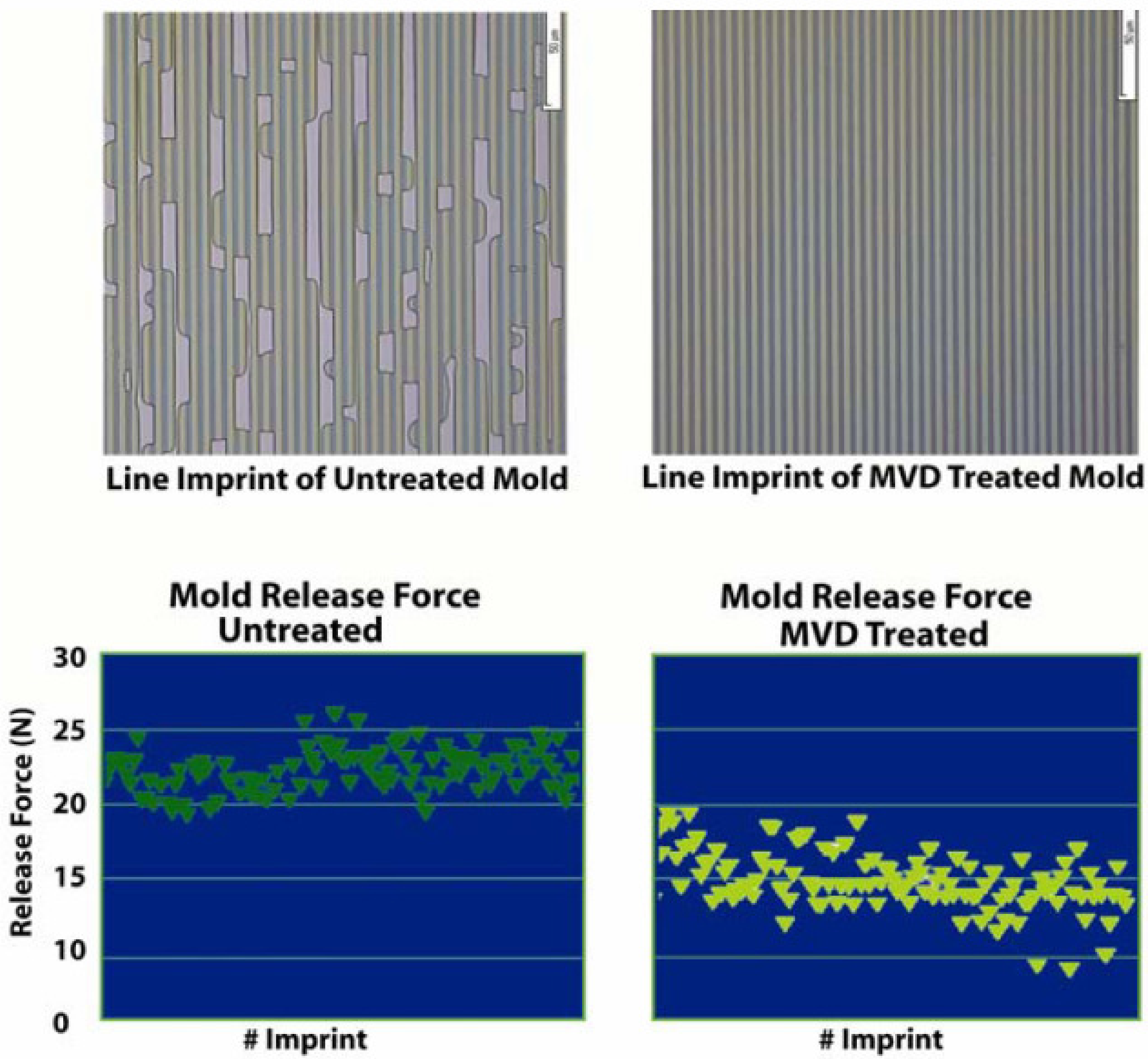
- Advantages of imprint for CD control
  - No diffraction or proximity effects
  - No lens aberrations
- Disadvantages of imprint for CD control
  - Smaller CD control allowance for template compared to optical mask
  - Breakthrough etch is added CD error term

Importance of Antistick



T. Zhang et al., SPIE 2006

NIL with and without Antistick



T. Zhang et al., SPIE 2006

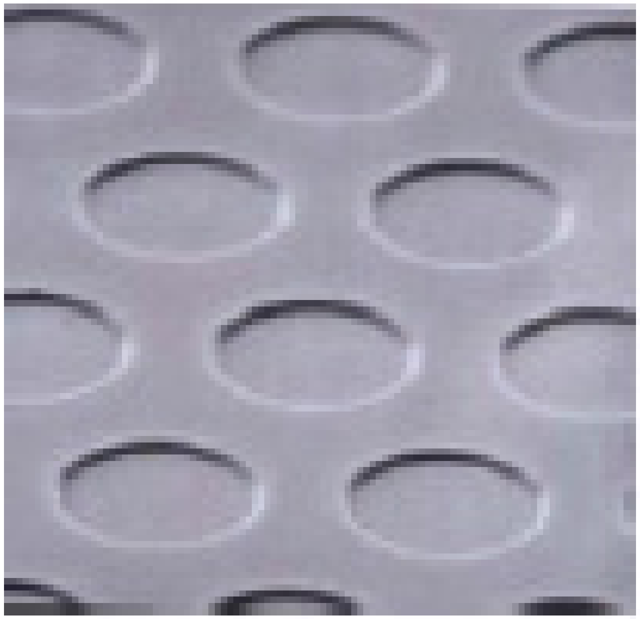
NIL Issues and Complications

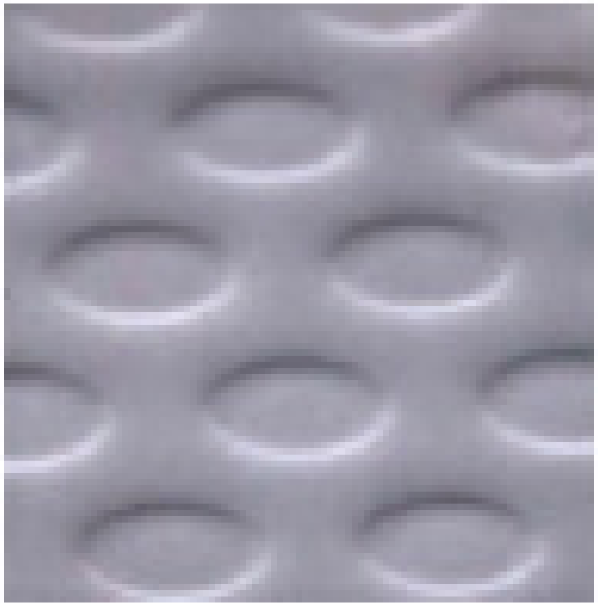
- Template
- Resists
- Overlay accuracy
- Defect control

Resist Issues

- Low temp and low pressure
- Minimal shrinkage
- Mechanical strength and tear resistance
- Mold fill
- Tg for thermoplatic resist (imprint usually done 70-80℃ above Tg)
- Viscosity

If Tg too Low …



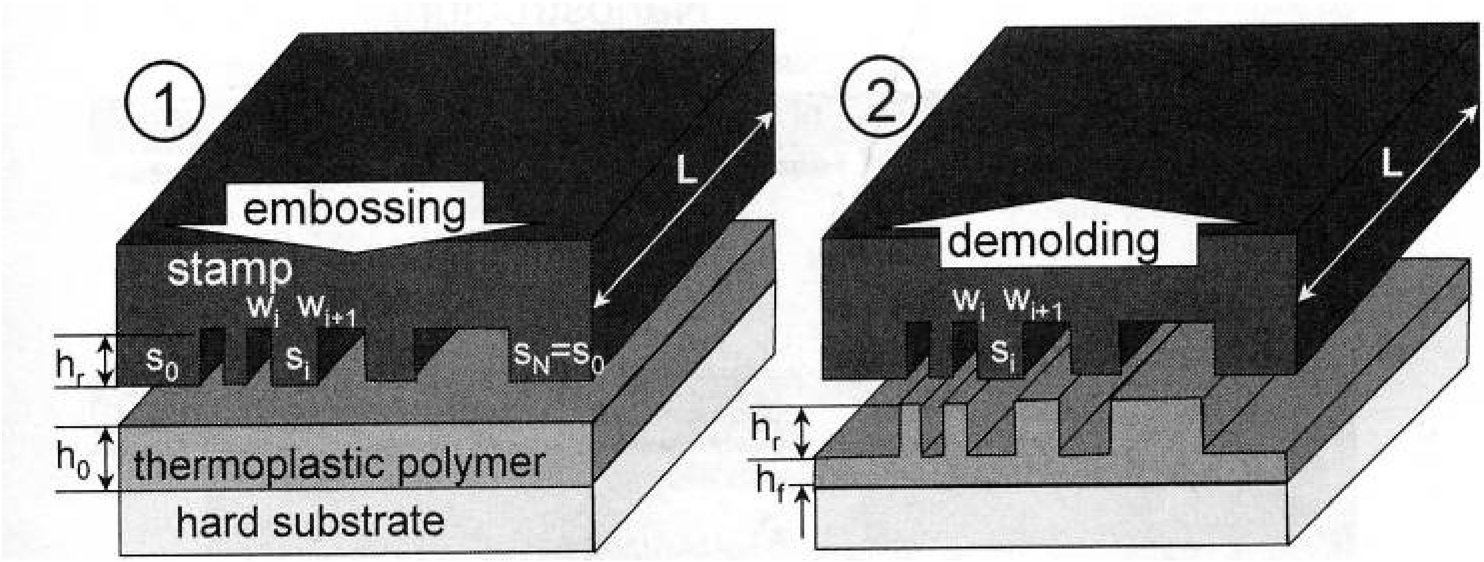


10 days after imprinting a low Tg resist

Resist/Polymers Available at MiRC

- PMMA
  - Tg: ~100C,
  - low etch selectivity over SiO_2
- MRI-7000e
  - Tg: ~75C, ~20bar
  - >2:1 etch selectivity over SiO_2
  - $$$
- MRI-9000e
  - Thermoset, ~20 bar, T=150
  - >2:1 etch selectivity over SiO_2
  - $$$
- SU8
- Avatrel

How Much Initial Material (Resist) is Needed?

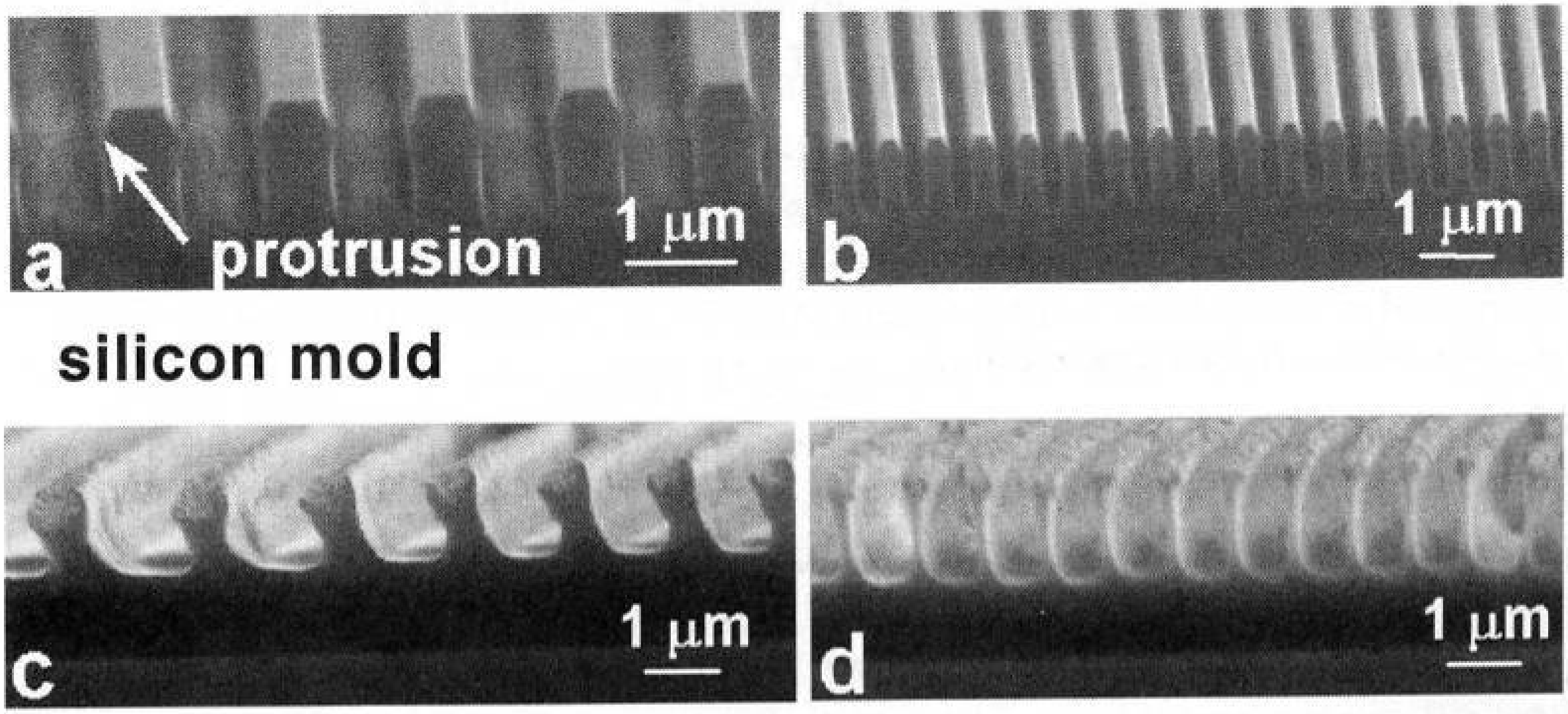


$$h_0 \sum_{i=1}^{N} \left(s_i + w_i \right) = h_f \sum_{i=1}^{N} \left(s_i + w_i \right) + h_r \sum_{i=1}^{N} w_i$$

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

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

Template Quality & Demolding

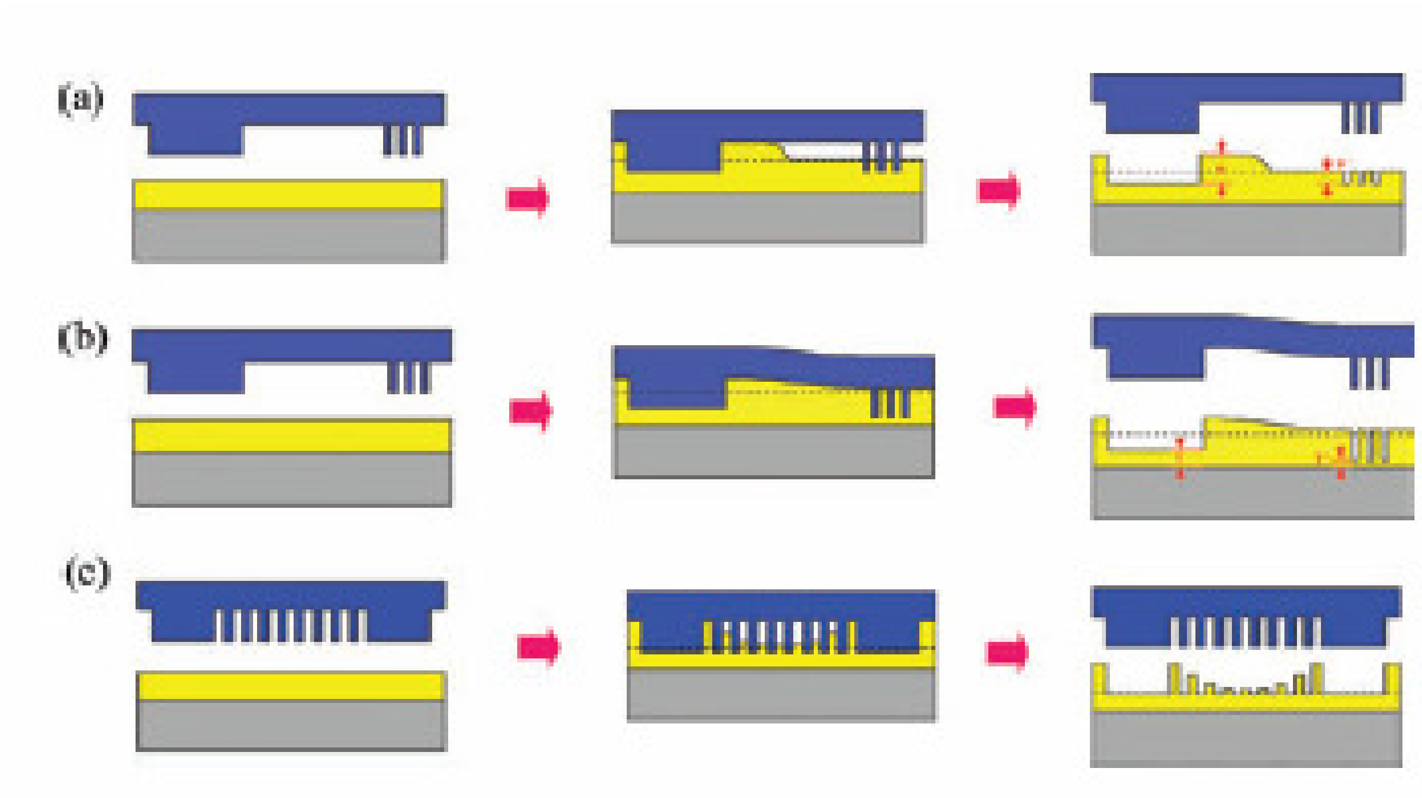


*C. Torres, Editor, *Alternative Lithography: Unleashing the Potentials of Nanotechnology*, Kluwer, 2003

Overlay Accuracy

- NIL has no distortion due to lens (since no lens is used)
- Smaller error budget for template pattern placement
- Mask/template distortion due to pressure and/or temperature & defects

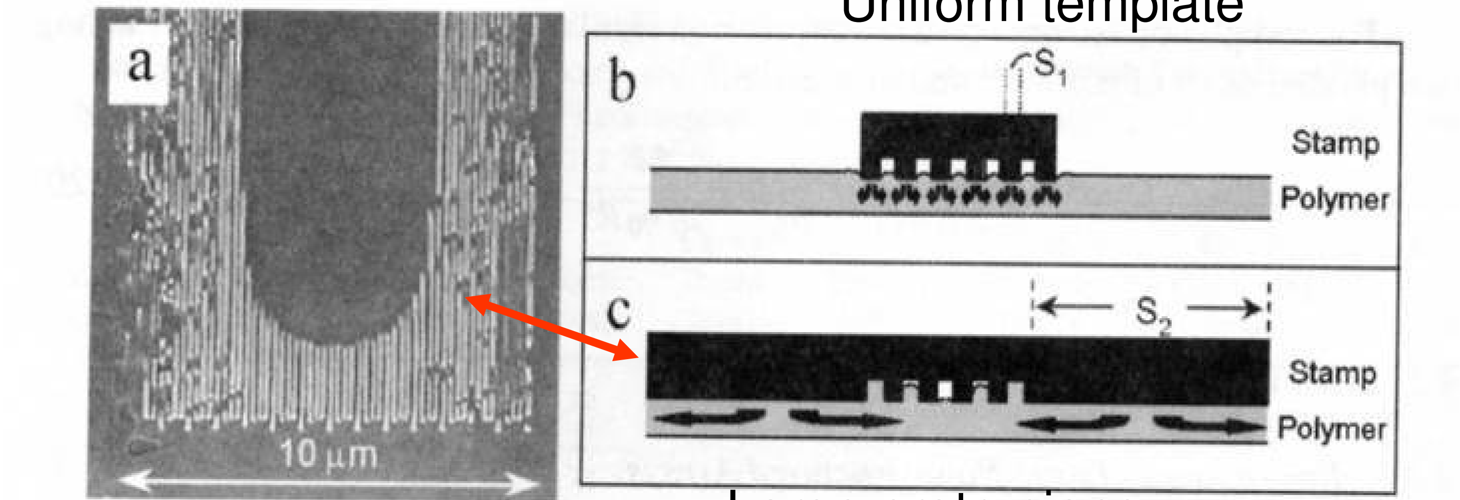
Issues with Imprinting Micro & Nano Features



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

Template Uniformity

Uniform template

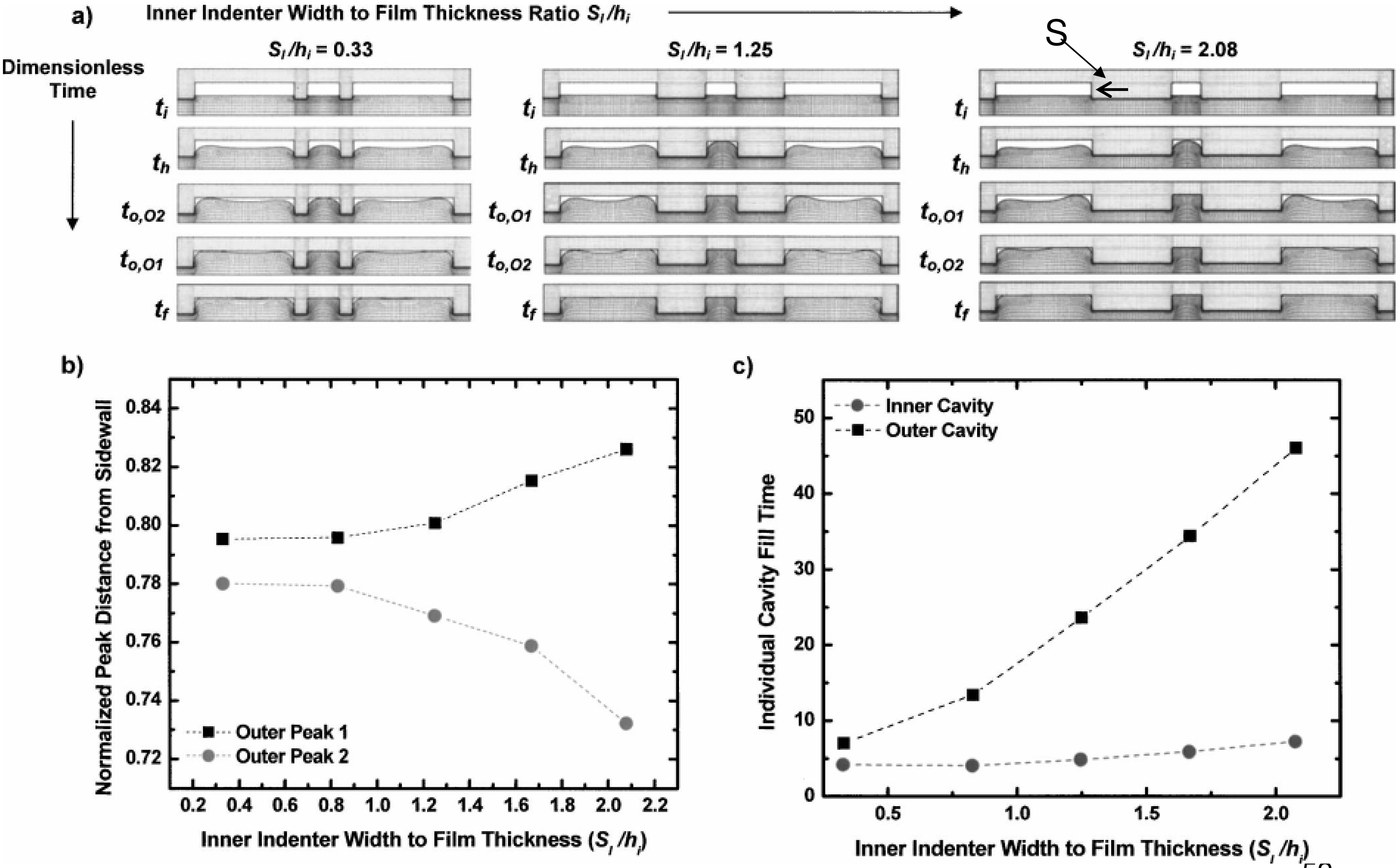


Large protrusions dominate (large s_i)

- 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

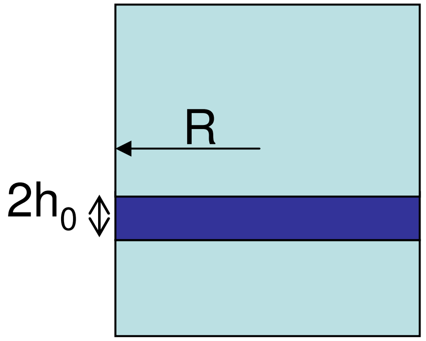
Simulations of Flow for Nonuniform Template Features



*H. Rowland et al., *J. Vac. Sci. Technol*, 2005

Newtonian Liquid between Two Parallel Disks

Steady-state solution to the Stefan eq:



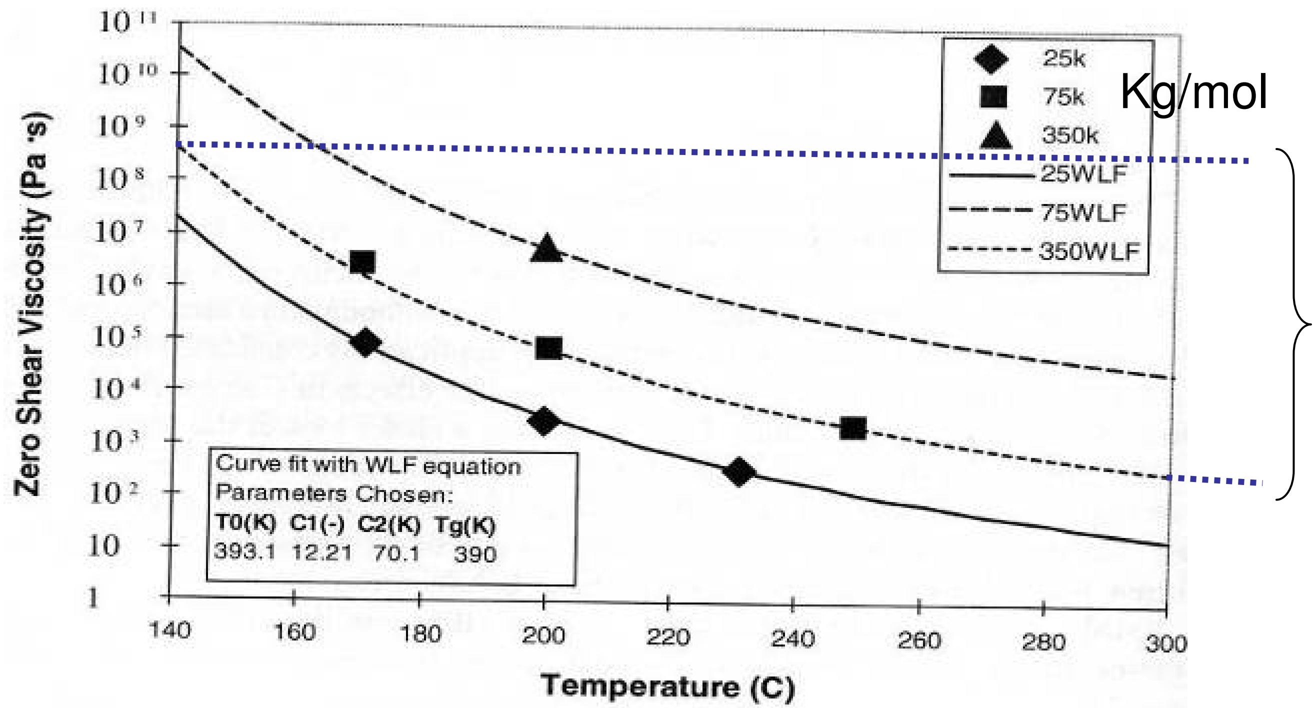
$$F = -\frac{3\pi R^4}{4h_0^3}\frac{dh}{dt}\eta_0$$

$$F \propto R^4$$

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

$$F \propto \eta_0$$

Changes by *orders* of magnitude with temp



x10^5

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

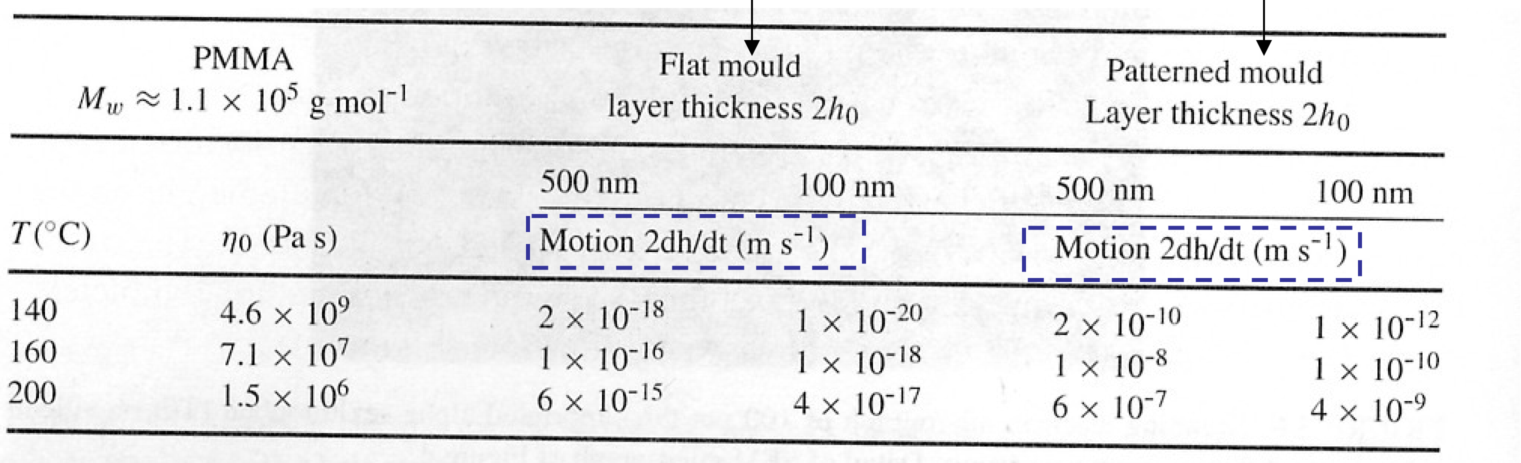
*C. Torres, Editor, *Alternative Lithography: Unleashing the Potentials of Nanotechnology*, Kluwer, 2003

Patterned & Un-patterned Templates

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

Applied pressure = 10 MPa

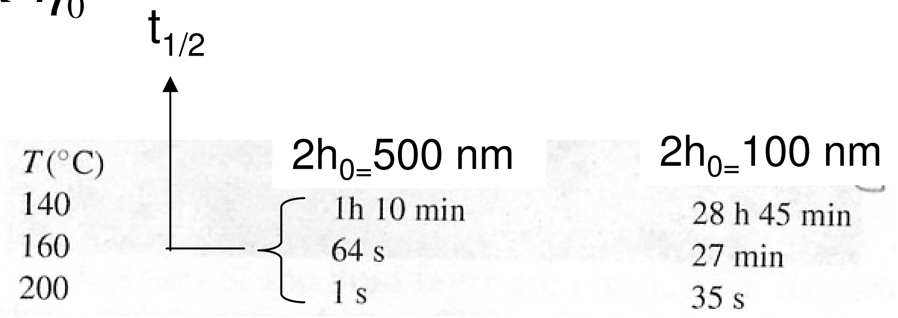
R=1 cm



PMMA $M_w \approx 1.1 \times 10^5$ g mol^{-1}		Flat mould layer thickness $2h_0$		Patterned mould Layer thickness $2h_0$	
		500 nm	100 nm	500 nm	100 nm
T(°C)	η_0 (Pa s)	Motion 2dh/dt (m s^{-1})		Motion 2dh/dt (m s^{-1})	
140	4.6×10^9	2×10^{-18}	1×10^{-20}	2×10^{-10}	1×10^{-12}
160	7.1×10^7	1×10^{-16}	1×10^{-18}	1×10^{-8}	1×10^{-10}
200	1.5×10^6	6×10^{-15}	4×10^{-17}	6×10^{-7}	4×10^{-9}

$$\frac{1}{h_1^{\ 2}} - \frac{1}{h_0^{\ 2}} = \frac{16Ft}{3\pi R^4 \eta_0}$$

$$t_{1/2} = \frac{9\pi R^4 \eta_0}{16Fh_0^{\ 2}}$$



T(°C)	$2h_{0=}500$ nm	$2h_{0=}100$ nm
140	1h 10 min	28 h 45 min
160	64 s	27 min
200	1 s	35 s

Applied pressure = 10 MPa

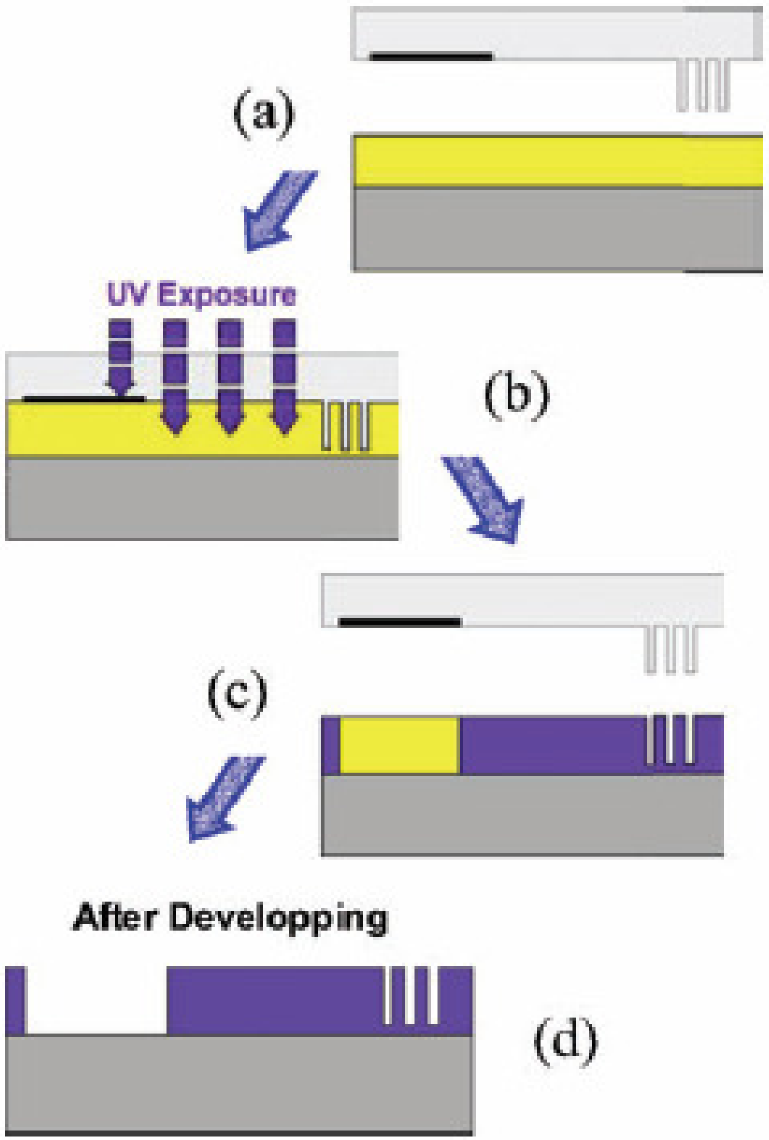
R=1 cm

$R_{feature}$=1 μm
[over 50% of surface]

PMMA

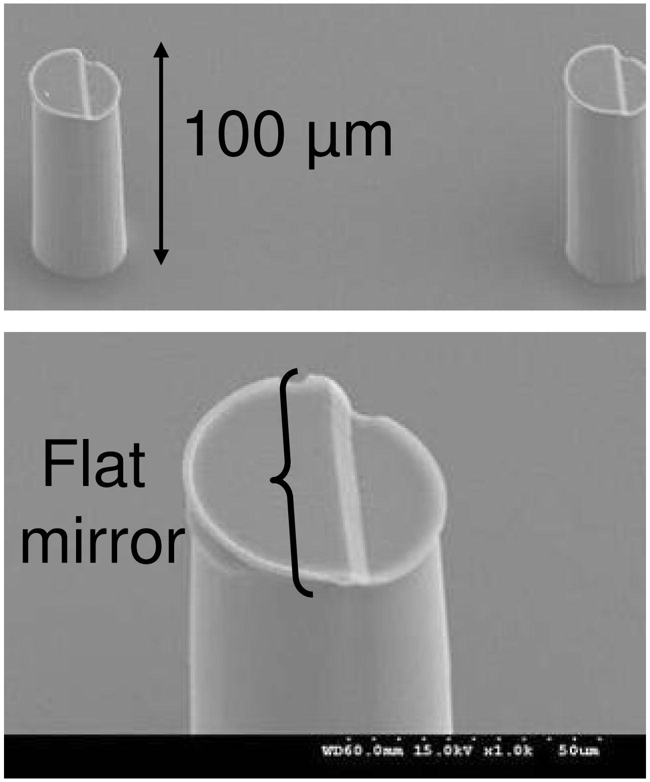
*C. Torres, Editor, Alternative Lithography

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

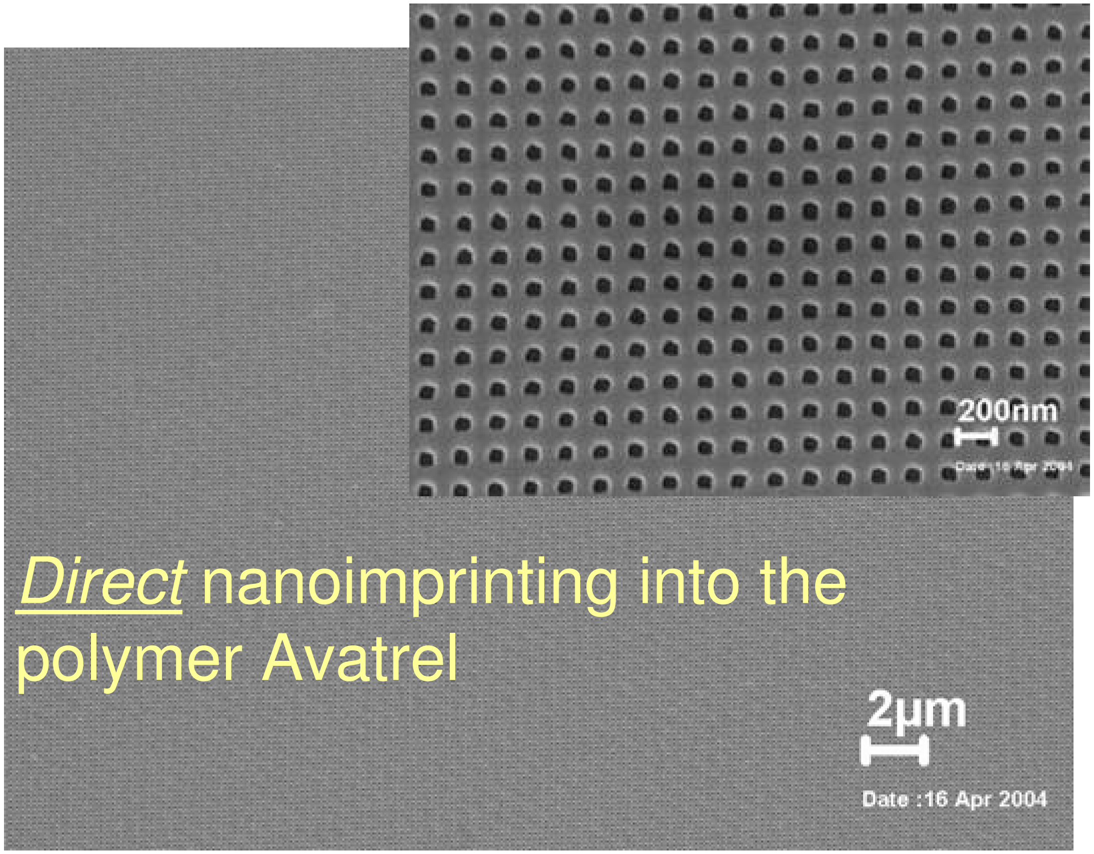


L. Guo, “Recent Progress in nanoimprint technology and its applications,” J. Phys. D, 37, 2004

Micro/Nano Imprinting in Avatrel



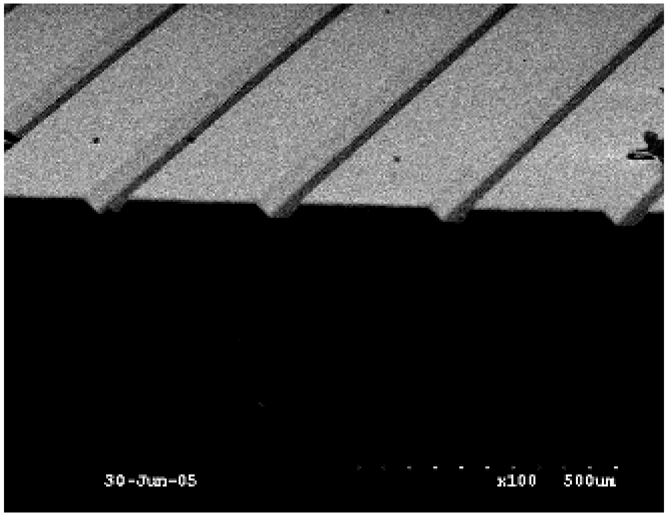
Mirror shape, angle, and height can be controlled

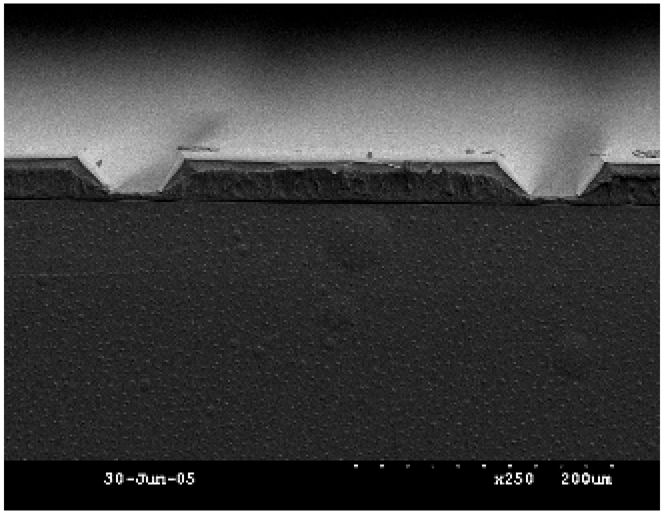


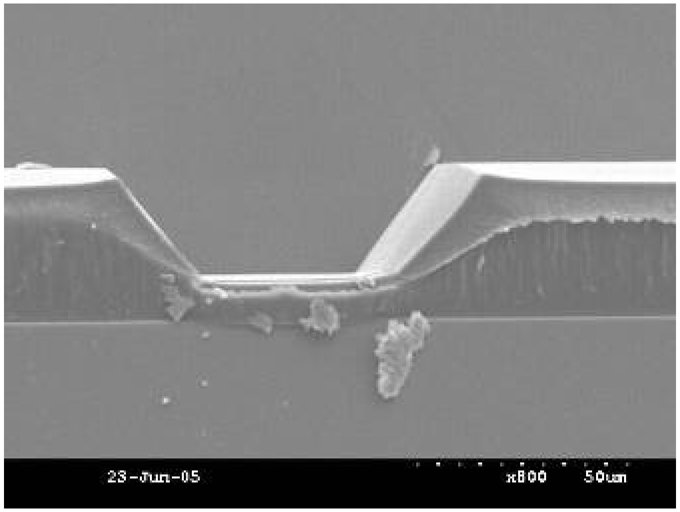
Direct nanoimprinting into the polymer Avatrel

M. Bakir & J. Meindl, *IEEE Trans. Electron Dev.*, vol. 51, no. 7, pp. 1069-1077, 2004

Imprinted Channels in Avatrel

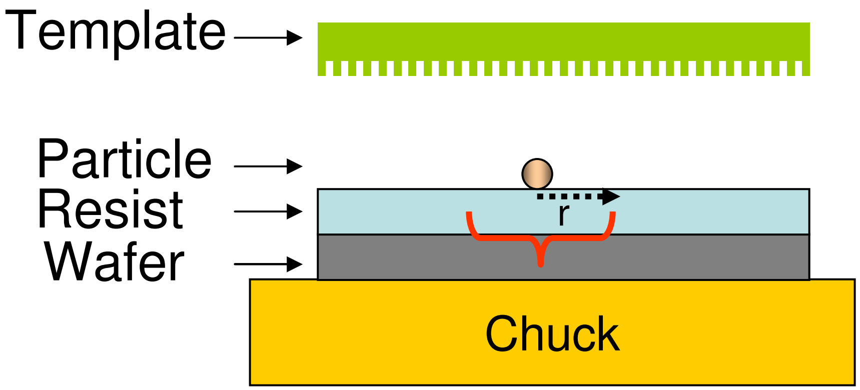




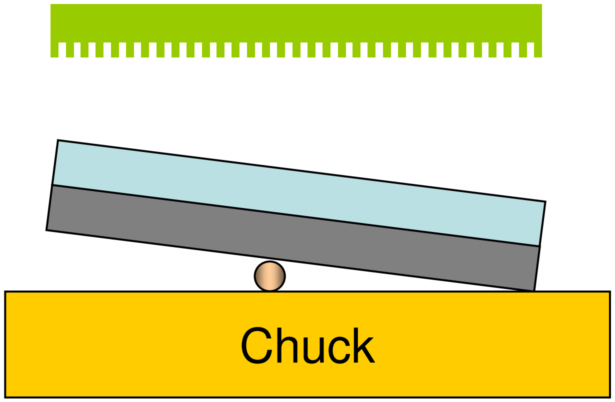


M. Bakir & J. Meindl, *to be published*

Imprinting in Presence of a Particle (Contamination)



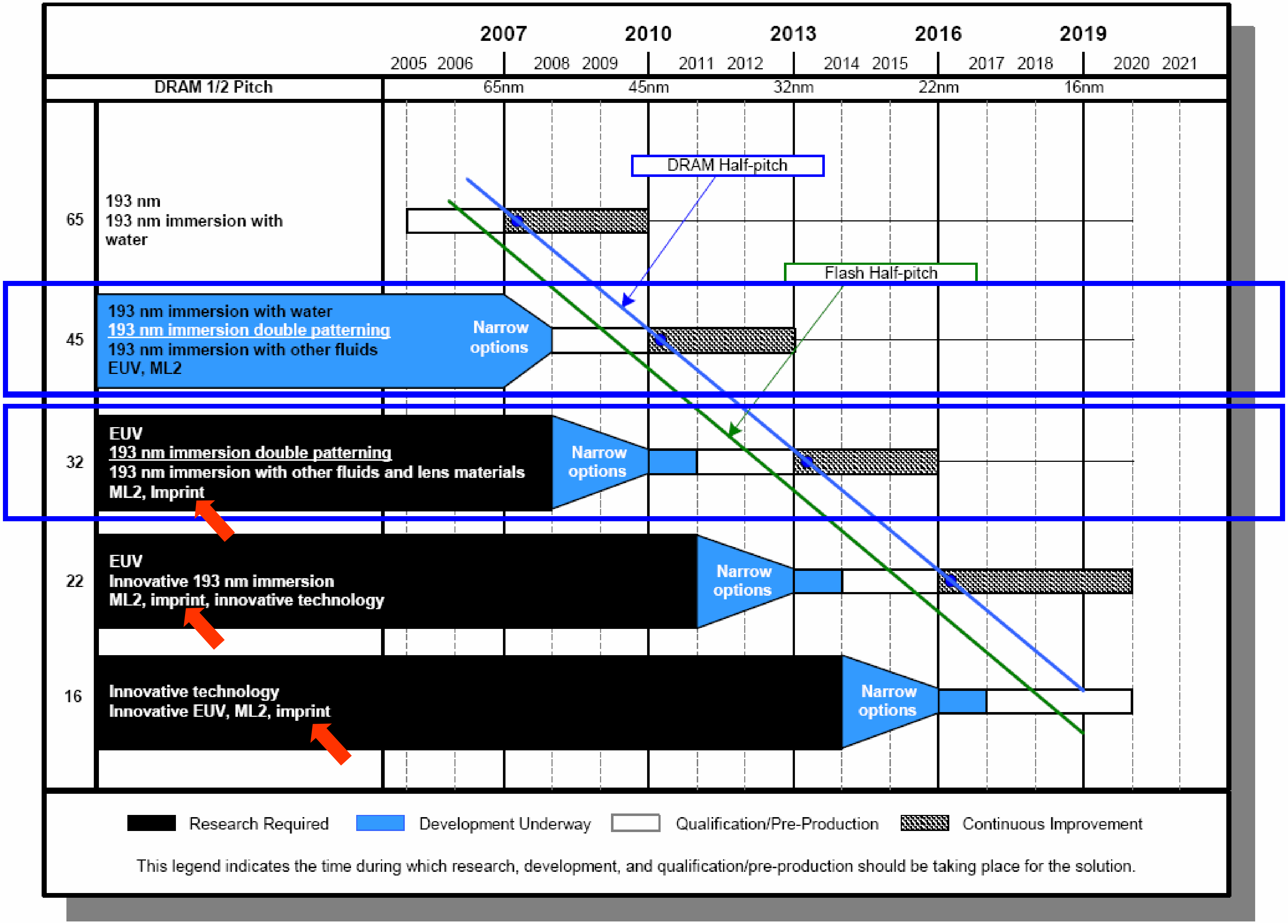
Region (area) of no imprint due to template not making contact with resist as a result of the presence of the particle



Wafer will crack!!!

- VERY important to perform imprint in clean environment

ITRS (2006) Projections for Lithography Technology



DRAM 1/2 Pitch		65nm	45nm	32nm	22nm	16nm
65	193 nm 193 nm immersion with water					
45	193 nm immersion with water 193 nm immersion double patterning 193 nm immersion with other fluids EUV, ML2					
32	EUV 193 nm immersion double patterning 193 nm immersion with other fluids and lens materials ML2, Imprint					
22	EUV Innovative 193 nm immersion ML2, imprint, innovative technology					
16	Innovative technology Innovative EUV, ML2, imprint					

■ Research Required ■ Development Underway ☐ Qualification/Pre-Production ▨ Continuous Improvement

This legend indicates the time during which research, development, and qualification/pre-production should be taking place for the solution.

So Many Unknown Issues with NIL (ITRS 2006)

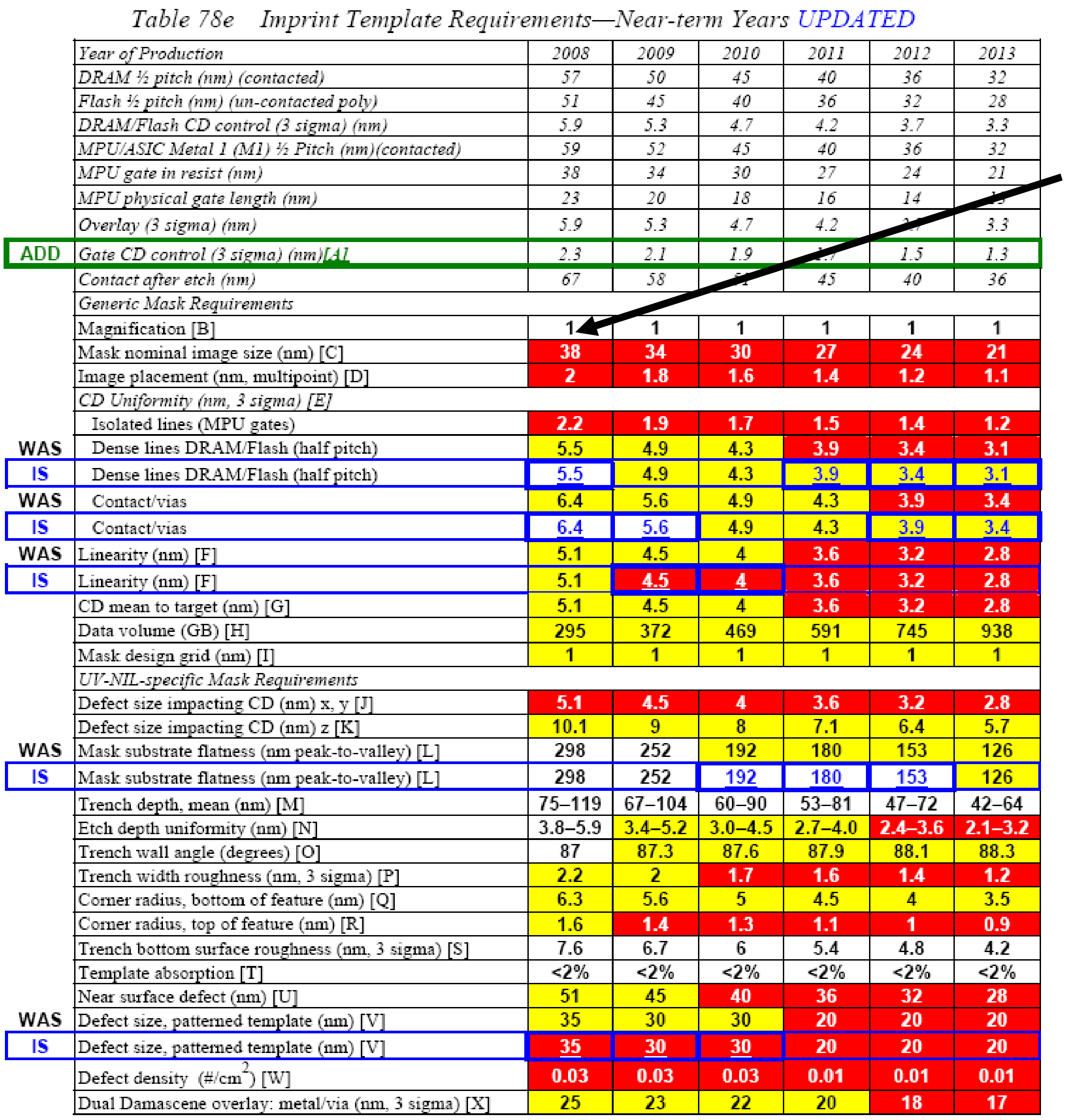


Table 78e Imprint Template Requirements—Near-term Years UPDATED

	Year of Production	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*
	DRAM ½ pitch (nm) (contacted)	*57*	*50*	*45*	*40*	*36*	*32*
	Flash ½ pitch (nm) (un-contacted poly)	*51*	*45*	*40*	*36*	*32*	*28*
	DRAM/Flash CD control (3 sigma) (nm)	*5.9*	*5.3*	*4.7*	*4.2*	*3.7*	*3.3*
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	*59*	*52*	*45*	*40*	*36*	*32*
	MPU gate in resist (nm)	*38*	*34*	*30*	*27*	*24*	*21*
	MPU physical gate length (nm)	*23*	*20*	*18*	*16*	*14*	*13*
	Overlay (3 sigma) (nm)	*5.9*	*5.3*	*4.7*	*4.2*	*3.7*	*3.3*
ADD	*Gate CD control (3 sigma) (nm)[A]*	*2.3*	*2.1*	*1.9*	*1.7*	*1.5*	*1.3*
	Contact after etch (nm)	*67*	*58*	*51*	*45*	*40*	*36*
	Generic Mask Requirements						
	Magnification [B]	1	1	1	1	1	1
	Mask nominal image size (nm) [C]	38	34	30	27	24	21
	Image placement (nm, multipoint) [D]	2	1.8	1.6	1.4	1.2	1.1
	CD Uniformity (nm, 3 sigma) [E]						
	Isolated lines (MPU gates)	2.2	1.9	1.7	1.5	1.4	1.2
WAS	Dense lines DRAM/Flash (half pitch)	5.5	4.9	4.3	3.9	3.4	3.1
IS	Dense lines DRAM/Flash (half pitch)	5.5	4.9	4.3	3.9	3.4	3.1
WAS	Contact/vias	6.4	5.6	4.9	4.3	3.9	3.4
IS	Contact/vias	6.4	5.6	4.9	4.3	3.9	3.4
WAS	Linearity (nm) [F]	5.1	4.5	4	3.6	3.2	2.8
IS	Linearity (nm) [F]	5.1	4.5	4	3.6	3.2	2.8
	CD mean to target (nm) [G]	5.1	4.5	4	3.6	3.2	2.8
	Data volume (GB) [H]	295	372	469	591	745	938
	Mask design grid (nm) [I]	1	1	1	1	1	1
	UV-NIL-specific Mask Requirements						
	Defect size impacting CD (nm) x, y [J]	5.1	4.5	4	3.6	3.2	2.8
	Defect size impacting CD (nm) z [K]	10.1	9	8	7.1	6.4	5.7
WAS	Mask substrate flatness (nm peak-to-valley) [L]	298	252	192	180	153	126
IS	Mask substrate flatness (nm peak-to-valley) [L]	298	252	192	180	153	126
	Trench depth, mean (nm) [M]	75–119	67–104	60–90	53–81	47–72	42–64
	Etch depth uniformity (nm) [N]	3.8–5.9	3.4–5.2	3.0–4.5	2.7–4.0	2.4–3.6	2.1–3.2
	Trench wall angle (degrees) [O]	87	87.3	87.6	87.9	88.1	88.3
	Trench width roughness (nm, 3 sigma) [P]	2.2	2	1.7	1.6	1.4	1.2
	Corner radius, bottom of feature (nm) [Q]	6.3	5.6	5	4.5	4	3.5
	Corner radius, top of feature (nm) [R]	1.6	1.4	1.3	1.1	1	0.9
	Trench bottom surface roughness (nm, 3 sigma) [S]	7.6	6.7	6	5.4	4.8	4.2
	Template absorption [T]	<2%	<2%	<2%	<2%	<2%	<2%
	Near surface defect (nm) [U]	51	45	40	36	32	28
WAS	Defect size, patterned template (nm) [V]	35	30	30	20	20	20
IS	Defect size, patterned template (nm) [V]	35	30	30	20	20	20
	Defect density (#/cm^2) [W]	0.03	0.03	0.03	0.01	0.01	0.01
	Dual Damascene overlay: metal/via (nm, 3 sigma) [X]	25	23	22	20	18	17

2008 is in red!!!!

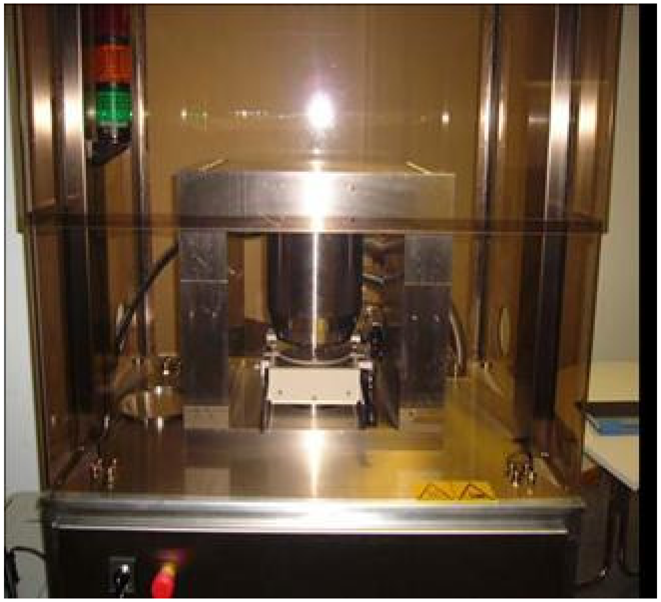
Outline

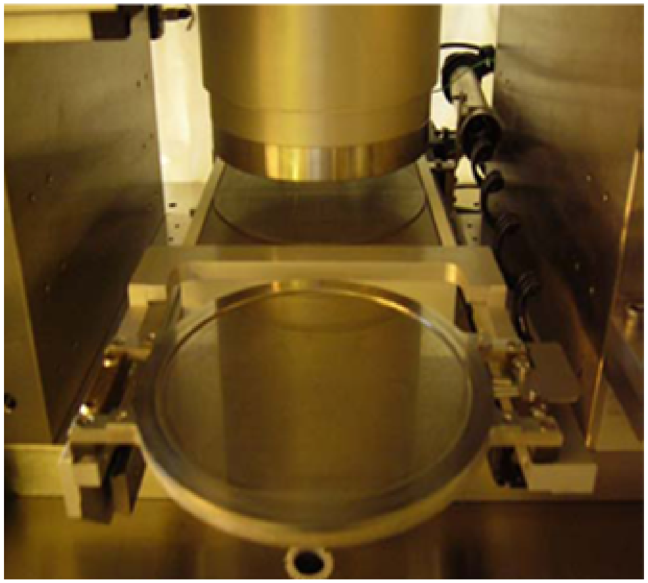
- Introduction
- Soft Lithography
- Nanoimprint Lithography (NIL)
- Obducat NIL System Overview
- Conclusion

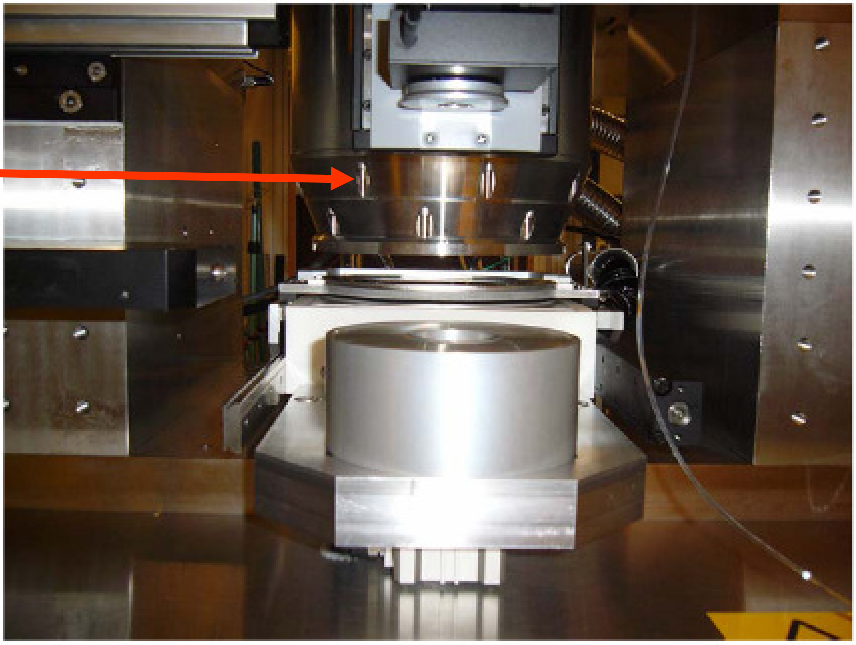
Georgia Tech MiRC’s Nanoimprint System

- 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

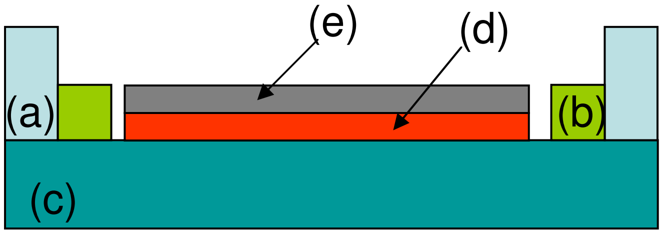


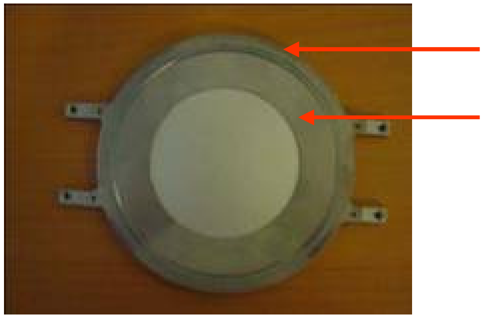




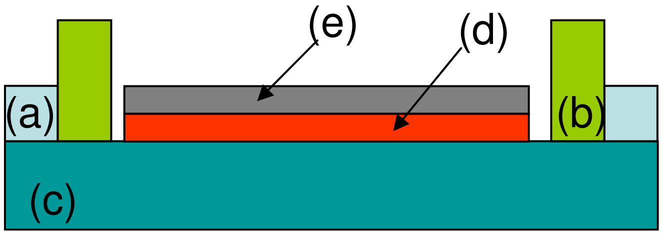
UV module

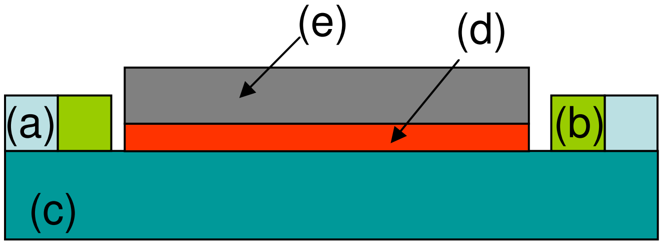
Which of these is/are Correct??

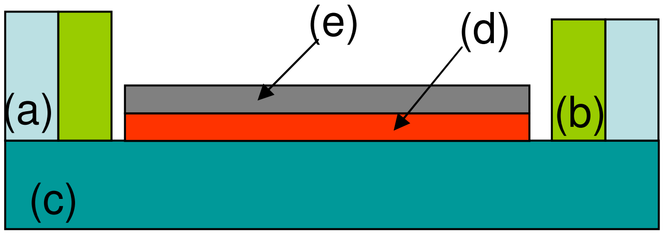


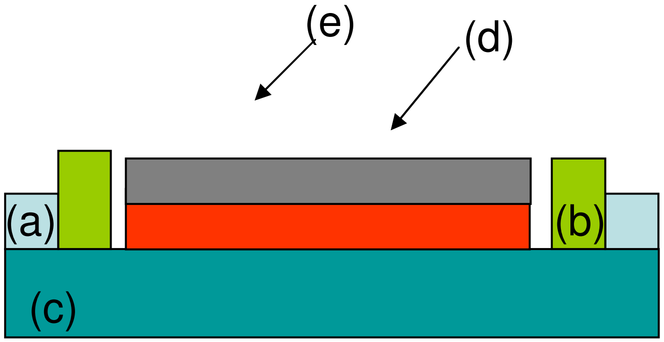


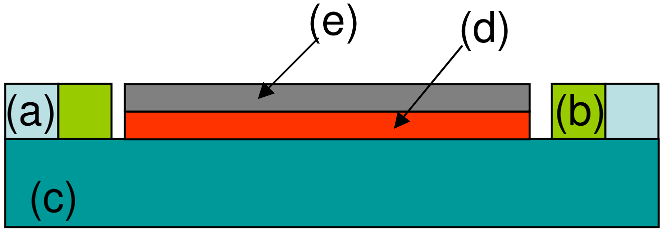
a) Spacer
b) Ring
c) Chuck
d) Bottom substrate
e) Top substrate











Spacers and Rings Available at MiRC (+ more arrived recently)

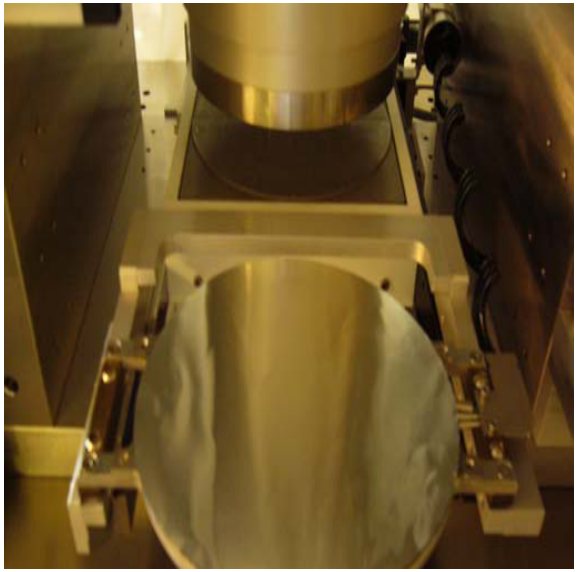
Alignment Fixtures	**Thickness**	**Size**	**Quantitiy**	**Geometry**
		5.5"	1	Circle
		3.5"	1	Circle
		1.5"	1	Circle

Spacers	5 mm	6"	1	Circle
	3 mm	6"	1	Circle
	1 mm	6"	1	Circle
	1 mm	6"	2	Circle + major flat

Rings	6 mm	4"x4"	1	Sqaure
	6 mm	2"x2"	1	Square
	3 mm	2"x2"	1	Square
	3 mm	4"x4"	1	Square
	1 mm	2" radius	1	Circle
	1 mm	4" radius	2	Circle + major flat
	1 mm	4" radius	1	Circle

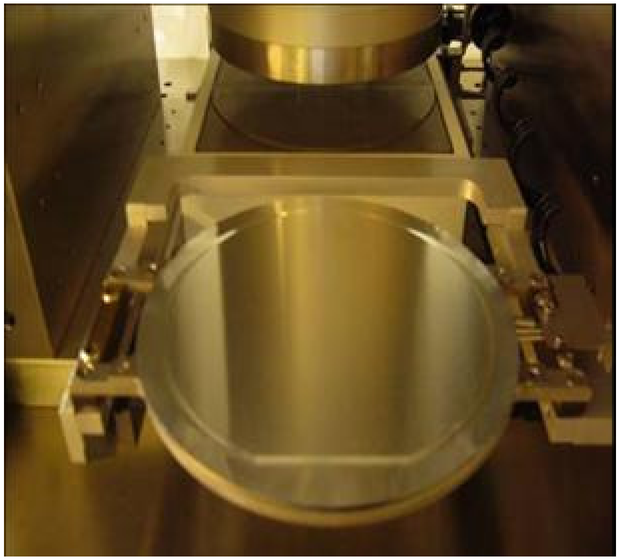
Chucks		6"	1	
		6"	1	
		2.4"	1	

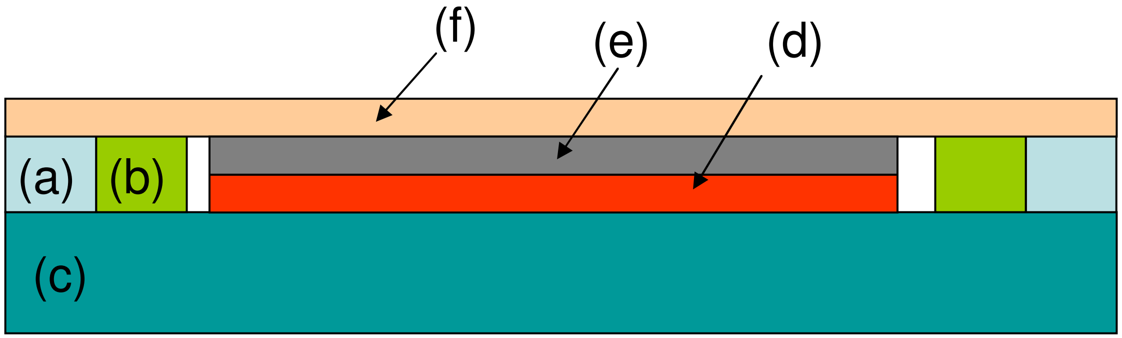
Foil use [When no alignment is needed]



Before chamber vac

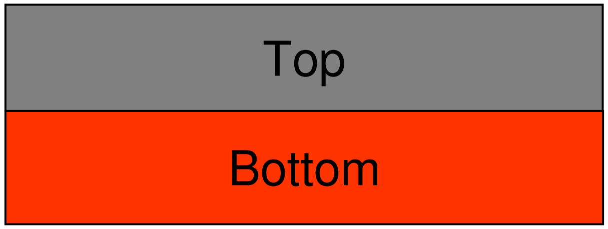
After chamber vac

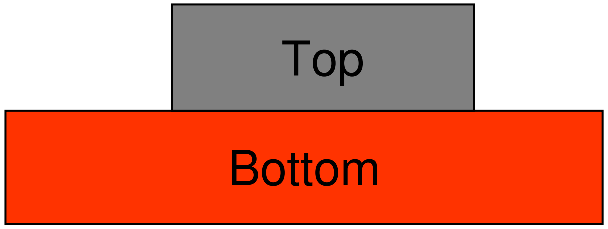


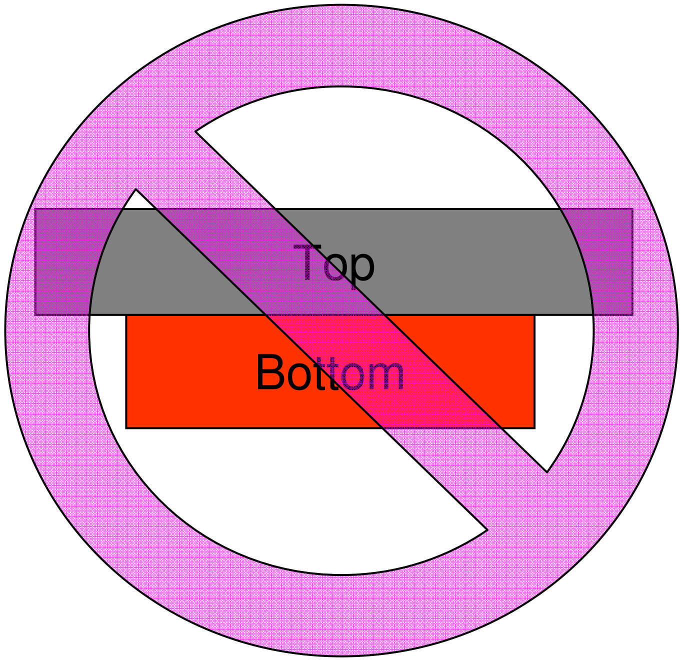


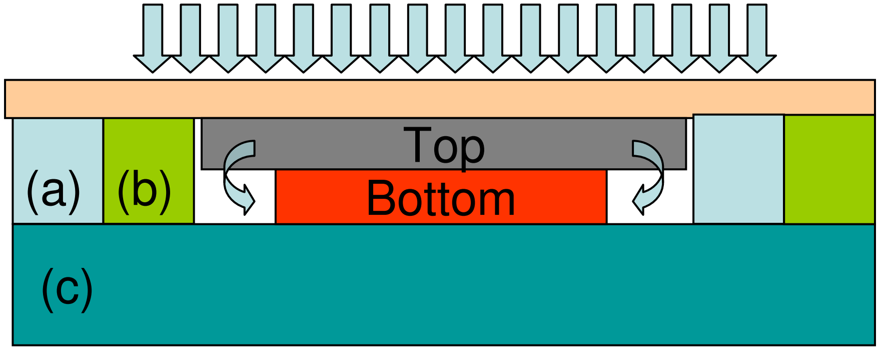
a) Spacer
b) Ring
c) Chuck
d) Bottom substrate
e) Top substrate
f) Foil

Relative Size of Top & Bottom Substrates

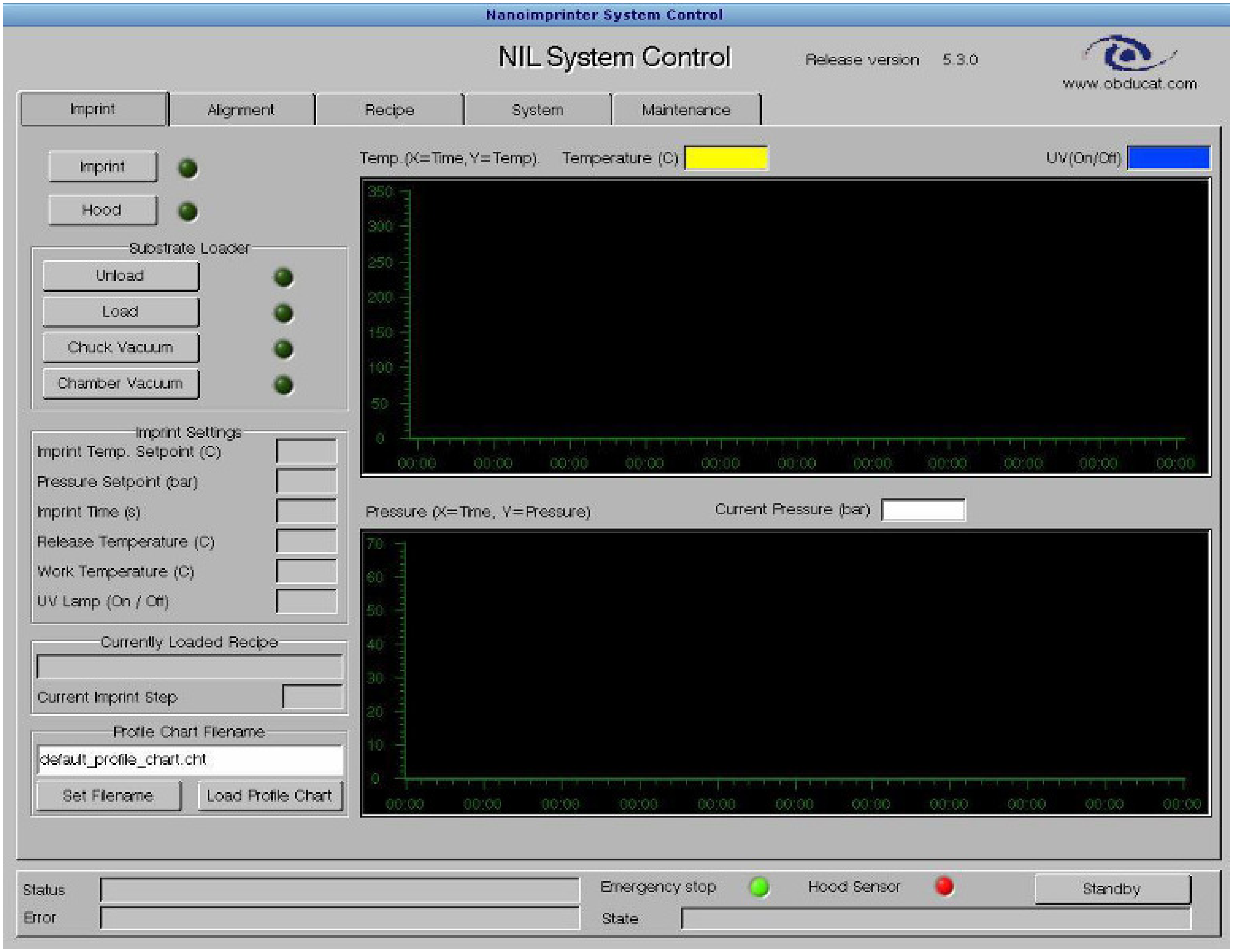






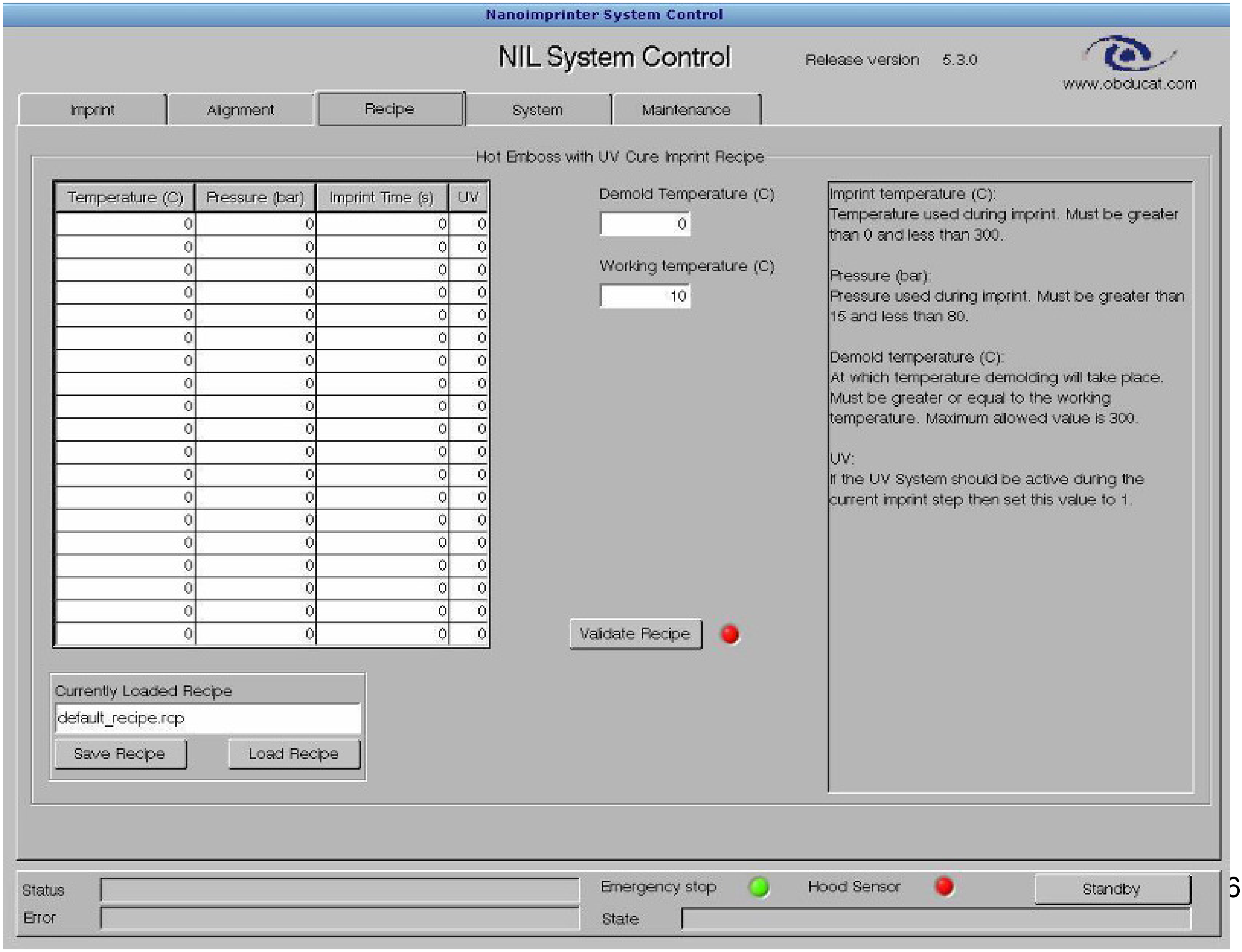


Main Operating Window in Software



default_profile_chart.cht

Recipe Definition in Software



Release version 5.3.0

Hot Emboss with UV Cure Imprint Recipe

Temperature (C)	Pressure (bar)	Imprint Time (s)	UV
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Demold Temperature (C): 0

Working temperature (C): 10

Currently Loaded Recipe: default_recipe.rcp

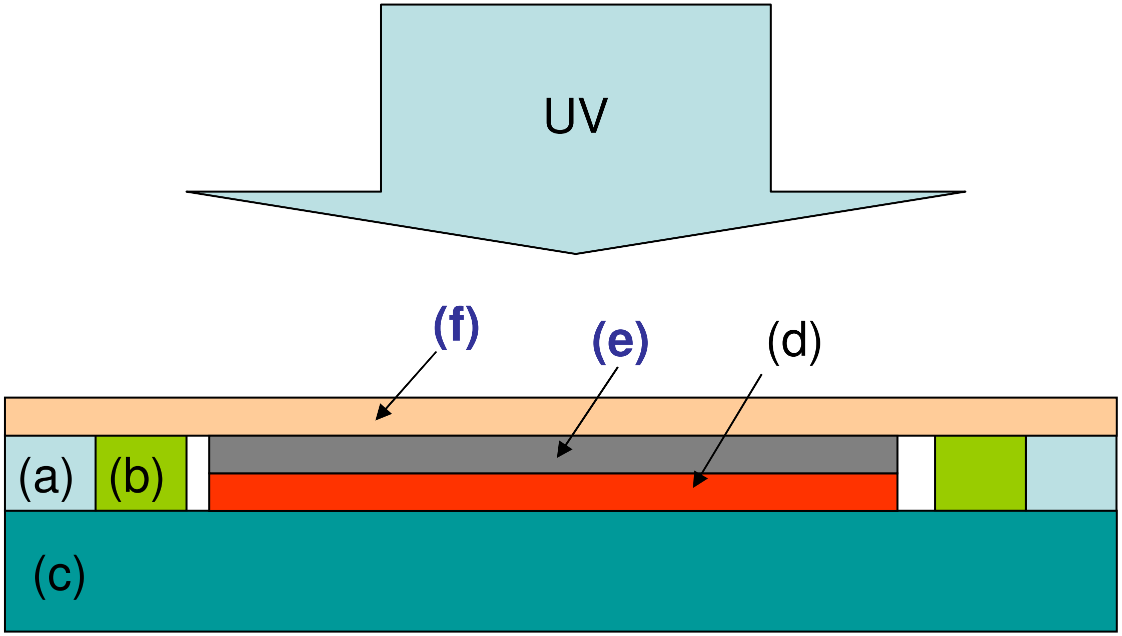
Imprint temperature (C):
Temperature used during imprint. Must be greater than 0 and less than 300.

Pressure (bar):
Pressure used during imprint. Must be greater than 15 and less than 80.

Demold temperature (C):
At which temperature demolding will take place. Must be greater or equal to the working temperature. Maximum allowed value is 300.

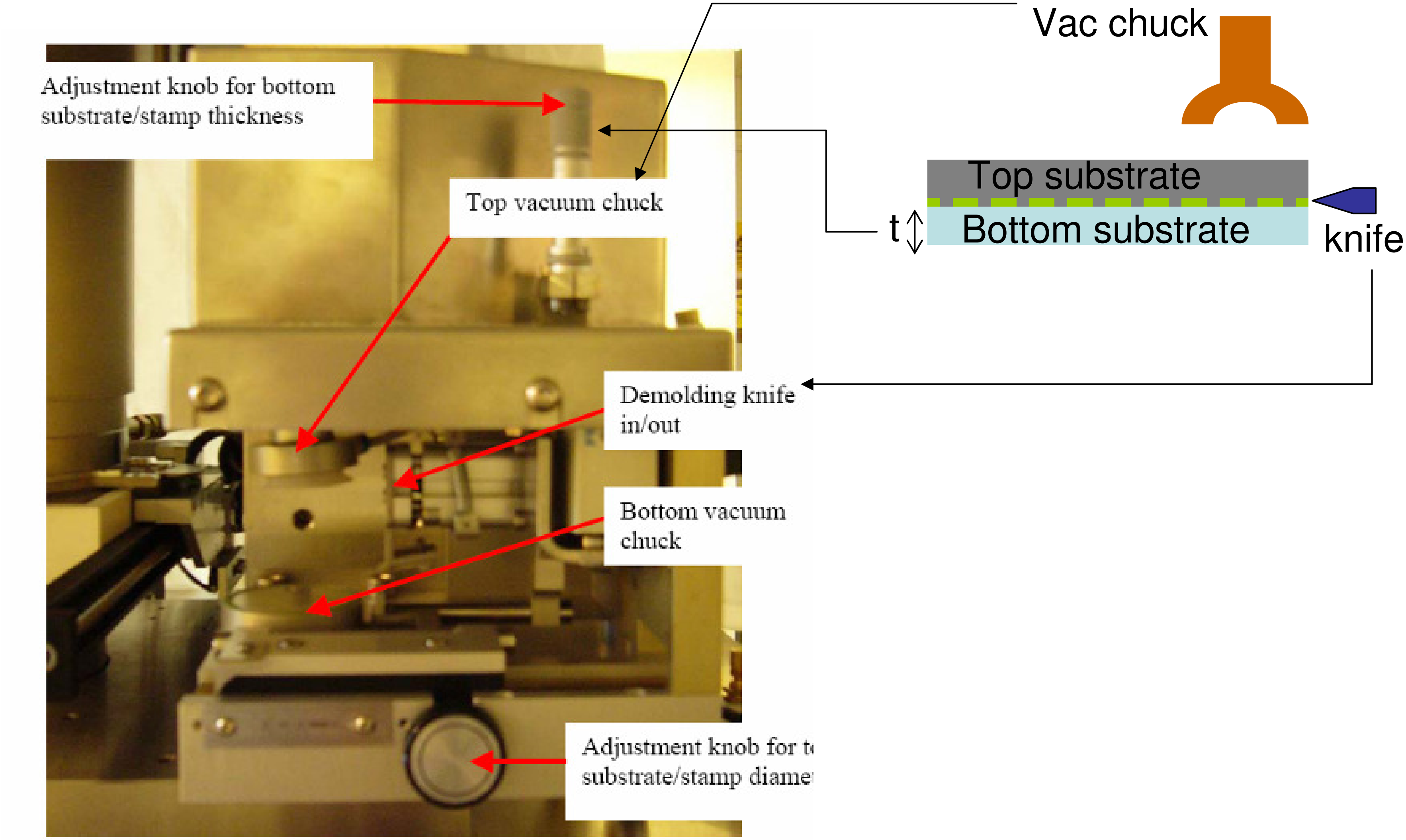
UV:
If the UV System should be active during the current imprint step then set this value to 1.

Sample Mounting Procedure when UV is Needed



a) Spacer
b) Ring
c) Chuck
d) Bottom substrate
e) UV Transparent template/mask (i.e., quartz)
f) UV Transparent foil

Demolding



Adjustment knob for bottom substrate/stamp thickness

Top vacuum chuck

Demolding knife in/out

Bottom vacuum chuck

Adjustment knob for t
substrate/stamp diame

Vac chuck

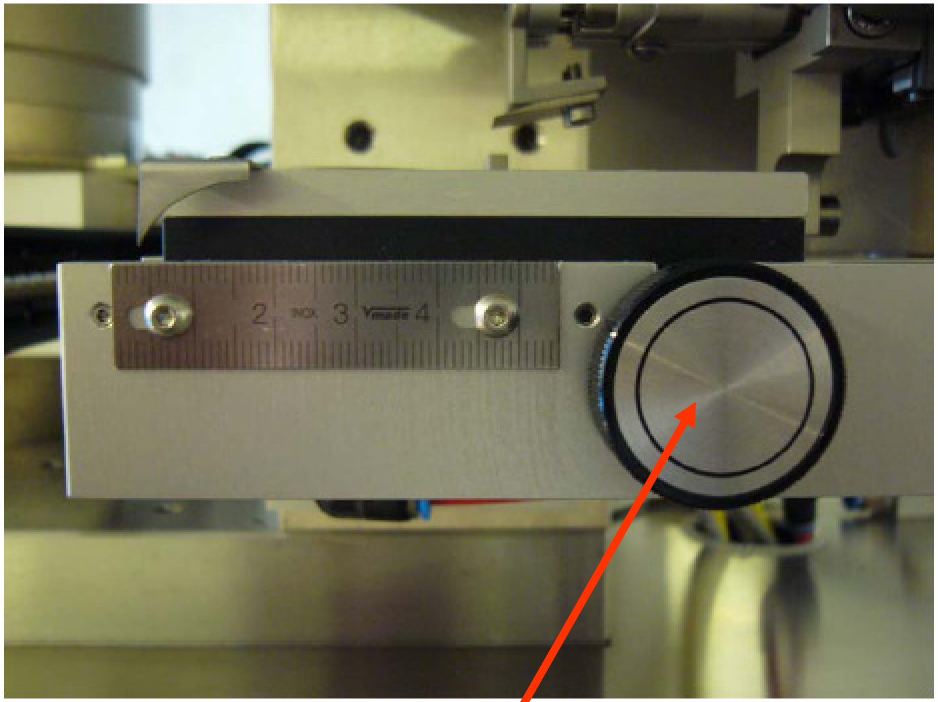
Top substrate

Bottom substrate

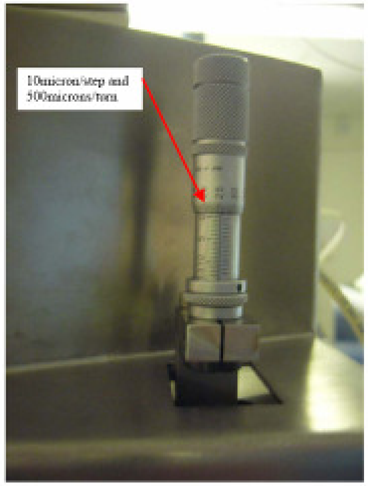
t

knife

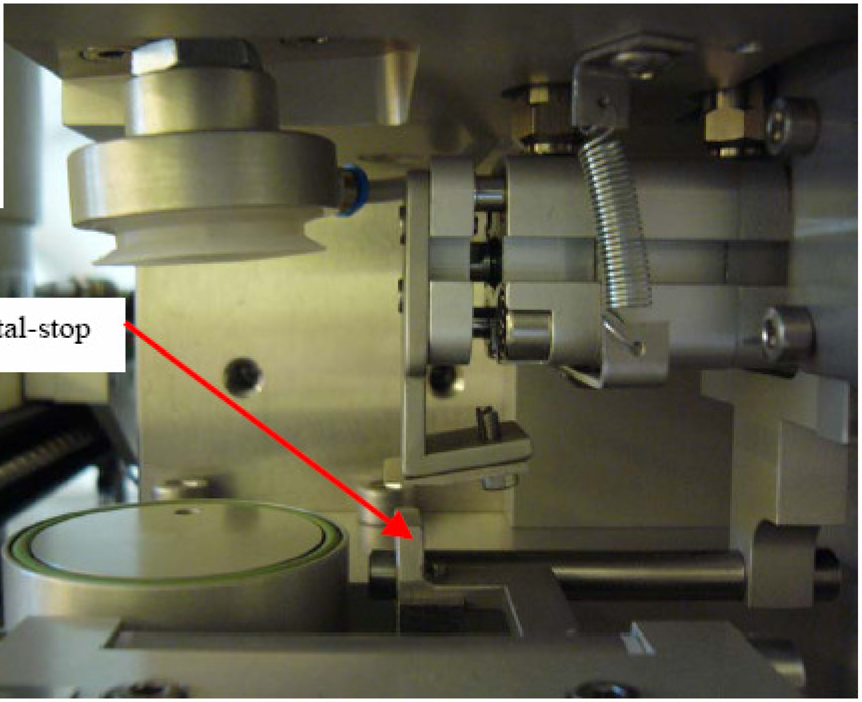
Closer look at Demolding Unit



Set for appropriate wafer diameter

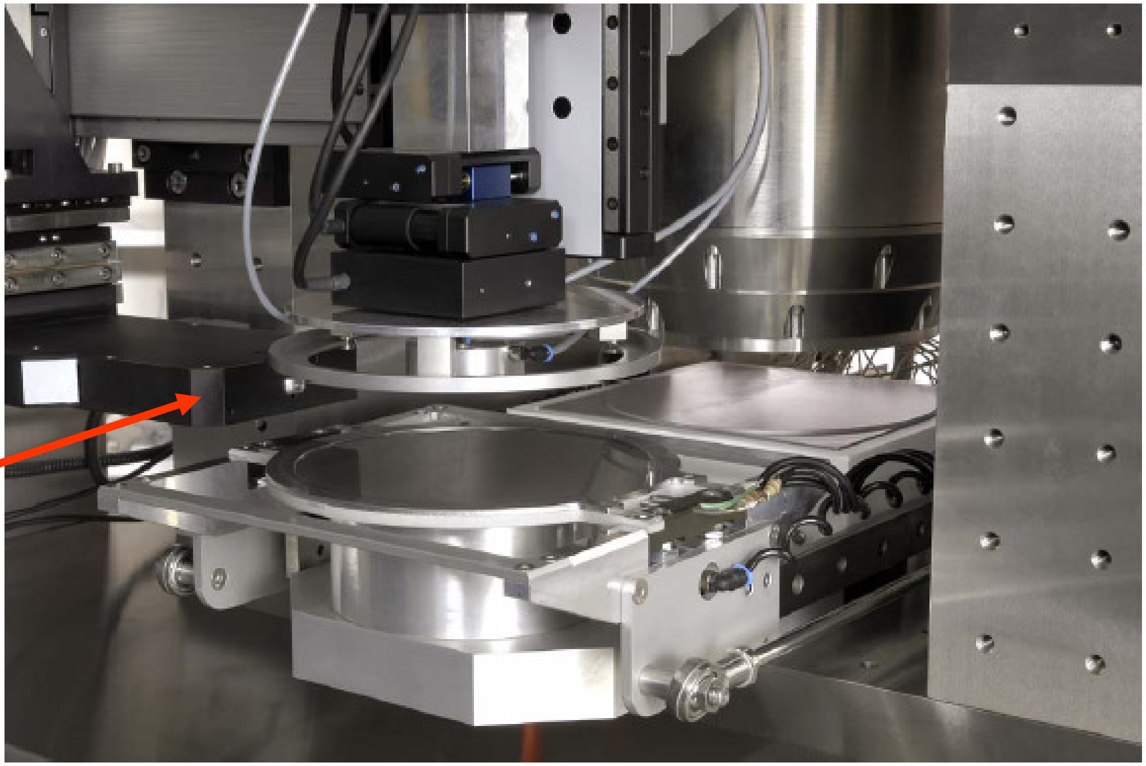


10micron/step and 500microns/turn

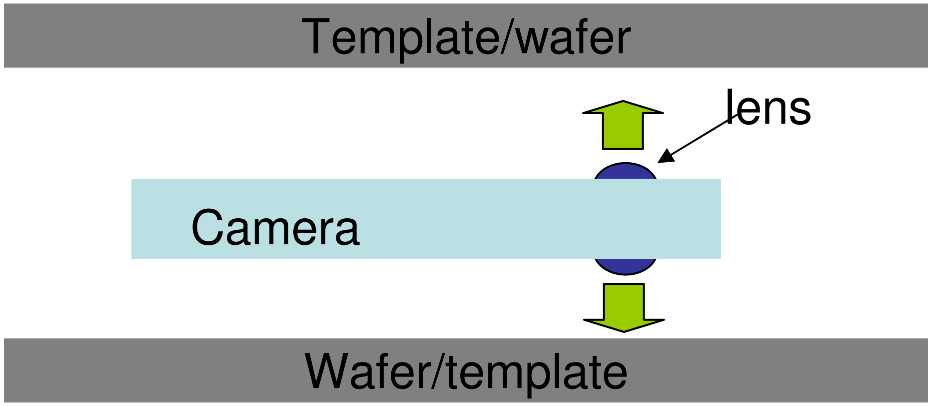


Metal-stop

Alignment System



Split-optics camera



Template/wafer

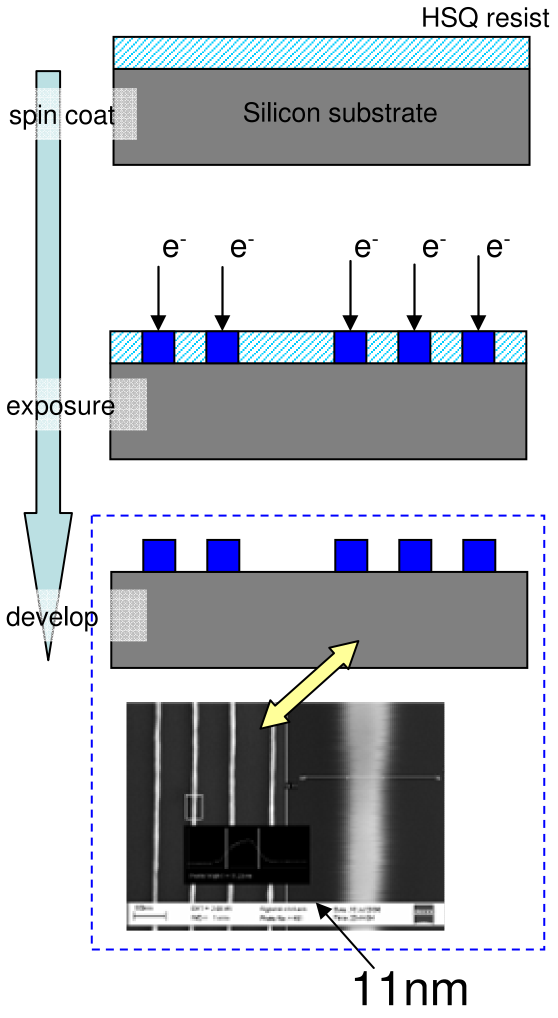
lens

Camera

Wafer/template

Nanoimprint Template Fab & Use @ MiRC

EBL



HSQ resist

spin coat

Silicon substrate

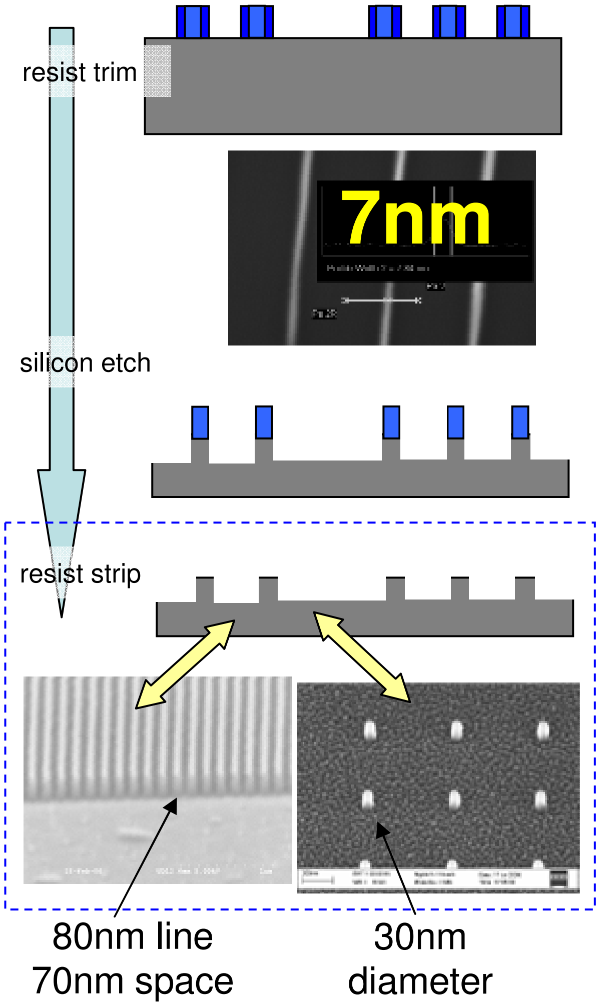
e- e- e- e- e-

exposure

develop

11nm

Plasma Etch



resist trim

7nm

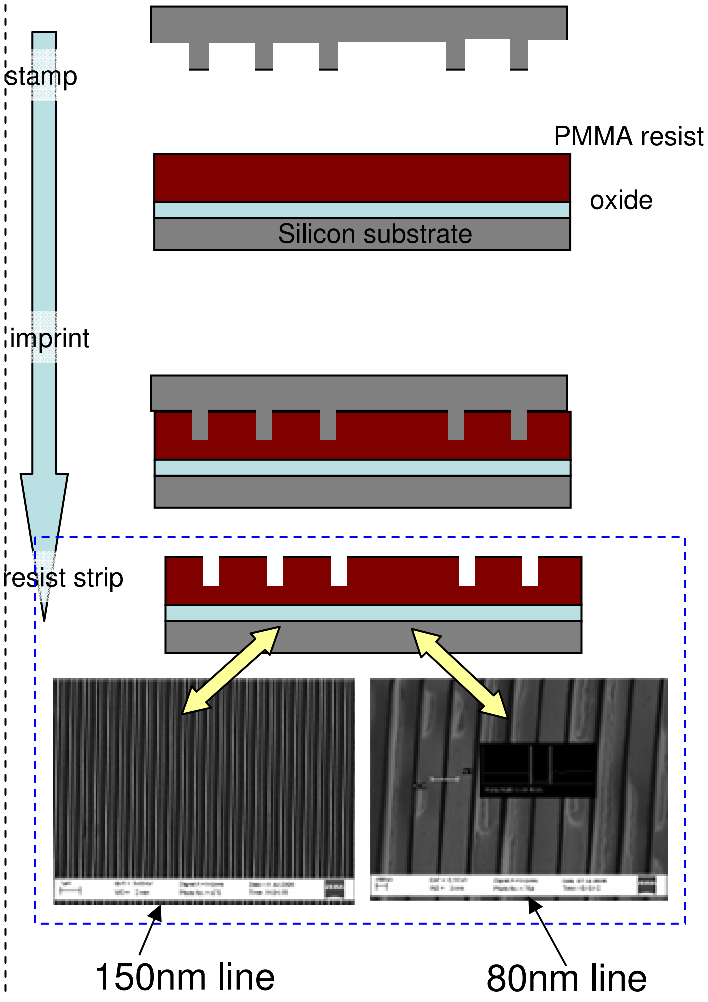
silicon etch

resist strip

80nm line
70nm space

30nm
diameter

NIL



stamp

PMMA resist

oxide

Silicon substrate

imprint

resist strip

150nm line

80nm line

Slide courtesy of Devin Brown, MiRC, GT

Conclusion

- Exciting non-optical based litho systems extend the reach of semiconductor processing: new window of opportunities for the fabrication of same/novel device structures at low cost

- There are major differences between soft-litho & nanoimprint-litho:
    - Soft template vs. hard template
    - The resist used
    - Resolution and applications
    - Practicality/availability of infrastructure to implement

- GT MiRC offers state-of-the-art nanolitho systems to address all nano fabrication needs
    - E-beam litho system
    - Nanoimprint litho system: UV and thermal

{5 minute movie of NIL system working} …