15-398 Introduction to Nanotechnology

Nanoscale Lithography

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Pushing The Limits of Photolithography

- Reduce wavelength (λ)
- Use Reducing Lens
- Increase Numerical Aperture (NA) of Lens
  - E.g., Immersion optics
- Hacks (k_1)
  - PSM, OPC, RET, off-axis illumination
- Rayleigh eqn: min-feature-size=$k_1\lambda$/NA

Trends in λ, NA, k_1

Table 1. Minimum linewidth and exposure wavelength versus ye

Year	Linewidth (nm)	Wavelength (nm)
1986	1,200	436
1988	800	436/365
1991	500	365
1994	350	365/248
1997	250	248
1999	180	248
2001	130	248
2003	90	248/193
2005 (fcst)	65	193
2007 (fcst)	45	193

ICKnowledge.com

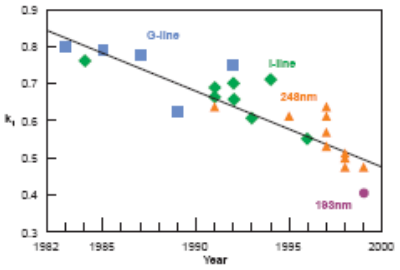
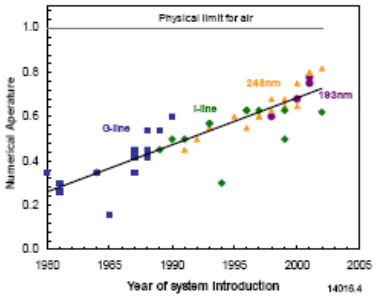
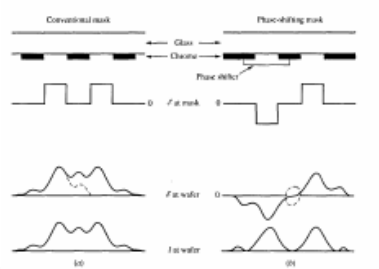


Figure 2. K_1 trend [5].





CUHG, Chap 5.

NA & Immersion

- NA = n sinα = d/(2f)
  - N is index of refraction of medium
  - α is angle of acceptance
- Air, n=1
- Water, n≅1.47

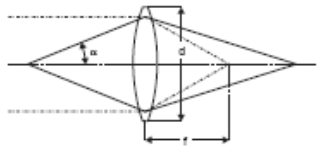
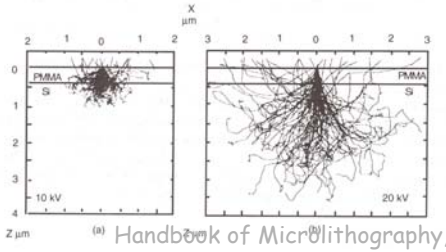


Figure 3. Numerical aperture.

- Result -> improve min linewidth 30%!

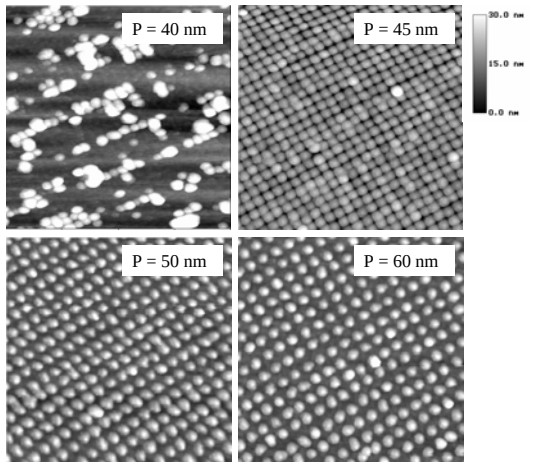
E-Beam? FIB?

- Use high-energy electrons to alter/ablate a resist
- Issues:
  - Secondary electrons
  - Scattering in resist (or off substrate)
  - Serial process
  - alignment



Handbook of Microlithography, Micromachining and Microfabrication, SPIE (1997)

Example of E-beam patterning



UofA, Nanolithography

Microelectronics isn't everything

- Reactive organics
- 3-D structures

Today

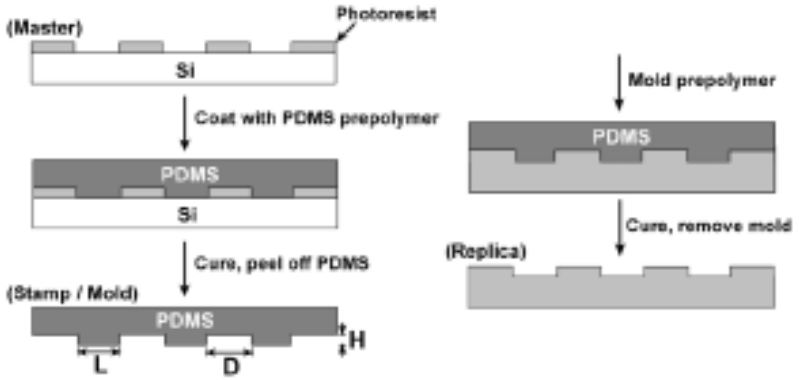
- Soft Lithography/Nanoimprint
- Scanning Probe Lithography
- Edge Lithography

- Top-down fabrication to create nanoscale features using a physical mold or tip for patterning.

Soft Litho

- Replica Molding
  transfer features from master to replica by curing a liquid
- Embossing
  transfer of features from master to replica by pressing
- Microcontact Printing
  transfer of material on master to replica by stamping

Basic Example



Unless otherwise notes, pictures from Unconventional Nanofabrication, Gates etal, ARMR 2004

The Mold

- Some important features:
  - Master should be reusable many times (self-cleaning)
  - Create fine features
  - Flexible
  - Stable
  - Optically transparant (for some processes)
  - Thermally stable
  - Inert
  - Low adhesive forces

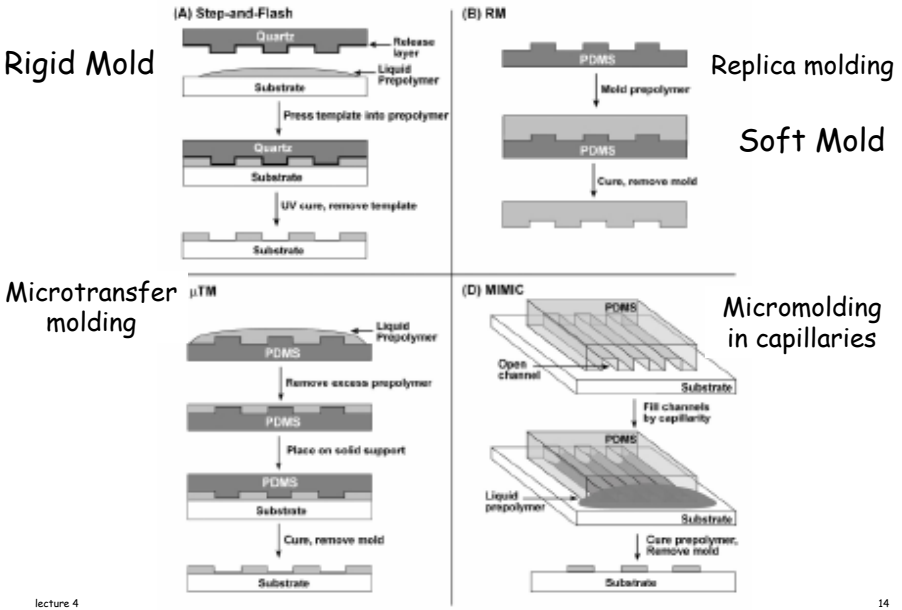
Causes of Distortion

- Differences in thermal expansion between master and replica
- Shrinkage during curing
  - x-linking
  - Evaporation
- Adhesion at time of separation
- Collapse at separation

PDMS

- Poly(dimethylsiloxane) silicone rubber
- Very common mold material. A resist
- Inert to materials being patterned
- Low surface energy (eases release)
- Optically transparant
- Thermally stable
- Tough
- Flexible
- No solvent evaporation
- Low-temp curing

Replica Molding



Rigid Molds

- E.g., Step-and-flash
  - Add Liquid pre-polymer
  - Press master
  - Expose to UV
- 30nm features
- High-aspect ratio of lines
- Rapid cycle-time
- Alignment of master and replica
- Replica needs to be planar
- Multi-layer structures hard

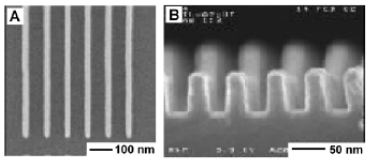
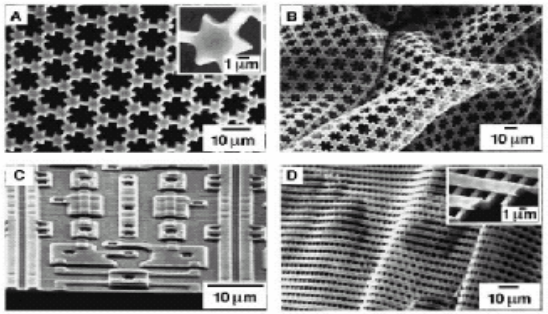


Figure 3 (*a*) Scanning electron microscopy (SEM) image of 30-nm wide lines molded into UV-cured 1,3-bis(methacryloxypropyl)tetramethyldisiloxane as patterned by step-and-flash lithography (22) (reprinted with permission, © SPIE 2002). The image in (*b*) shows a cross-section of these lines.

Soft Molds

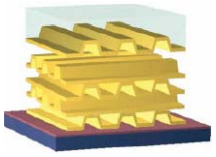
- Can pattern non-planar and soft surfaces
- Photo- or thermal curing large range of materials can be molded
- Potential for large surface area molds

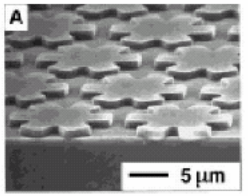
Examples

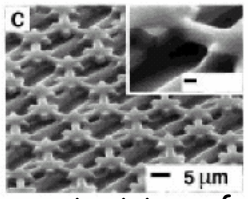


MIMIC

E. Kim *et al*, Nature, 376, 581 (1995)





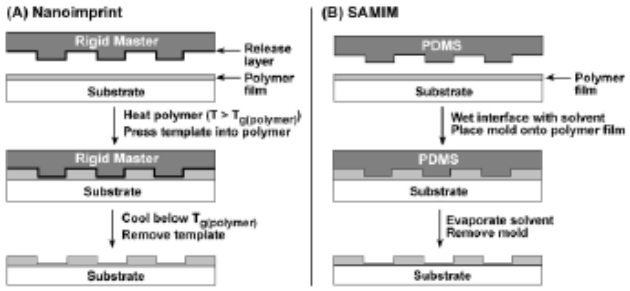


Microcontact transfer

S. Jeon *et al.*, Advanced Materials, 16, 1369 (2004)

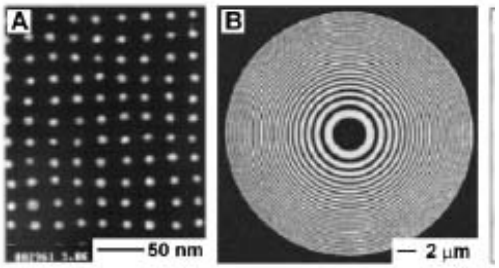
Embossing

- Press mold into replica to create structures
- Generally, thermally assisted
- Used at microlevel commercially (e.g., DVD)
- Nanoscale features <50nm



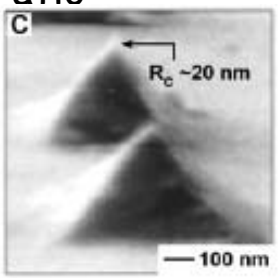
Embossing – rigid molds

- Nanoimprint lithography (NIL)
- Press mold, heat polymer, cool, release
- Features 10nm, high-aspect ratio
- Long exposure times (5 – 10 min)
- Hard for large areas



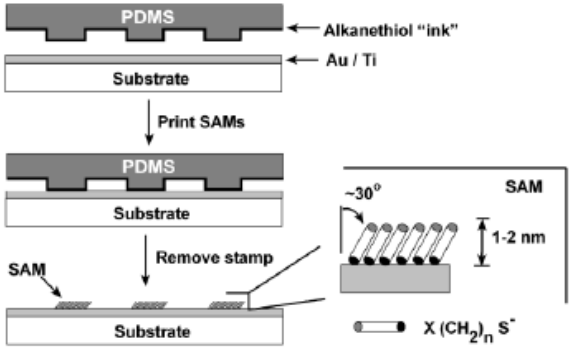
Embossing – soft molds

- SAMIM, solvent-assisted micromolding
- Reduces pressure and temp needed due to solvent
- Eliminates trapped air pockets
- 60nm features, low aspect ratio
- Non-planar surfaces
- Large areas



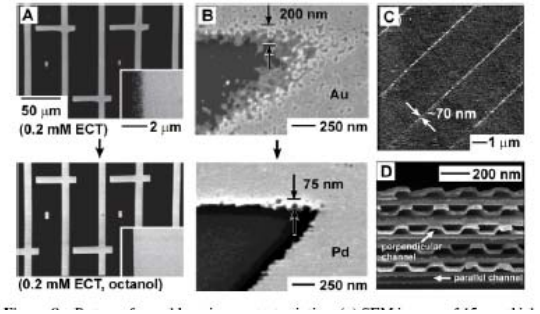
Mircocontact Printing

- Transfers "ink" from master to replica
- Ink is a self-assembled monolayer (SAM)
- 50nm features



Microcontact printing

- Planar and curved surfaces
- Many different kinds of "ink"
- Min resolution affected by diffusion of molecules
- Organics supported
- Multilayers ok



Soft Lithography

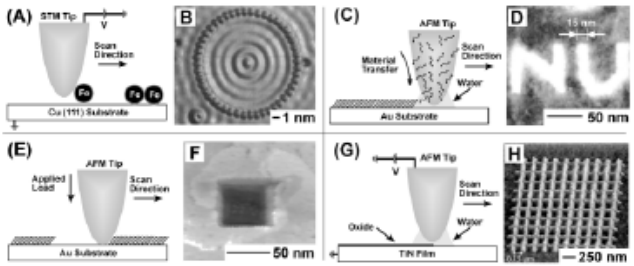
- Pluses and minues?

Soft Lithography

- Advantages
  - Avoids complexity of photolithography
  - Inexpensive
  - Some 3-D possible
  - Organics can be patterned
- Disadvantages
  - Heat, pressure can be harmful
  - Still experimental (low yield)
  - Limits due to lift-off?

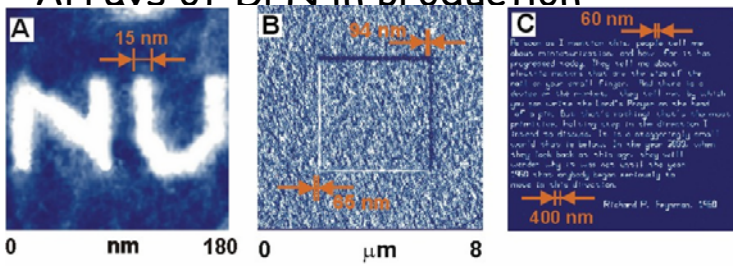
SPL

- Scanning Probe Lithography
  - STM tip
  - AFM tip
  - Dip-Pen lithography



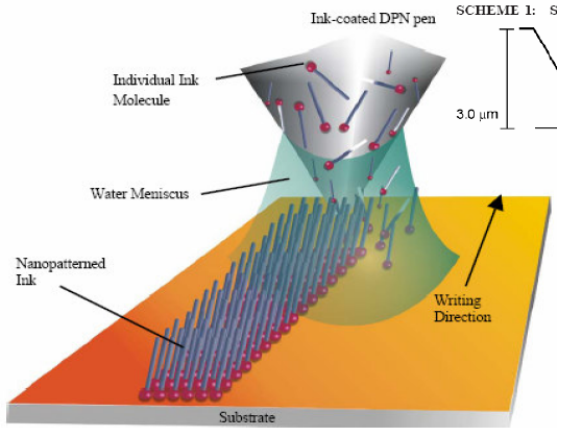
DPN

- AFM tip is "inked" with material to be deposited
- Material is adsorbed on target
- <15nm features
- Arrays of DPN in production



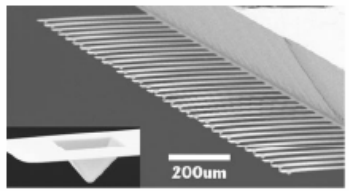
http://www.chem.northwestern.edu/~mkngrp/dpn.htm

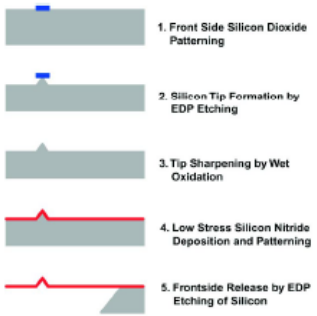
Schematic of DPN

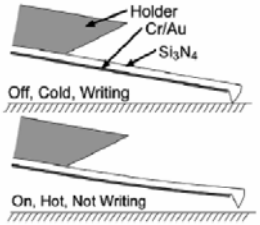


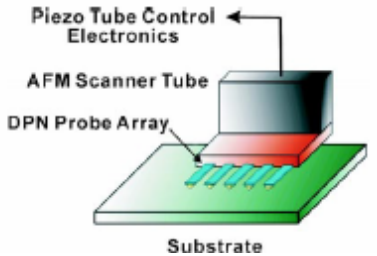
www.nanoink.net

Arrays



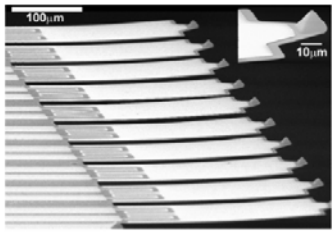


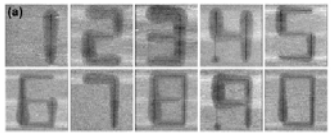




Nanotechnology 13 (2002) 212–217

Array Example



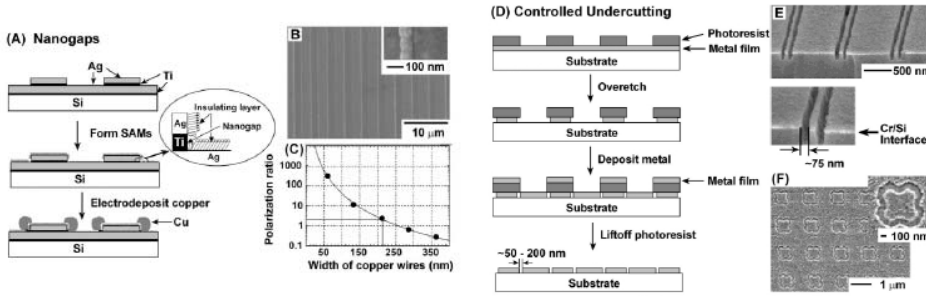


Ten different DPN patterns written simultaneously by the ten probes of a TA-DPN array. Deposited ODT shows up dark in these 8 um x8 um LFM scans.

JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, VOL. 13, NO. 4, P 594, 2004

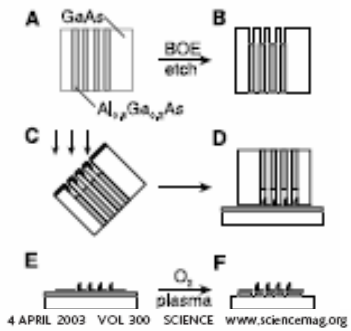
Edge Litho

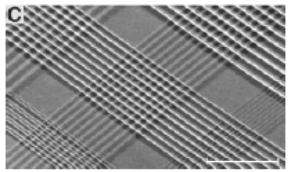
- Using Edges produced in another process to double pitch
- Using Edges in material as a stamp (more like NIL)



SNAP

- Create a stamp by using the cleaved edges of a layered material formed through MBE
- Then, e.g., transfer SAMS





8nm Pt nanowire array

SNAP V. Other

- EBL can make 20nm patterns, but …
  - Lift-off for small wires at low pitch or high-pitch limits final result
  - Result is min pitch much higher (~60nm?)
  - Pitch is everything?
  - EBL serial
- Soft-litho master – how created?

Summary

- Top-down litho can get to fine features and fine pitches.
- What about complexity of the pattern?
- Keep in mind:
  - Master manufacturing
  - Alignment, imprinting, releasing
  - resist/solvent/material chemistry