



# *Introduction to Micro/Nano Fabrication Techniques*

**Lecture 1  
Dr. Yi-Chung Tung**

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## Fabrication of Nanomaterials

- Top-Down Approach
  - Begin with bulk materials that are reduced into nano-scale materials
  - Ex: Traditional Machining
- Bottom-Up Approach
  - Begin with atoms and molecules that can grown into zero, one, two, and three-dimensional nanostructures
  - Ex: Chemical Synthesis
- Hybrid
  - Top-Down + Bottom-Up

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## Top-Down Approach

- Mechanical energy
  - Ball milling, polishing, grinding
- Thermal
  - Annealing, evaporation, pyrolysis
- High energy
  - Arch, laser, ion milling, reactive ion etching
- Chemical
  - Chemical etching, CMP, electropolishing, anodizing
- Lithographic
  - Photo, e-beam, EUV, X-ray,  $\mu$ -cp, NIL, Nanosphere
- Nature
  - Erosion, decomposition, digestion



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## Bottom-Up Approach

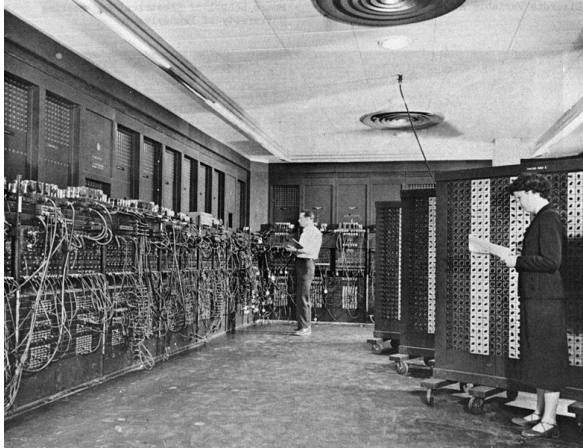
- Gas
  - Chemical vapor deposition, atomic layer deposition, MOCVD, MBE, ion implantation
- Liquid
  - Self-assembly, supermolecule, reduction, template synthesis
- Lithographic
  - Dip-pen, block co-polymer, STM writing
- Biological
  - Protein, nuclear acid crystal formation



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## Building a Computer



ENIAC: Electronic Numerical Integrator And Computer, 1946.

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## First Integrated Circuit



*"What we didn't realize then was that the integrated circuit would reduce the cost of electronic functions by a factor of a million to one, nothing had ever done that for anything before" - Jack Kilby 2000 Nobel Prize*

1958 Texas Instruments

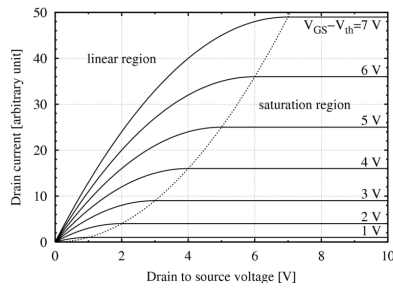
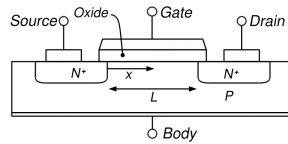
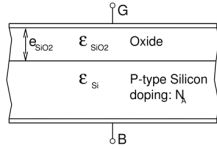


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# MOSFET

- Metal-Oxide-Semiconductor Field-Effect Transistor

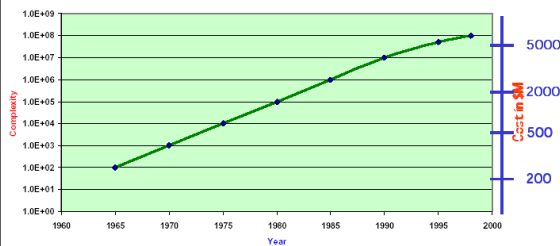
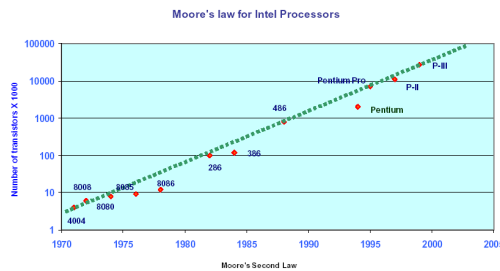


- Small Print
- Low Power Dissipation
- Batch Process
- Fast Response
- Pure Electrical Switch, No Moving Parts

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# Moore's Law



## Moore's Laws

First Law: Number of components in a chip (IC) will double roughly every 18 months (1965, in *Electronics*). This has held true more or less since then.

Second Law: Facility costs increase on a semilog scale (terminology due to Eugene Meieran, Intel Fellow). Fab costs double approximately every four years.



Intel @intel-1h  
Official  
Today, we lost a visionary.

Gordon Moore, thank you for everything.

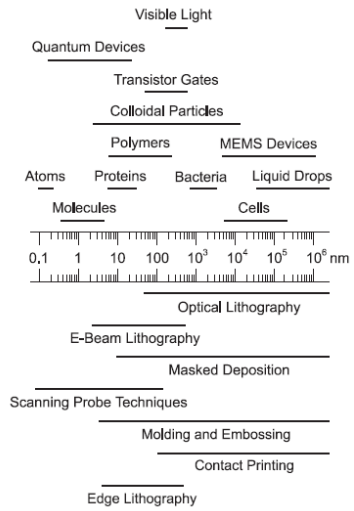
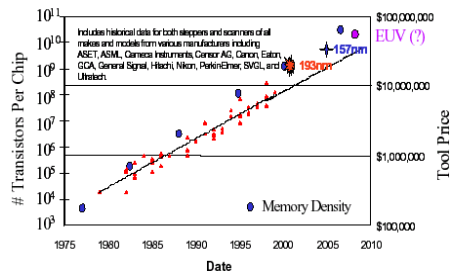


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# Tool Cost

- Why does the tool cost increase so fast?
- What is the bottleneck?



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# Industrial Process

- Lithography
- Deposition
- Etching
- Planization
- Packaging



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# STEP I: Cleaning

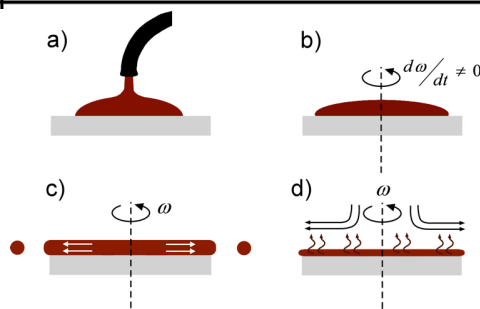
## RCA Cleaning (By Radio Corporation of America in 1965)

Chemicals	Volume ratio	Procedure Time (min)	Operation Temperature	Function
Trichlorothane		5	Room T	Dissolve Organic
Acetone		5	Room T	Dissolve Organic
DI Water		5	Room T	Washing
H <sub>2</sub> SO <sub>4</sub> (98%)-H <sub>2</sub> O <sub>2</sub> (30%) (Piranha Solution)	3:1	10-20	~90°C	Oxide and Dissolve Organic and Metals
DI Water		5	Room T	Washing
HF(49 wt %)-H <sub>2</sub> O	~2:100	10-20	Room T	Dissolve surface SiO <sub>2</sub>
NH <sub>4</sub> OH(29%)-H <sub>2</sub> O <sub>2</sub> (30%)-H <sub>2</sub> O	1:1:5	10-20	~90°C	Oxide and Dissolve Metals
DI Water		5	Room T	Washing
HCl(37%)- H <sub>2</sub> O <sub>2</sub> (30%)-H <sub>2</sub> O	1:1:5	10-20	~90°C	Oxide and Dissolve Metals
DI Water		5	Room T	Washing
Spin Dry (In lad - N <sub>2</sub> blow )				

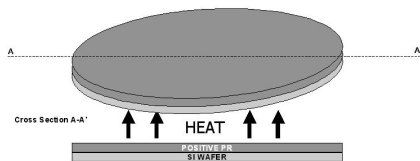
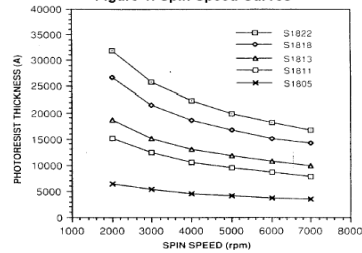
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# STEP II: PR Spin Coating/Soft Bake



MICROPOSIT S1800 PHOTO RESIST UNDYED SERIES  
Figure 1. Spin Speed Curves

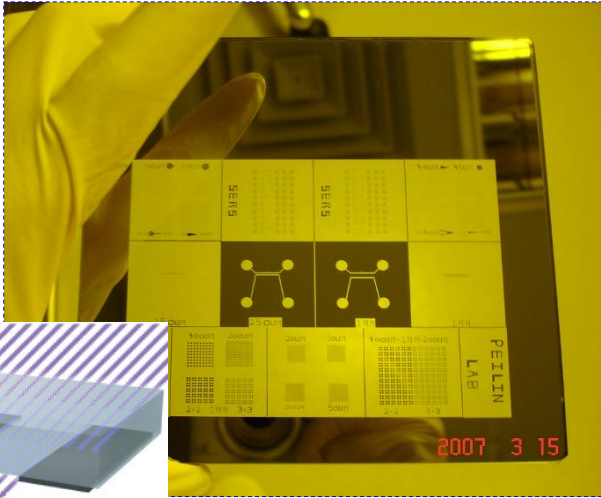
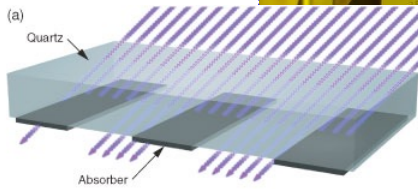


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## STEP III: Align and Exposure

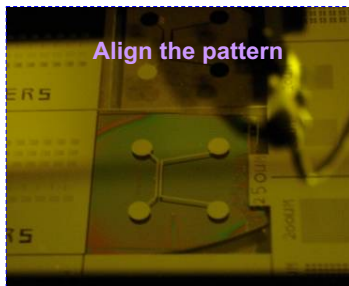
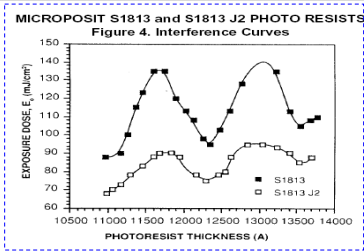
- Mask: Quartz + Cr Patterns



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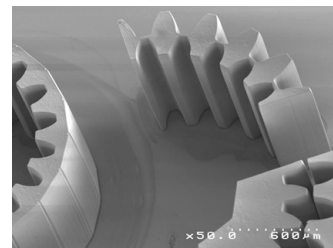
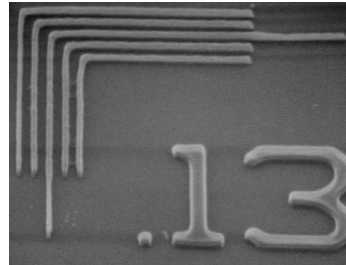
## STEP III: Align and Exposure



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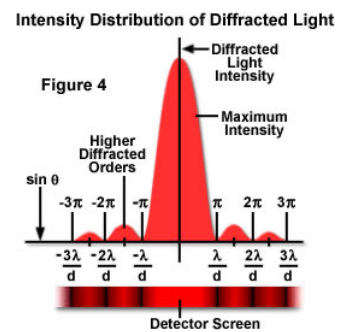
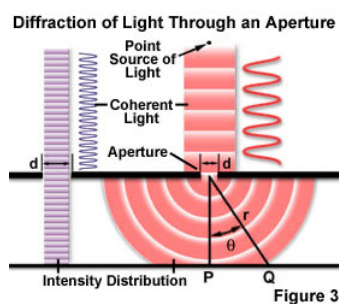
## STEP IV: (PEB) and Develop



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## Limitation of Optical Lithography

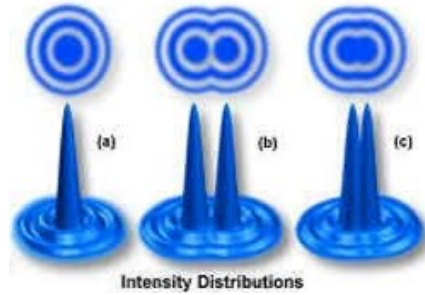


$$r = 1.22 \times \lambda / (2 \times \text{N.A.})$$
$$\text{N.A.} = n \times \sin(\theta)$$

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## Diffraction Limit

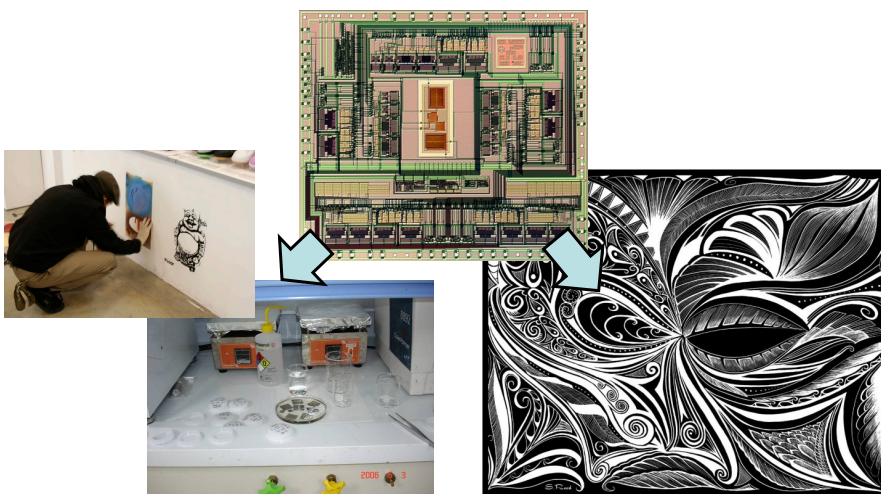


$$\text{Resolution} = K \times \lambda / (\text{N.A.})$$
$$\text{Depth of Focus} = \lambda / (\text{N.A.})^2$$
$$K = 0.61$$

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## Nano/Micro Fabrication



**Lift-Off**

**Etching**

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## Thin Film Deposition

**Sputter**

**Thermal Evaporator**

**E-Beam Evaporator**

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## Etching (Wet and Dry)

- Wet Etching: Chemical Reactions
- Dry Etching: Physical (and Chemical) Reaction

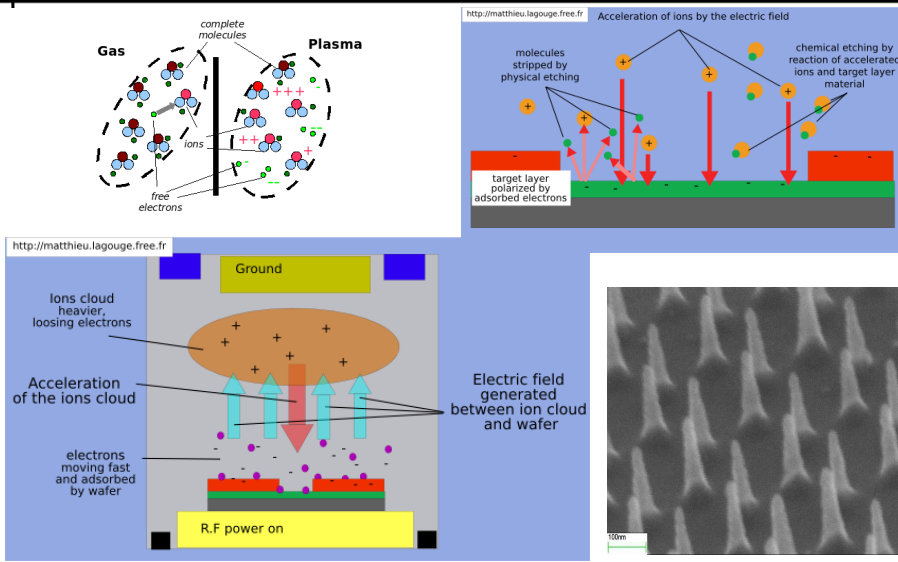
a) 1 mm 30.1 kV 7.50E1 0074/80 16

31nm 34nm 33nm  
Acc.V Spot Magn Det WD Exp  
0.00 kV 5.0 20000x TLD 2.0 1  
http://www.mmc.be

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## Reactive Ion Etching (RIE)



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## Inductively Coupled Plasma (ICP)

An ICP is different than an RIE because it uses two power supplies to generate plasma. One power source is used to generate a dense plasma (~10x more reactive species than RIE), while the second power source accelerates the ions towards the etching surface. This combination increases the anisotropy of the etched feature as compared to conventional RIE.

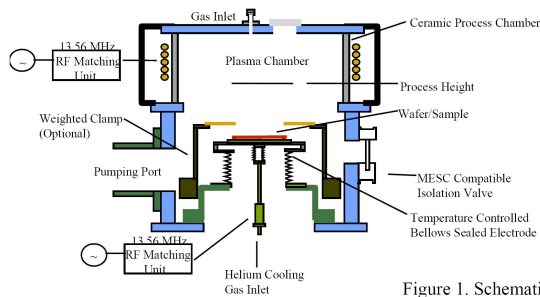
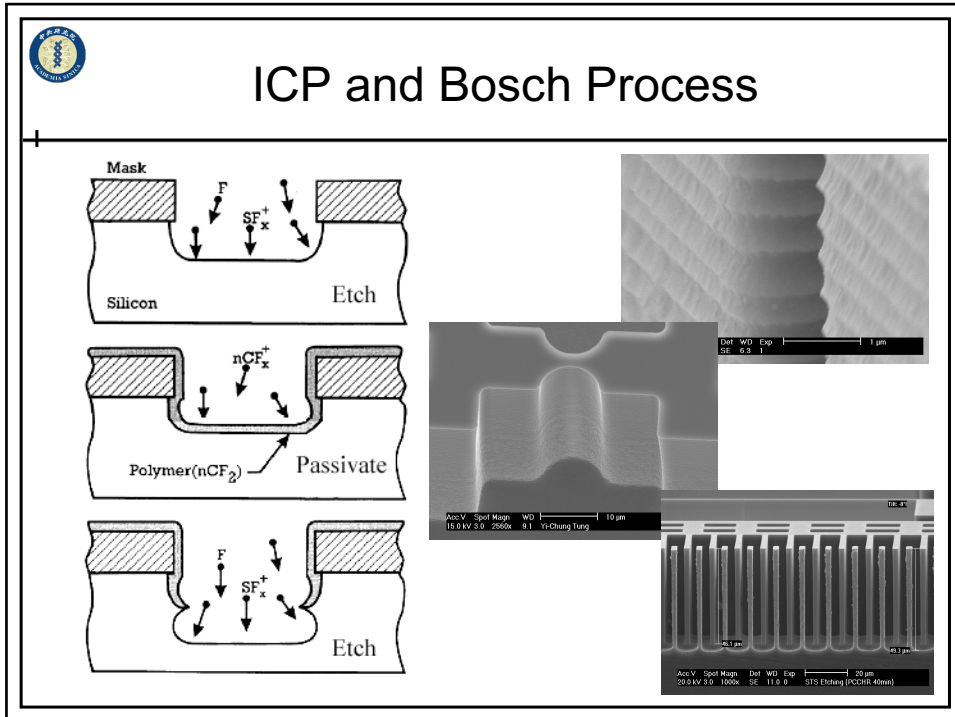
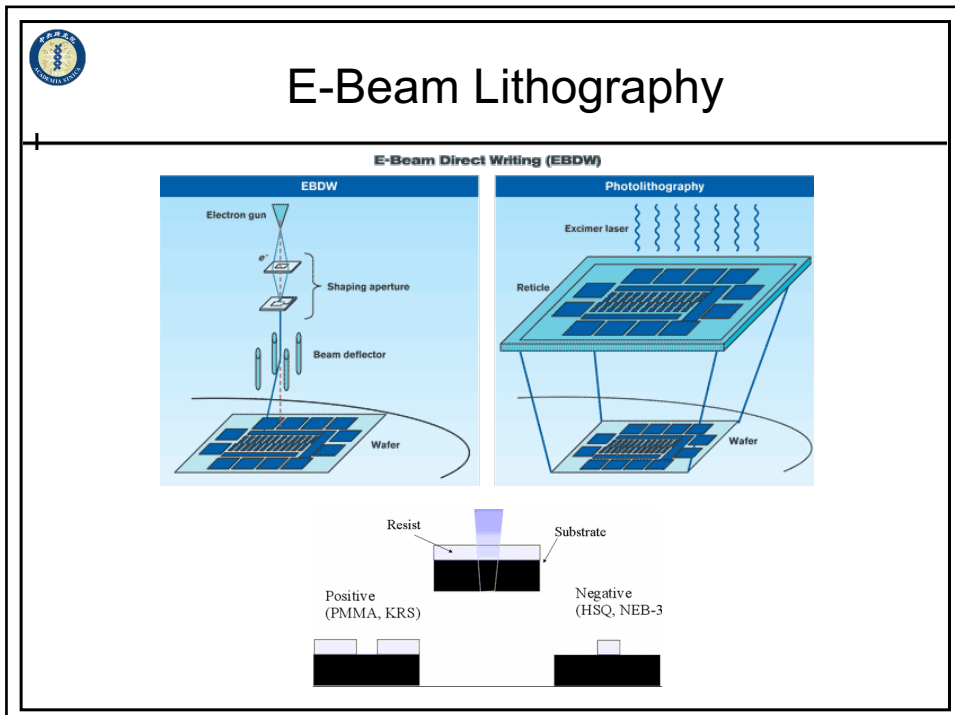


Figure 1. Schematic of STS ICP system.

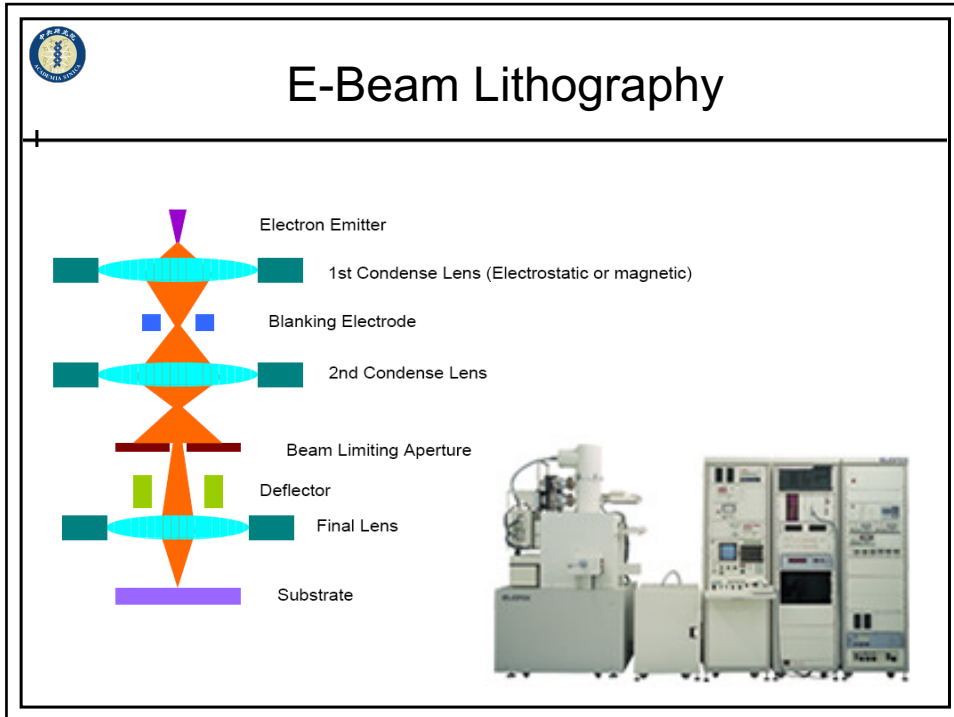
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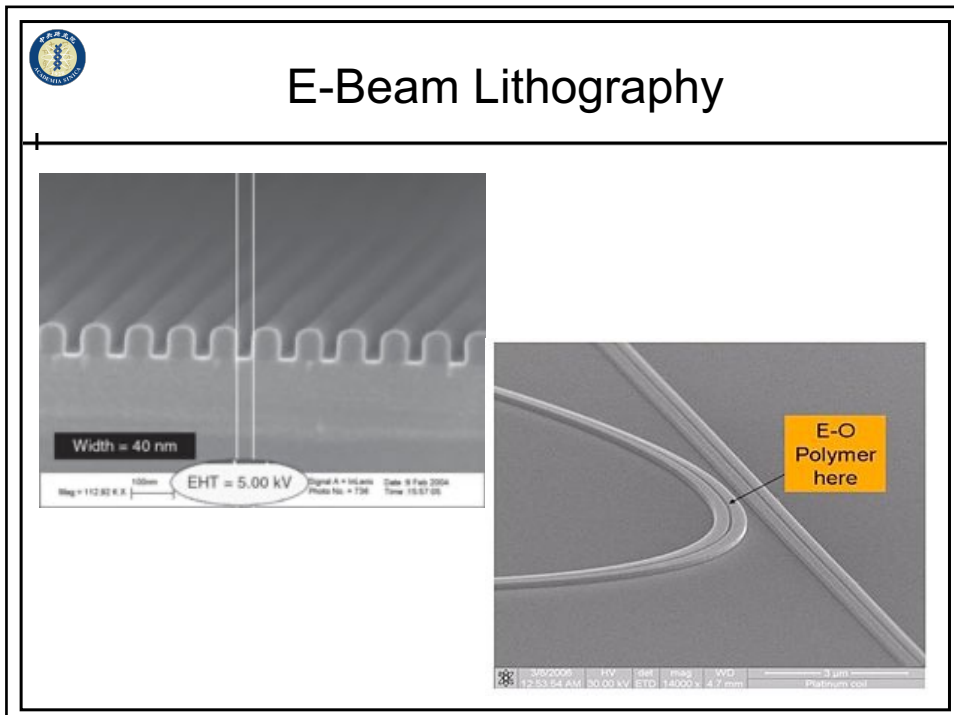
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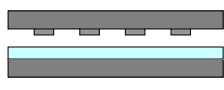
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# Nanoimprint Lithography (NIL)

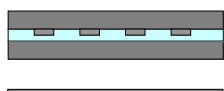
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**Mold**

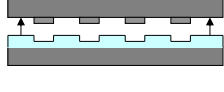


**PMMA Substrate**

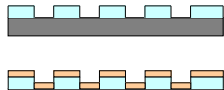
**Imprint**




**Remove Mold**



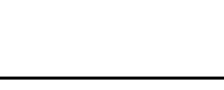
**RIE**

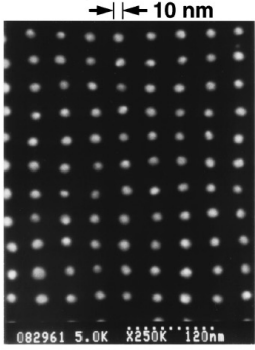


**Evaporation**



**Lift-off (or Etching)**







**Stephen Chou**  
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 Professor of Electrical Engineering

Ph.D., Massachusetts Institute of Technology, 1986  
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 B.S., Physics, University of Science and Technology of China, 1978

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 Webpage: [Chou's Lab](http://Chou's Lab)



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# Nanoimprint Lithography (NIL)


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## Ultrafast and direct imprint of nanostructures in silicon

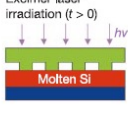
NATURE | VOL. 417 | 20 JUNE 2002 |

Stephen Y. Chou\*, Chris Keimel & Jian Gu

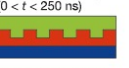
**a** Contact mould and substrate ( $t = 0$ )



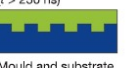
**b** Excimer laser irradiation ( $t > 0$ )




**c** Silicon embossing ( $0 < t < 250$  ns)



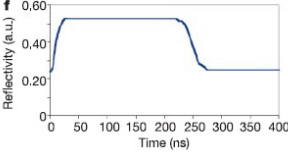
**d** Silicon solidification ( $t > 250$  ns)

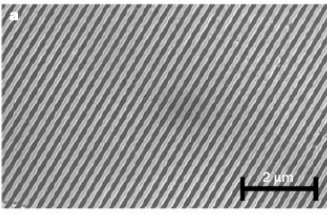
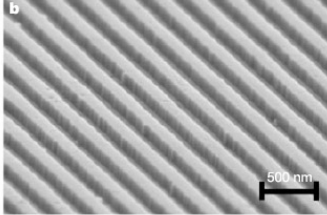


**e** Mould and substrate separation



**f**

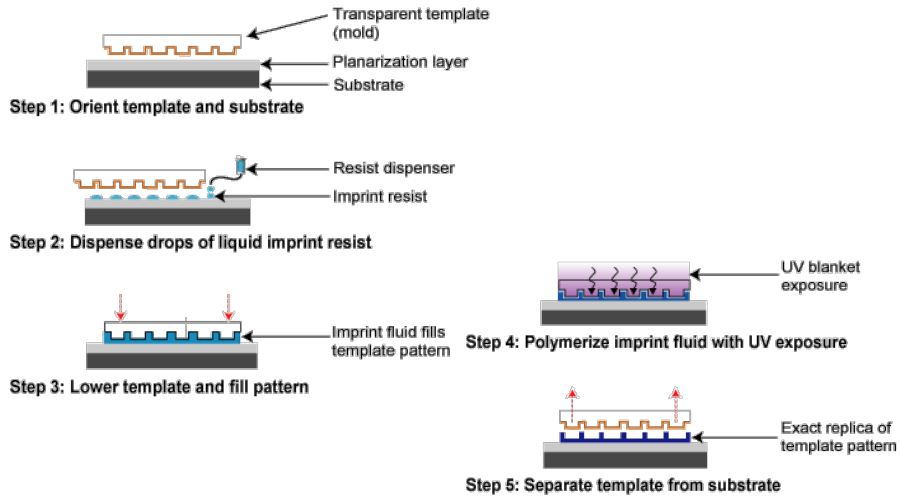


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## Step and Flash Imprint Lithography



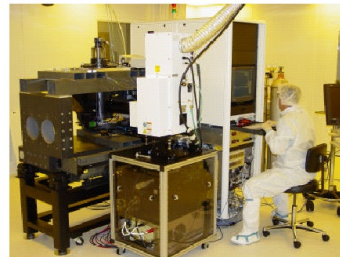
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## Nanoimprinter



NX-2000, Nanoimprinter, Nanonex



**IMPRIO**  
100

**Molecular Imprints, Inc.**

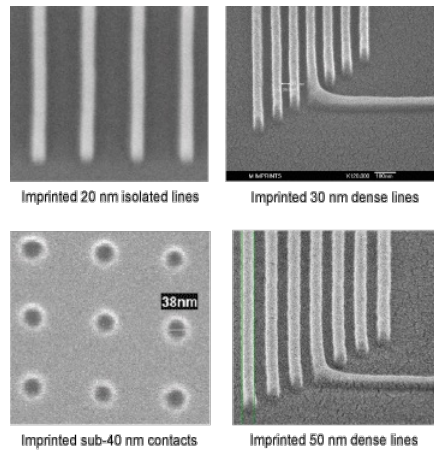
- Resolution: Sub-50 nanometers, imprint template (mold) limited.
- Alignment: < 500 nm, 3 $\sigma$  (X, Y, and Rotation).
- Flexibility: Handles up to 8 inch wafers, including fragile substrates.
- Field size: 25 x 25 mm full active print area, 100  $\mu$ m street width.

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## Nanoimprint Results and Challenge

- Mask Fabrication (1:1)
- Lift-off process
- Resist
- Mask Design

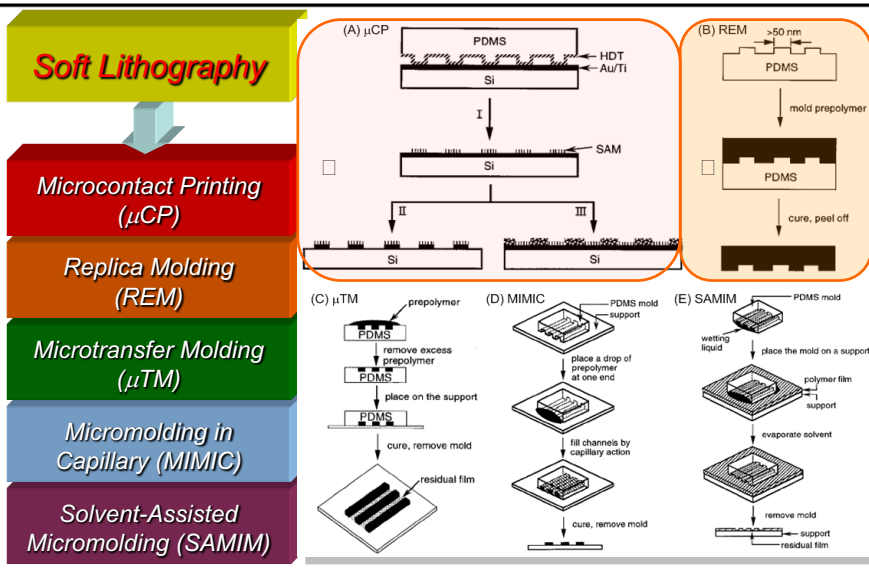


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## Soft Lithography

### Soft Lithography

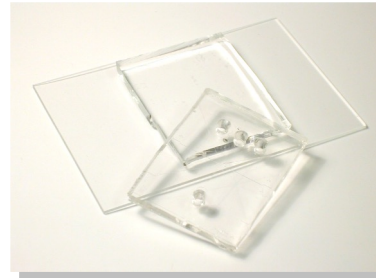
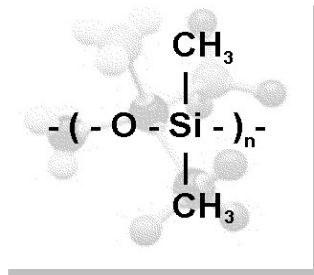


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## Soft Lithography - PDMS

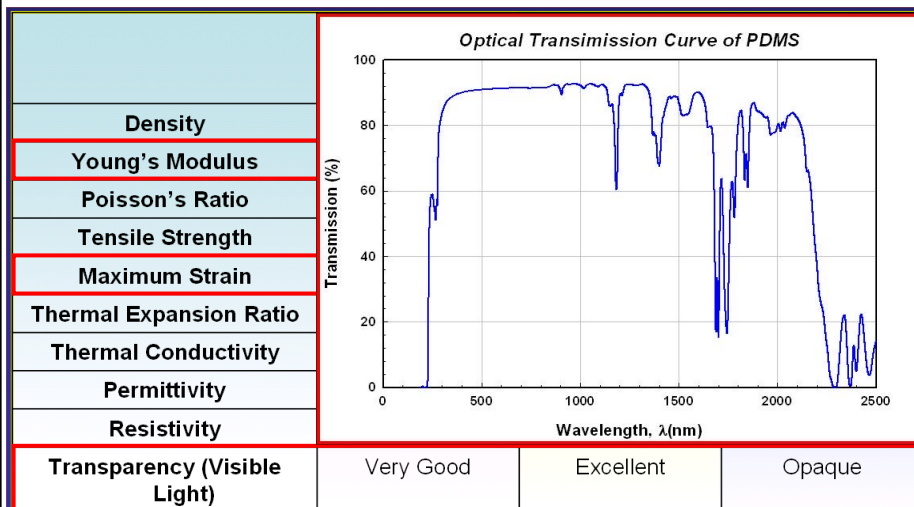
- PDMS (Polydimethylsiloxane)
  - PDMS is durable, optically transparent, and inexpensive
  - PDMS can be patterned by *Soft Lithography*



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## PDMS Material Properties



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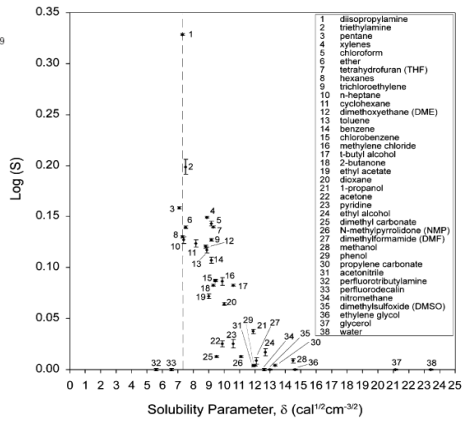


# PDMS

## Solvent Compatibility of Poly(dimethylsiloxane)-Based Microfluidic Devices

Anal. Chem. 2003, 75, 6544–6554

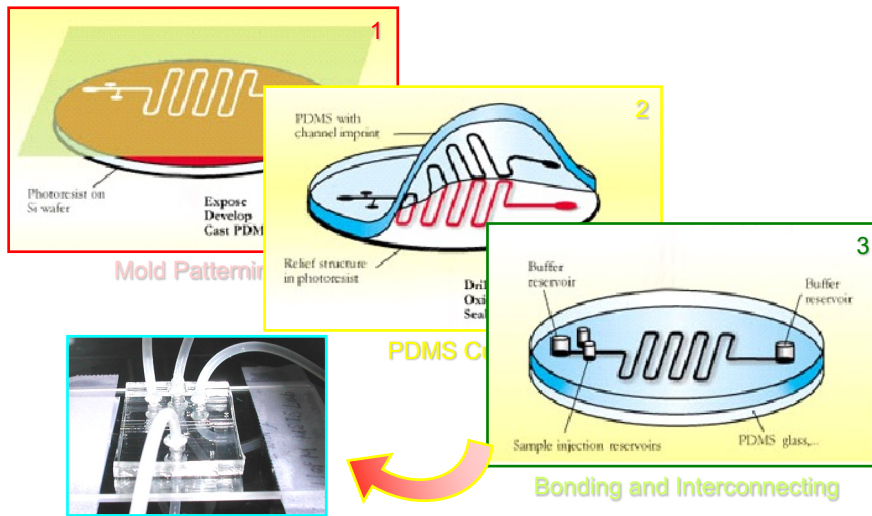
solvent	$\delta^d$	$\delta^p$	$\mu$ (D)
perfluorotributylamine	5.6	1.00	0.0
perfluorodecalin	6.6	1.00	0.0
pentane	7.1	1.44	0.0
poly(dimethylsiloxane)	7.3	$\infty$	0.6–0.9
diisopropylamine	7.3	2.13	1.2
hexanes	7.3	1.35	0.0
n-heptane	7.4	1.34	0.0
triethylamine	7.5	1.58	0.7
ether	7.5	1.38	1.1
cyclohexane	8.2	1.33	0.0
trichloroethylene	9.2	1.34	0.9
dimethoxyethane (DME)	8.8	1.32	1.6
xylenes	8.9	1.41	0.3
toluene	8.9	1.31	0.4
ethyl acetate	9.0	1.18	1.8
benzene	9.2	1.28	0.0
chloroform	9.2	1.39	1.0
2-butanone	9.3	1.21	2.8
tetrahydrofuran (THF)	9.3	1.38	1.7
dimethyl carbonate	9.5	1.03	0.9
chlorobenzene	9.5	1.22	1.7
methylene chloride	9.9	1.22	1.6
acetone	9.9	1.06	2.9
dioxane	10.0	1.16	0.5
pyridine	10.6	1.06	2.2
N-methylpyrrolidone (NMP)	11.1	1.03	3.8
tert-butyl alcohol	10.6	1.21	1.6
acetonitrile	11.9	1.01	4.0
1-propanol	11.9	1.09	1.6
phenol	12.0	1.01	1.2
dimethylformamide (DMF)	12.1	1.02	3.8
nitromethane	12.6	1.00	3.5
ethyl alcohol	12.7	1.04	1.7
dimethyl sulfoxide (DMSO)	13.0	1.00	4.0
propylene carbonate	13.3	1.01	4.8
methanol	14.5	1.02	1.7
ethylene glycol	14.6	1.00	2.3
glycerol	21.1	1.00	2.6
water	23.4	1.00	1.9



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## Replica Molding (REM)

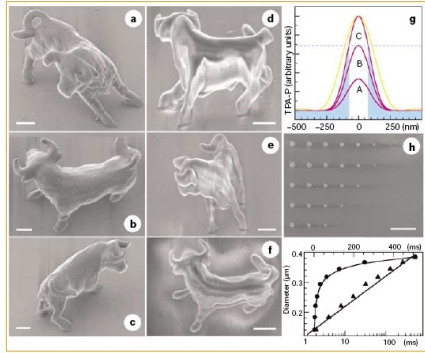


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# Others



NATURE | VOL. 412 | 16 AUGUST 2001

