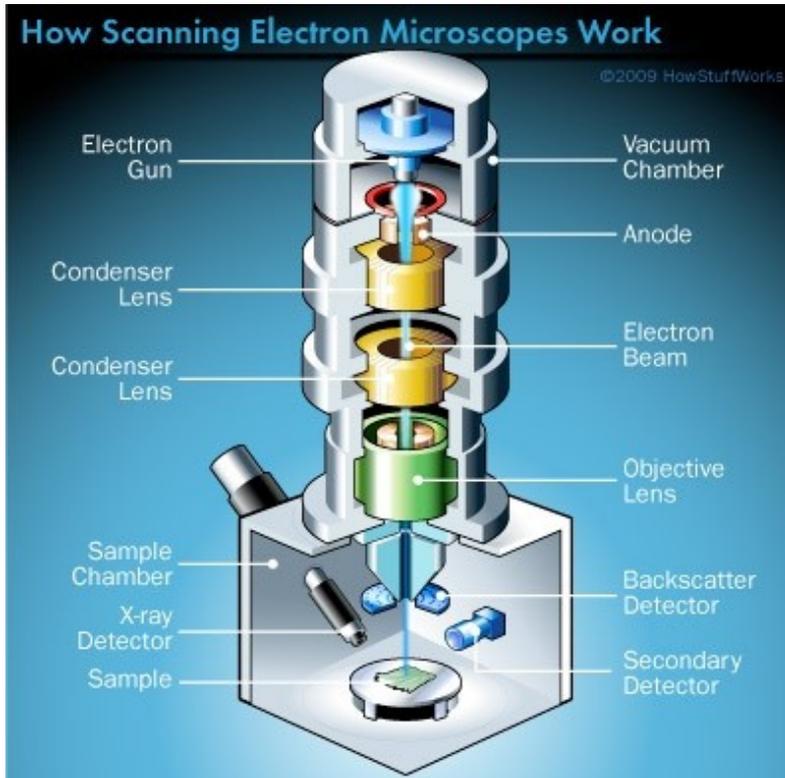
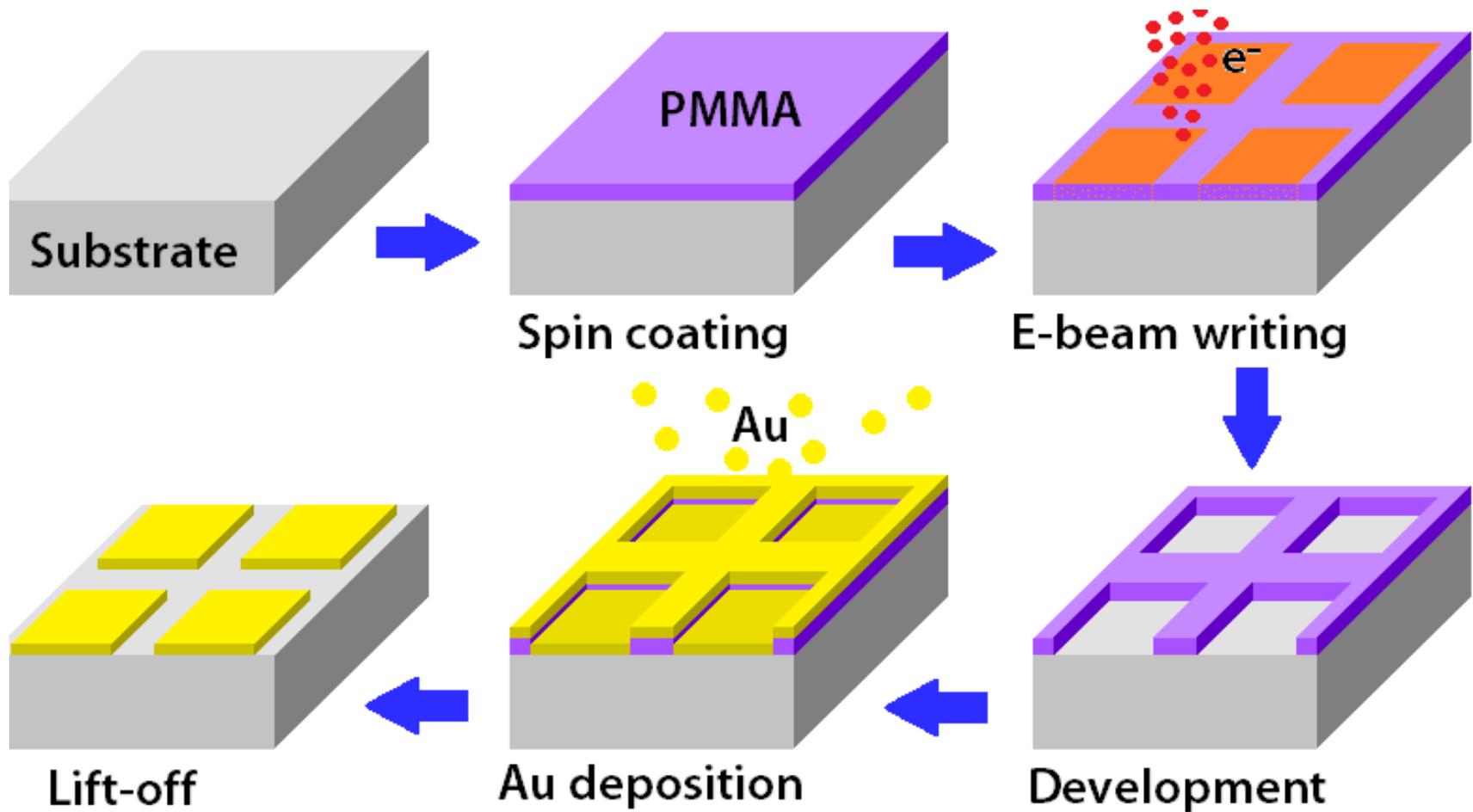


EBL

SEM

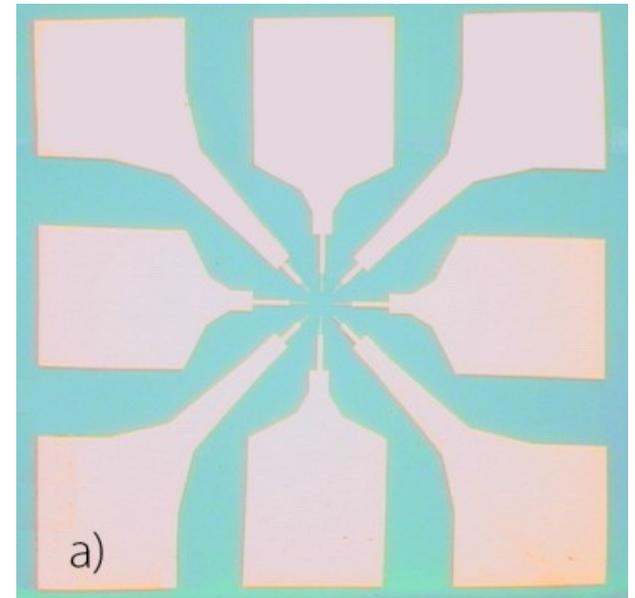


- Electron beam lithography is a mask-less technology.
- The final pattern is created directly from a digital representation on computer by scanning an electron beam in the pattern across a resist-coated substrate.



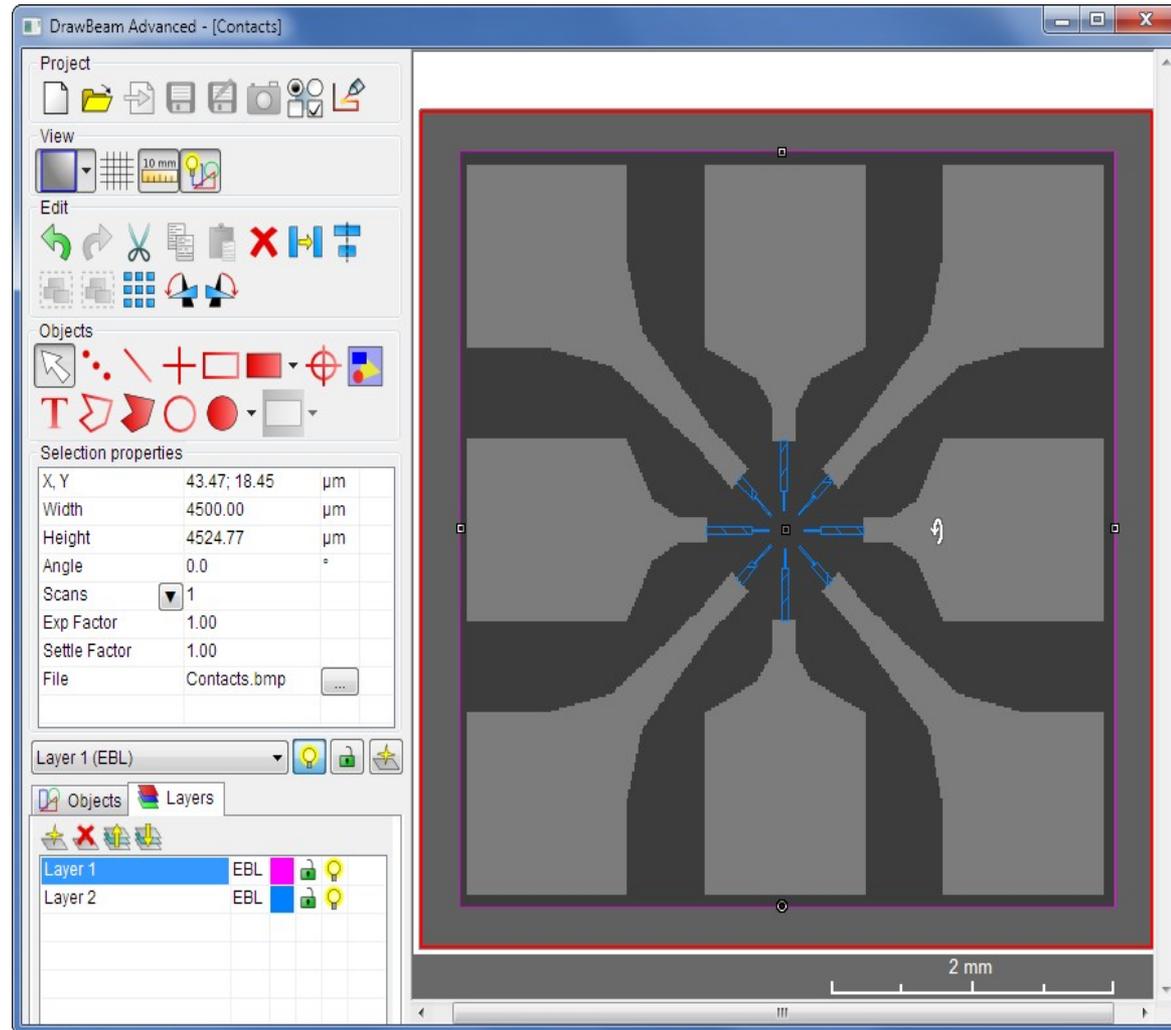
Steps involved

- Preparation of Si (100) substrate(10 x10 mm²) before the spin coating process – cleaning in the ultrasonic bath with IPA (isopropyl alcohol) and heating to the temperature of 180 °C for 30 minutes.
- Spin coating of the positive resist(PMMA – polymethyl methacrylate, type 495 A5.5) on the substrate .



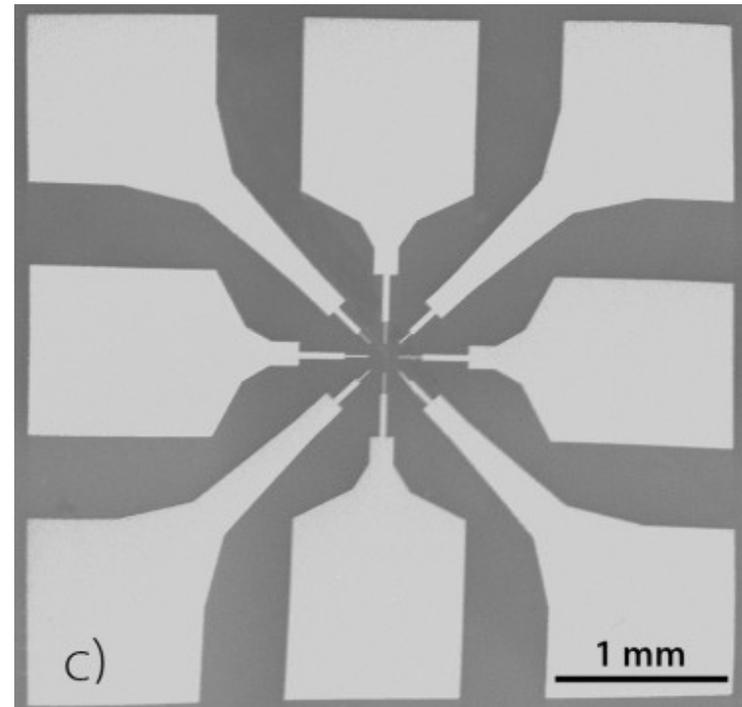
- Exposure of the resist to the electron beam was performed in two steps

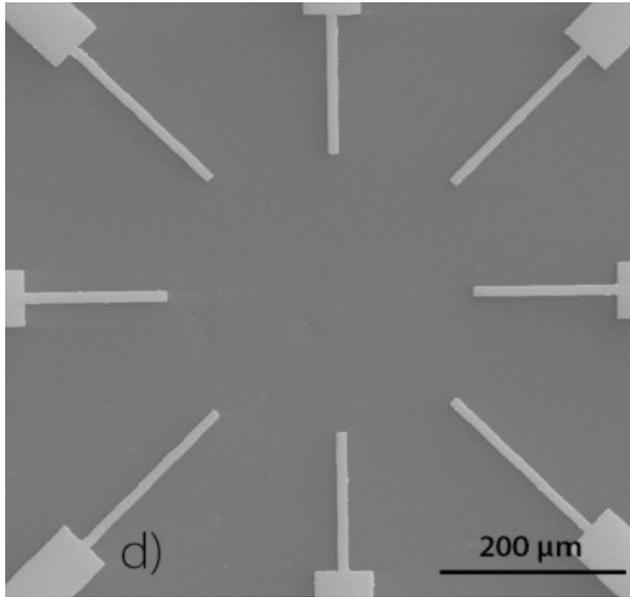
Design of contacts in the patterning module DrawBeam. Bigger contacts (about 1 mm²) are defined in loaded bitmap format. Smaller contacts (several hundredths μm²) were created by using predefined vector based objects in DrawBeam editor.



- Removal of the resist exposed to radiation by its development. The sample was immersed in the developer, a solution of MBIK (methylisobuthylketone) and IPA in the ratio 1:3, for 90 s and in IPA for 30 s.
- Subsequently, the sample was washed in deionized water and blew over with compressed nitrogen.

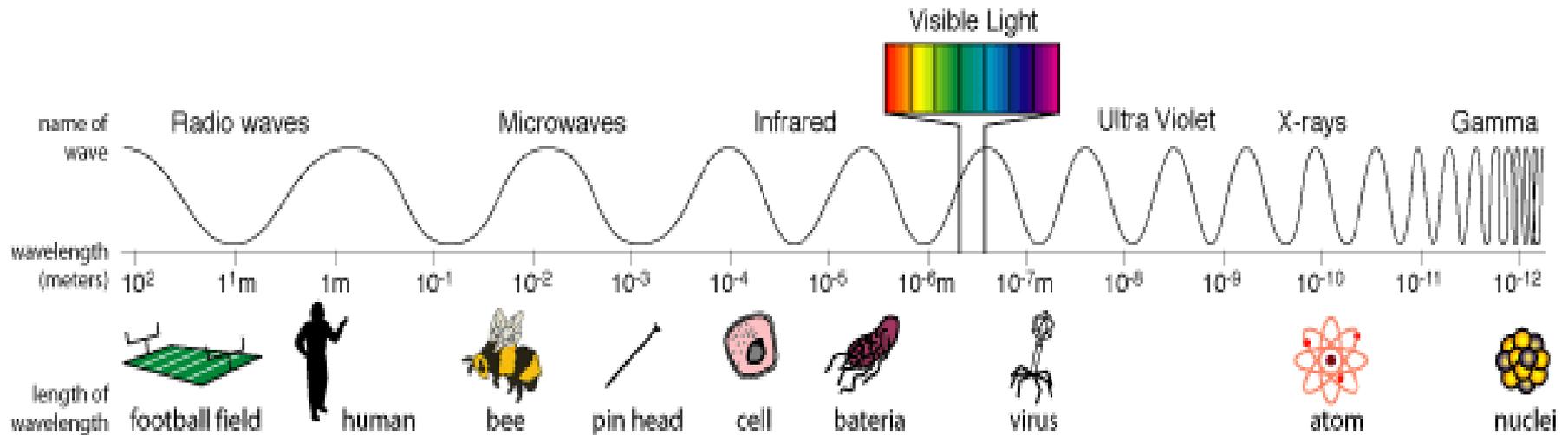
- Deposition of the active golden layer(magnetron sputtering for one hour; layer thickness ~ 100 nm).
- Removal of the remaining resist by its dissolution in an organic solvent:in acetone for one hour and in acetone using the ultrasonic bath for 30 s; after that the sample was washed in the acetone, IPA, deionized water and blew over by compressed nitrogen.





- SEM image of the pattern

EM spectrum

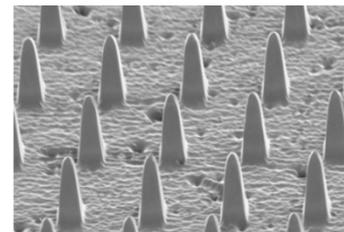
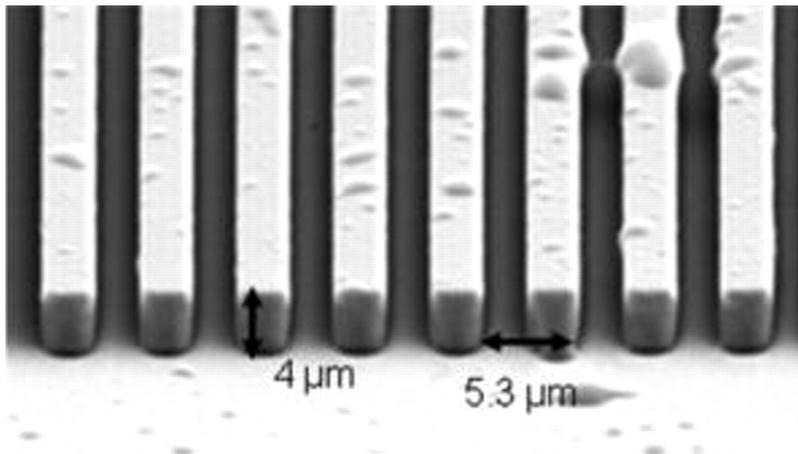


EBL

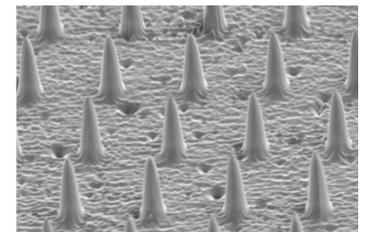
- Advantages
 - Print complex patterns directly on wafers
 - Eliminates the diffraction problem
 - High resolution up to 20 nm
 - Flexible technique
- Disadvantages
 - Slower than optical lithography
 - Expensive and complicated
 - Forward scattering; back scattering; secondary electrons

X-ray lithography

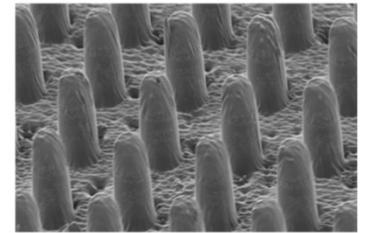
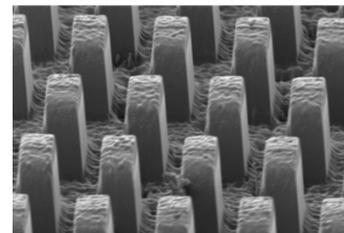
- Being much shorter in wavelength, x-rays provide increased lateral resolution
- Penetrating power of x rays deep into the photoresist is used
- Has 'great heights' and 'high aspect ratio'



(a)

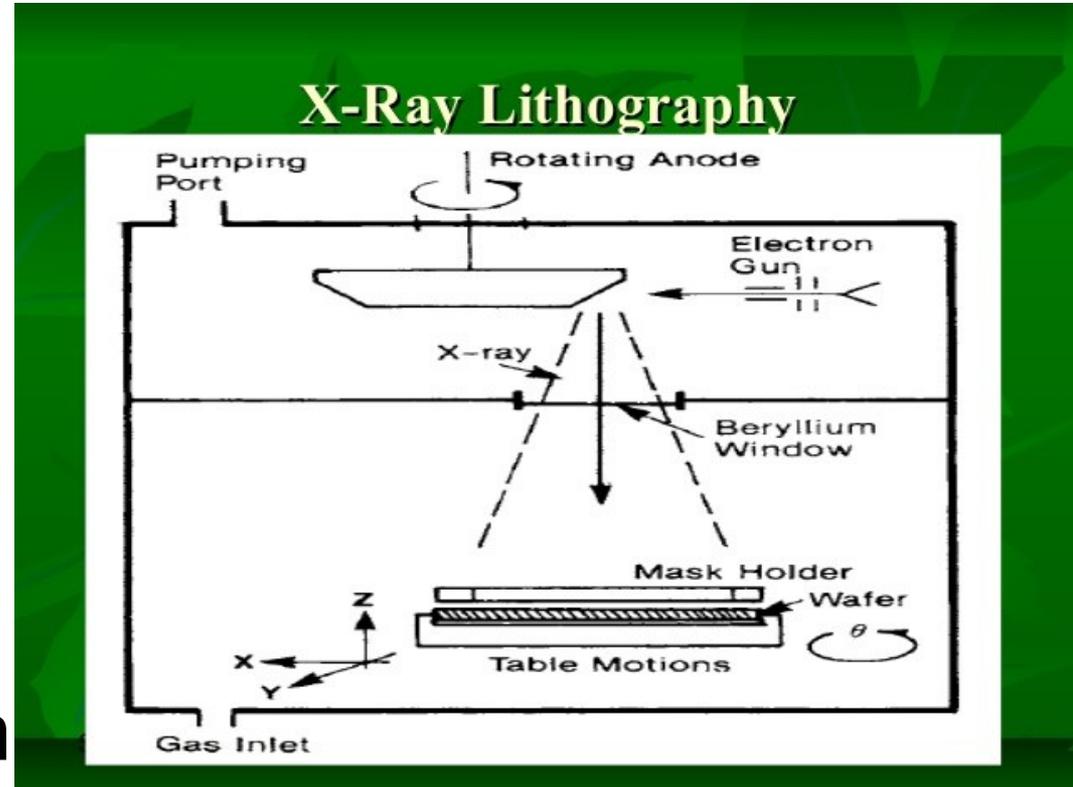


(b)



X – ray lithography

- It uses **X-rays** to transfer a geometric pattern from a mask to a **light-sensitive chemical photoresist**, or simply "resist," on the substrate



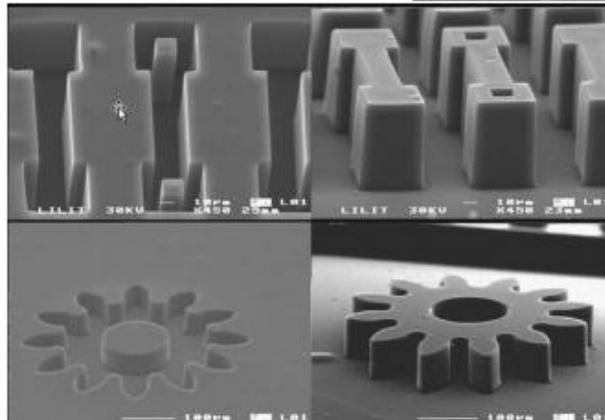
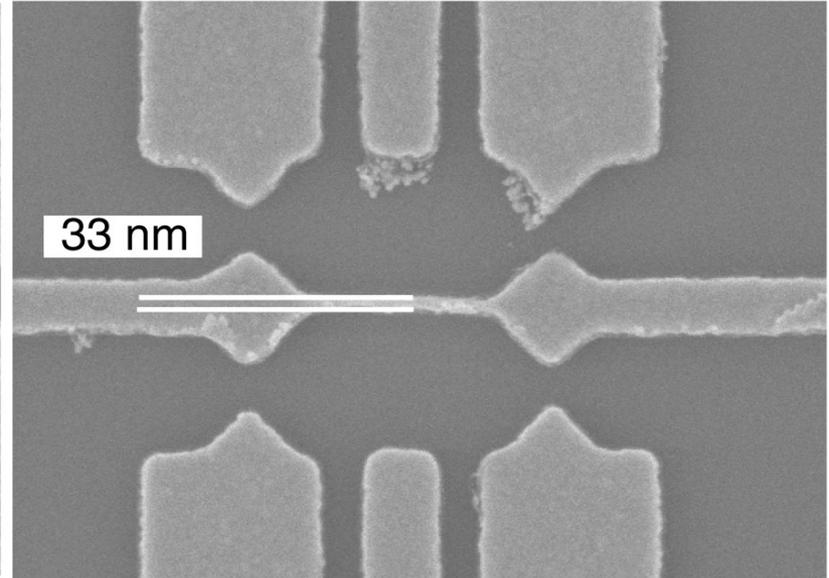
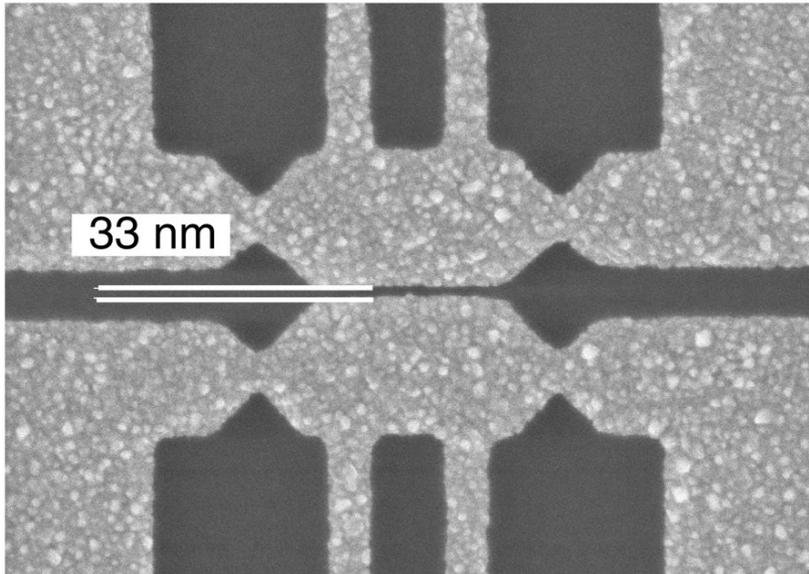
Mask preparation

- X rays interact differently with matter
- The mask substrate is low atomic number material like diamond, beryllium or polyimide or thin membrane of higher atomic number silicon or silicon carbide

Mask

X-ray Mask

X-ray Replication
& Liftoff (Ti/Au)



Procedures

PMMA is applied to the surface of silicon wafer

PMMA hardens when contacted with x-rays

X-ray mask is applied on top of silicon wafer before exposure (absorber; membrane)

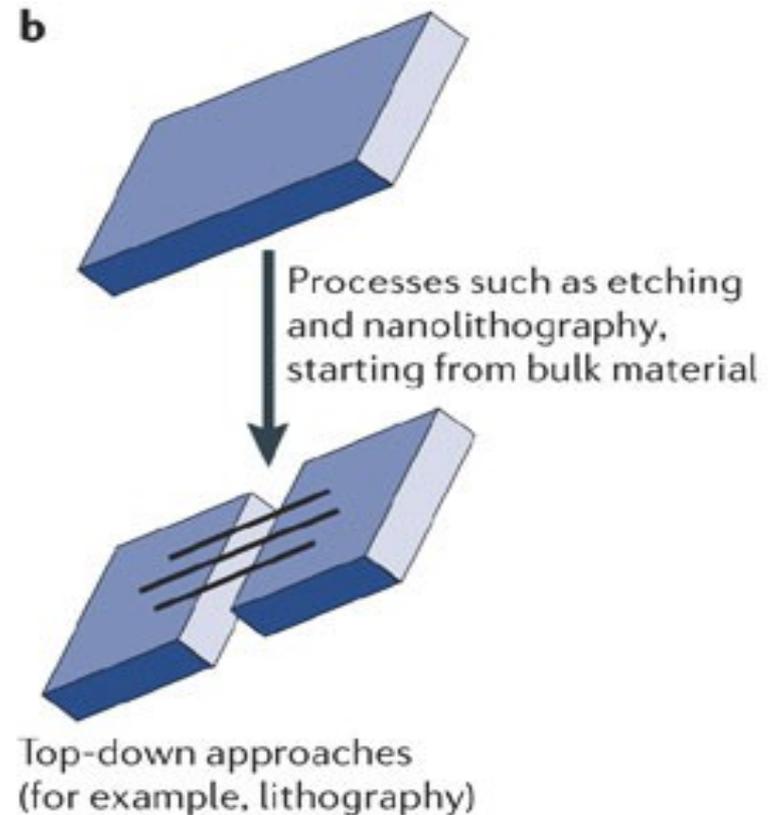
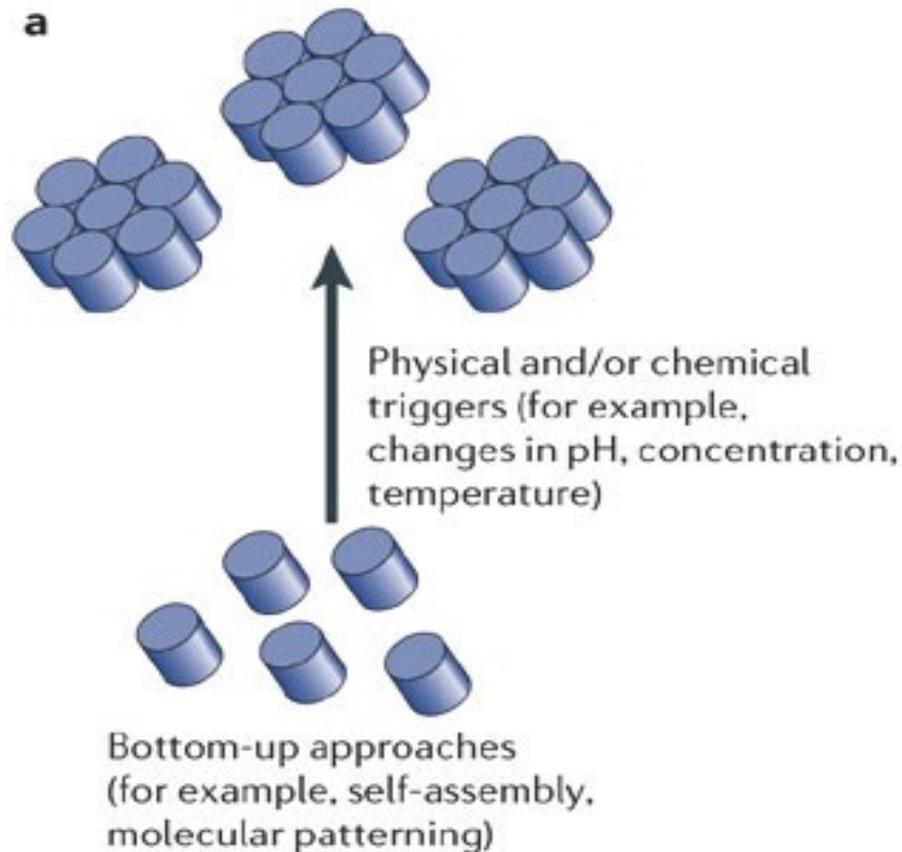
Advantages of X-Ray Lithography

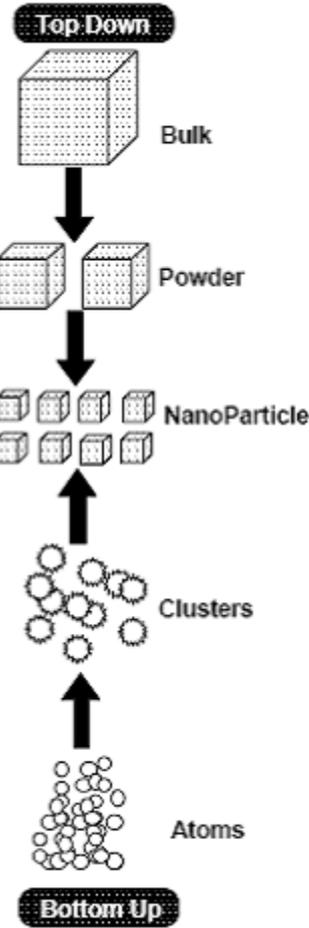
- ❑ Short wavelength from X-rays 0.4-4 nm
- ❑ No diffraction effect
- ❑ Simple to use
- ❑ No lens
- ❑ Faster than EBL
- ❑ Uniform refraction pattern
- ❑ High resolution for small feature size

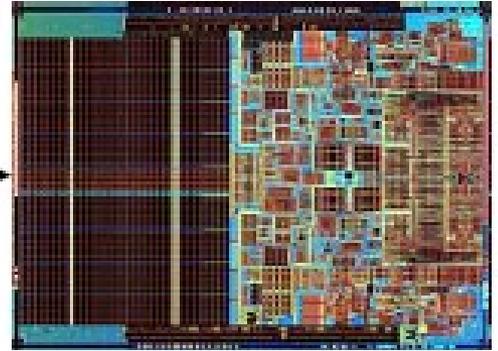
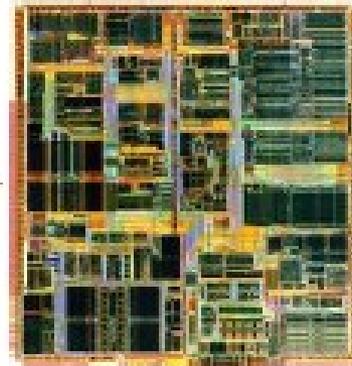
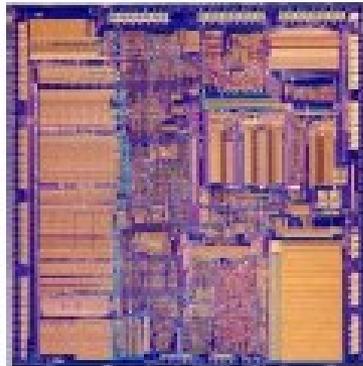
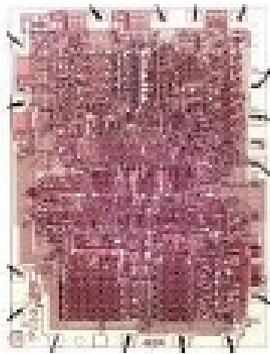
Disadvantages of X-Ray Lithography

- ❑ Thin lens
- ❑ Distortion in absorber
- ❑ Cannot be focused through lens
- ❑ Masks are expensive to produce

Approaches







1971

Intel 4004 μ P

2,300 transistors

108 KHz

10 μ m linewidth

1985

Intel 386 μ P

275K transistors

33 MHz

1.5 μ m

1997

Intel PII μ P

7.5 M-transistor

300 MHz

0.25 μ m

2006

Intel Core 2 Duo

291 M-transistor

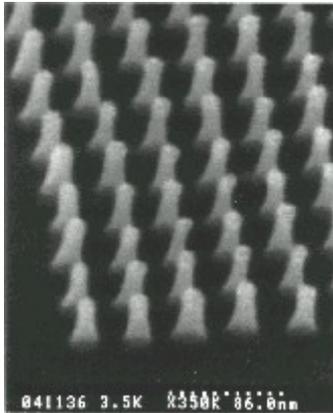
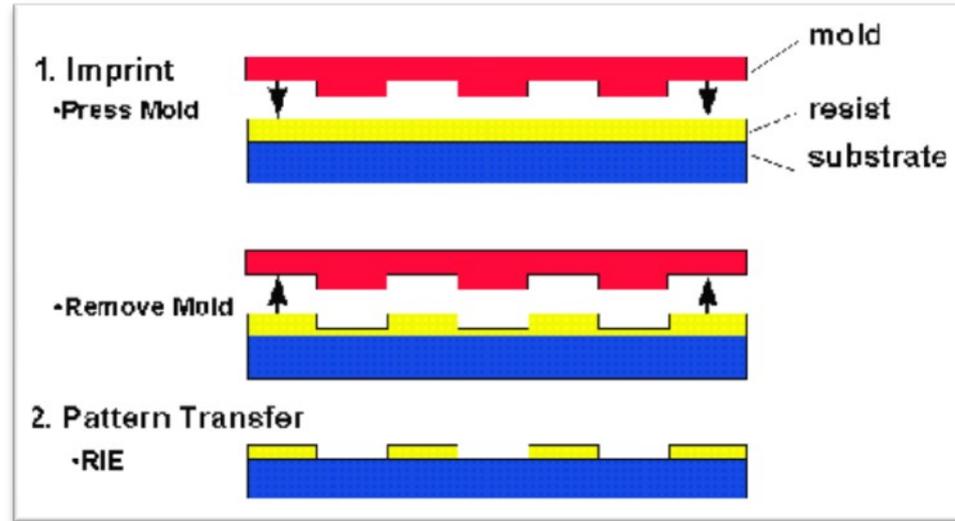
2.4 GHz

0.065 μ m

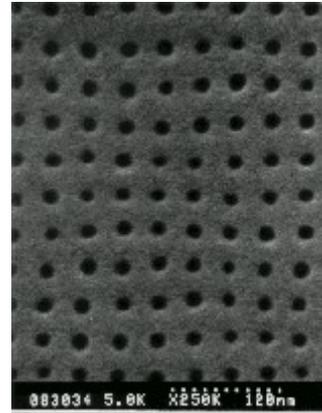
Nanoimprint Lithography (1994)



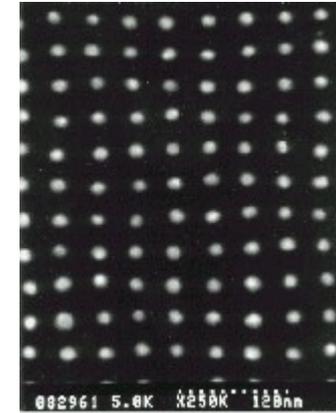
Prof. Stephen Y. Chou



Imprint mold with 10nm diameter pillars

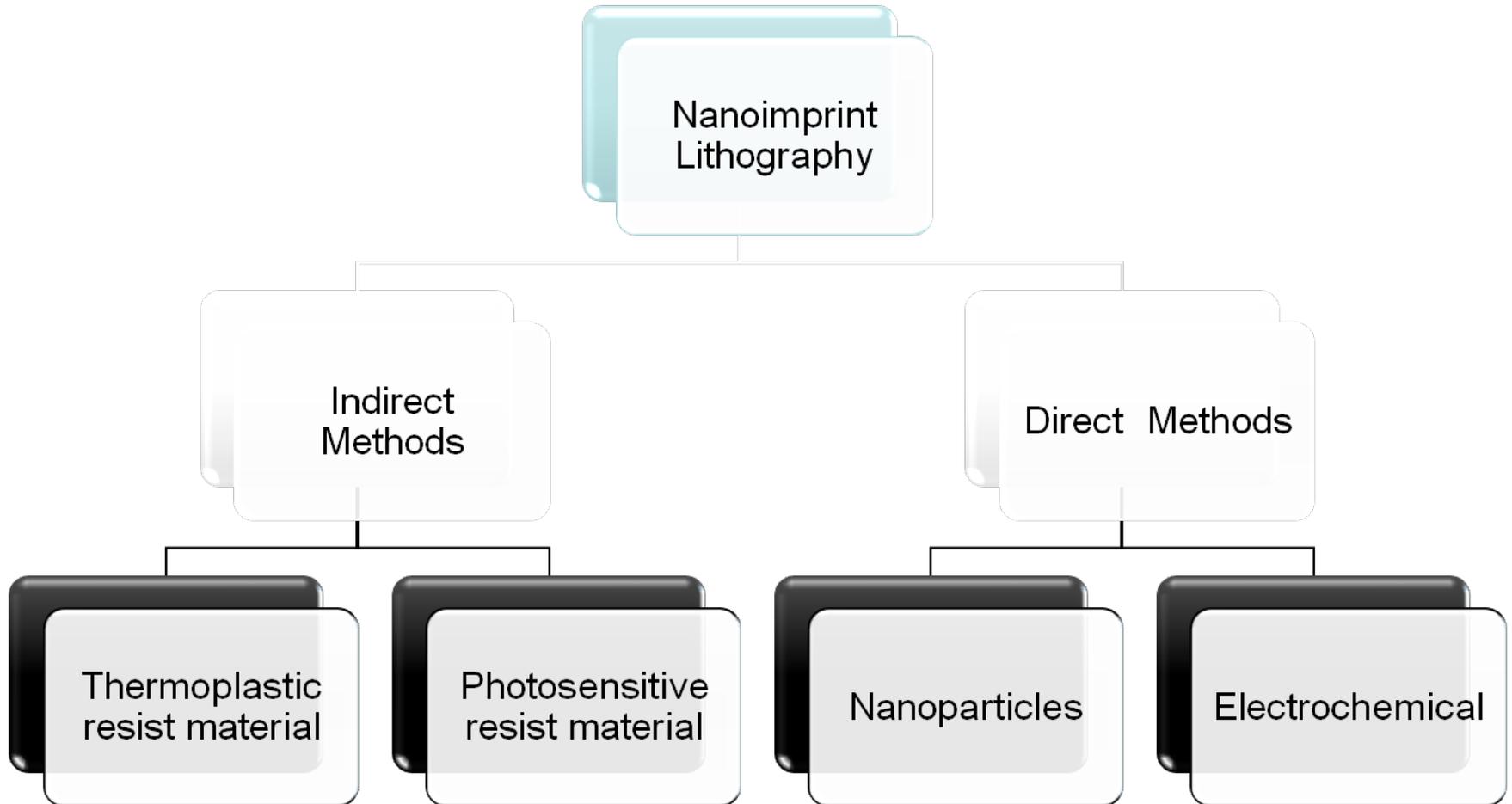


10nm diameter holes imprinted in PMMA



10nm diameter metal dots fabricated by NIL

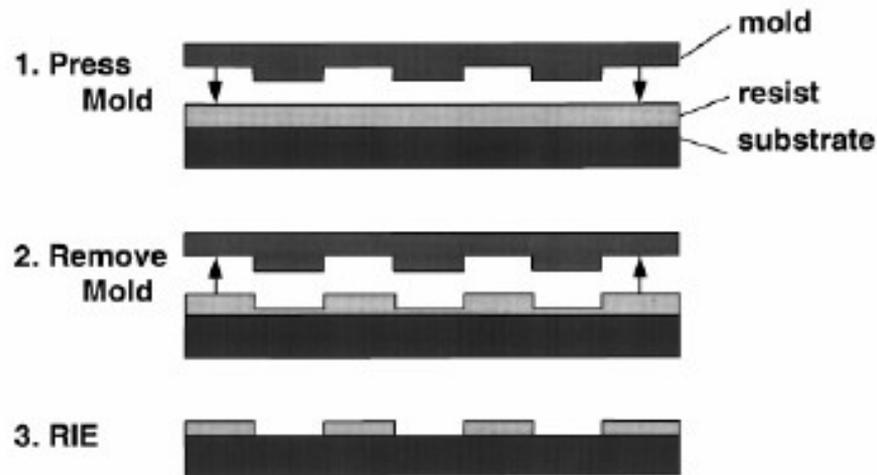
Nanoimprint Methods



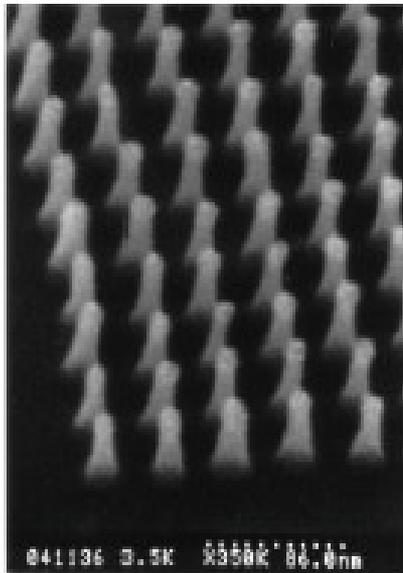
Thermoplastic resist

- A predefined mold is brought into contact with the resist coated substrate
- It has been heated to 140-180 C under high pressure
- The pattern has been transformed and cooled
- The residue resist will be wiped off by reactive ion etching in high vacuum

Basics of Nanoimprint – *Thermoplastic Resist*

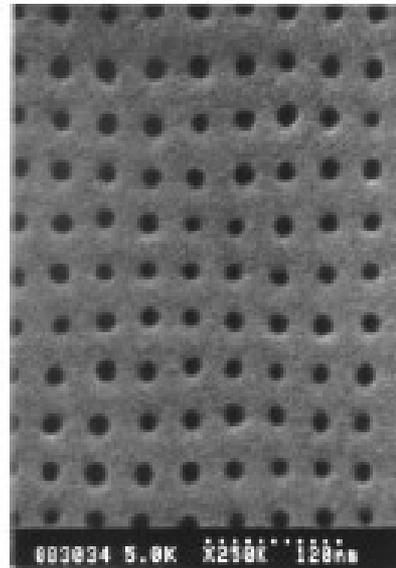


Mold



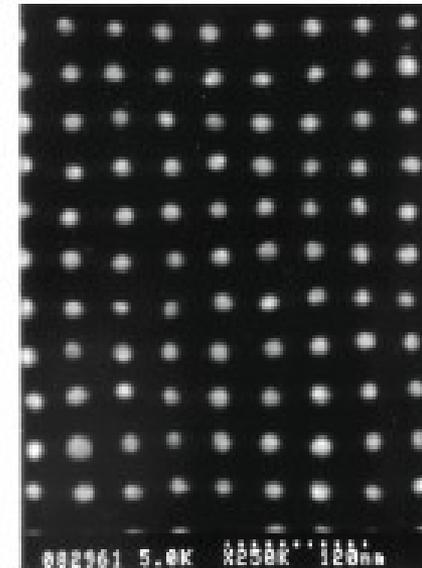
10 nm dia pillar mold

Resist



10 nm dia resist holes
by imprinting

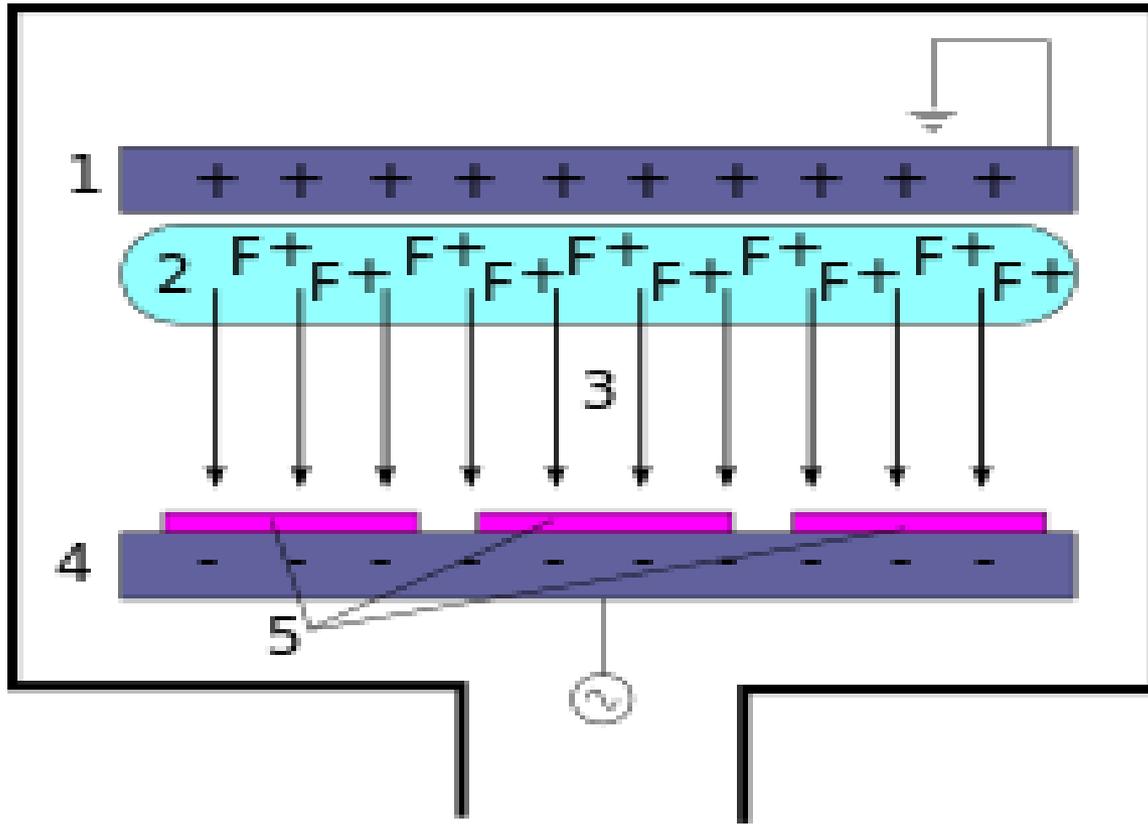
Lift-Off



10 nm dia metal dots
by imprint and lift-off

Reactive ion etching

- 1,4-electrodes; 2-ions; 5-samples



Rigid Master



PMMA
Si/SiO₂



Press
and Heat



Metal Evaporation
plus Lift-off



Reactive
Ion Etching



UV – curable resist

Molecular Imprint's website



Step 1: Orient template and substrate



Step 2: Disperse drops of liquid imprint resist



Step 3: Lower template and fill pattern



Step 4: Polymerize imprint fluid with UV exposure



Step 5: Separate template from substrate

For nanoimprinting

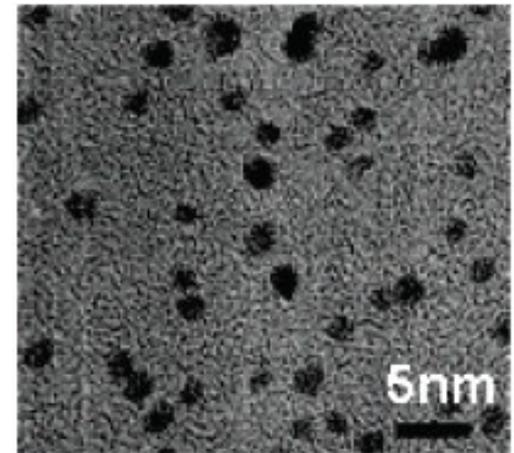
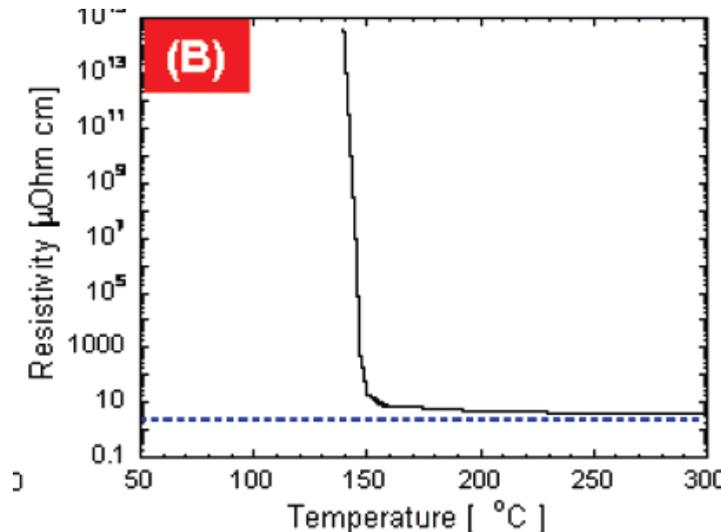
- Materials with low viscosities
- It should also have viscoelastic behavior
- Applied in various fields like biological nanodevices, nanophotonic devices (grating and photonic crystal structure),
- Organic electronics and patterning of magnetic materials

Direct imprinting

- Metal nanoparticle solution is preferred
- Eliminate the need to exceed the bulk metal melting temperature
- High surface to volume ration
- High surface energy
- Melting point temperature of np is very low than its own bulk

NP

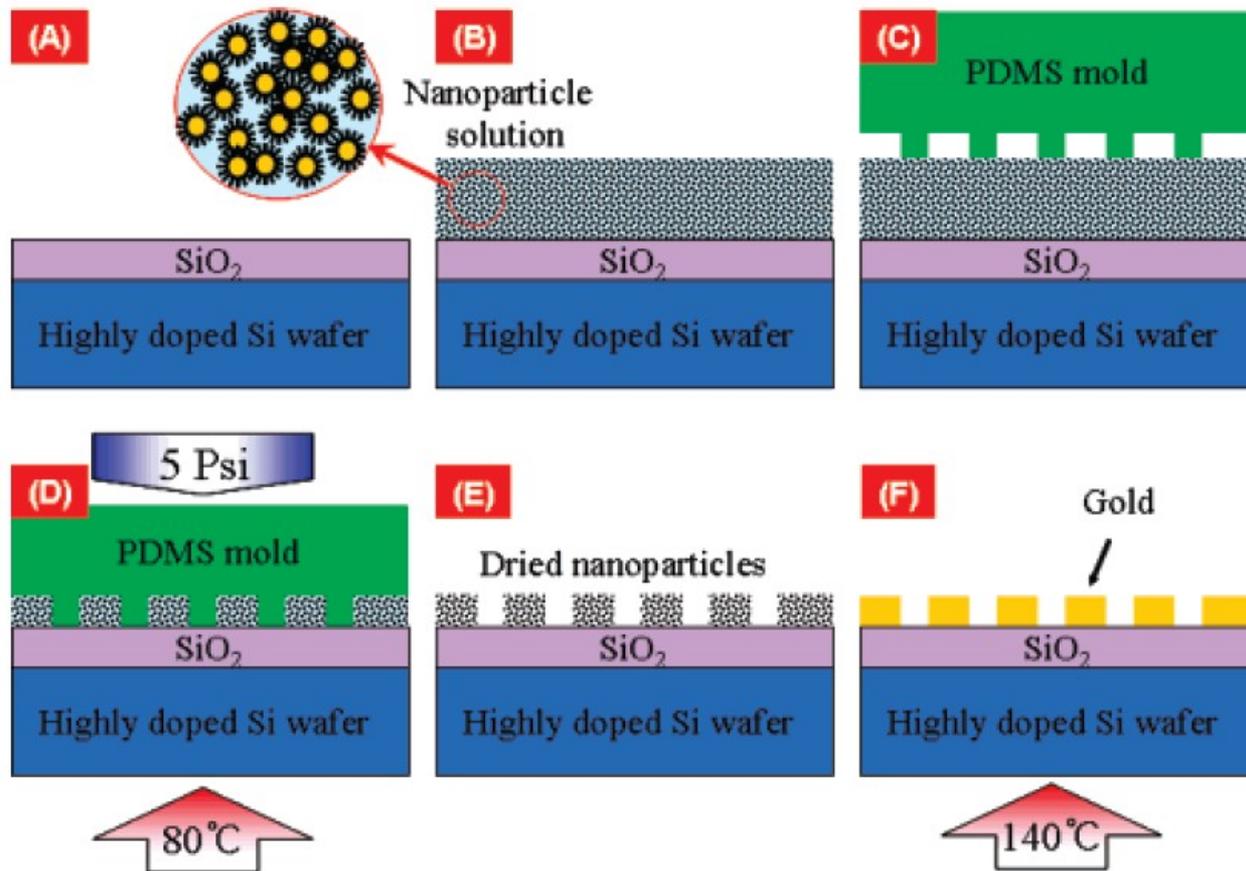
- Bulk gold temp is 1063 C; np melting temp is 130-140 C
- For eg. Gold np were encapsulated with a hexanethiol self assembled monolayer (SAM)



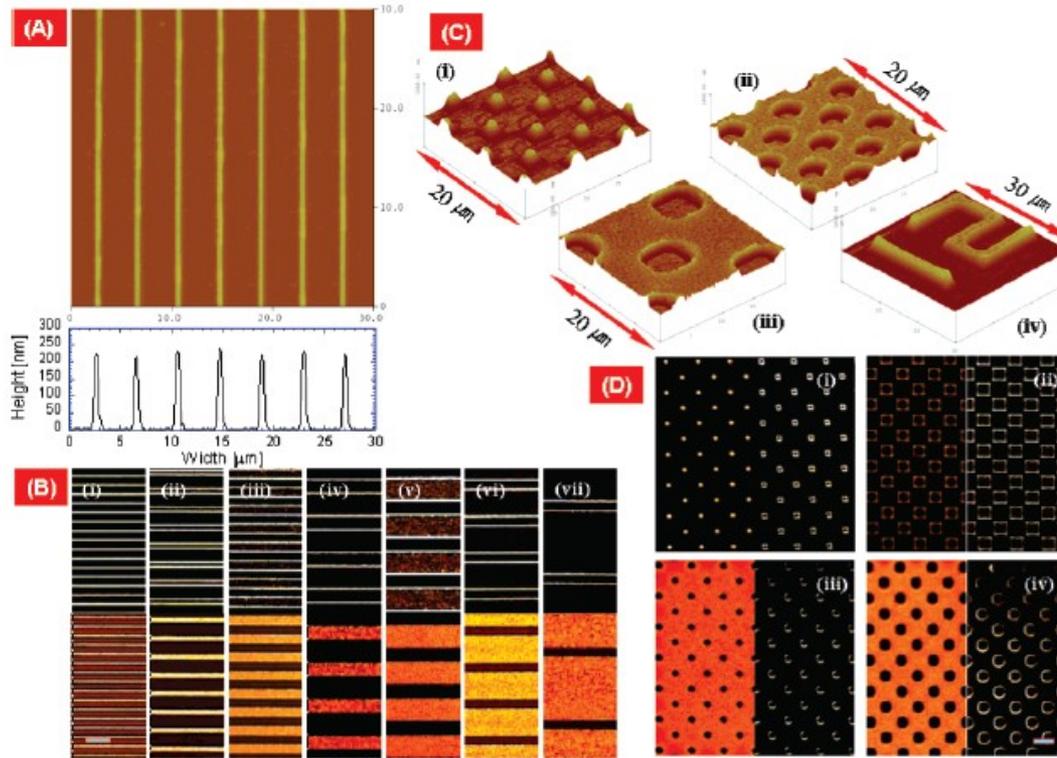
Steps involved

- SAM protected nanoparticles were suspended in an alpha-terpineol carrier solvent (it controls the size of np and stabilizes the np)
- Metal np solution is dispensed on SiO₂/P+Si wafer
- The deposit is imprinted using a polydimethylsiloxane (PDMS) mold
- The patterned are melted on a hot plate

Direct Nanoimprinting of Metal Nanoparticles

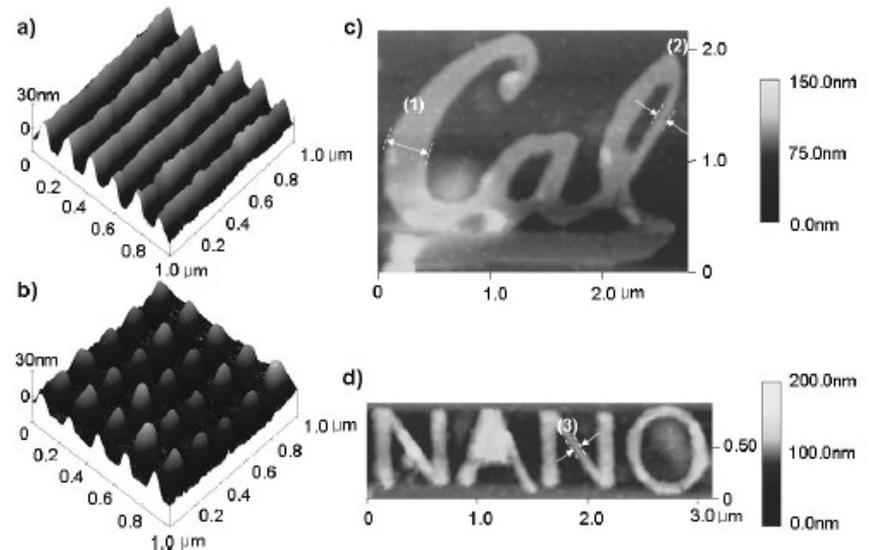
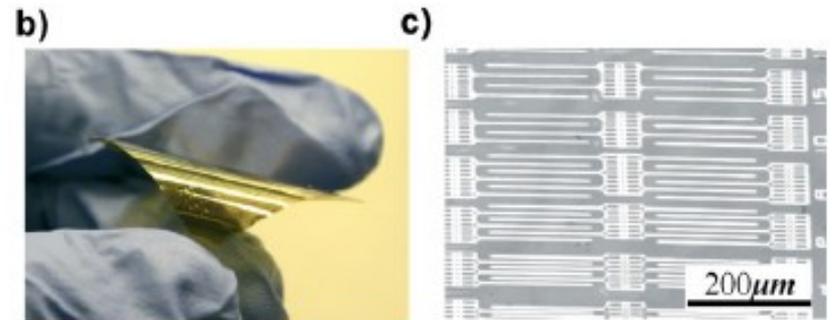
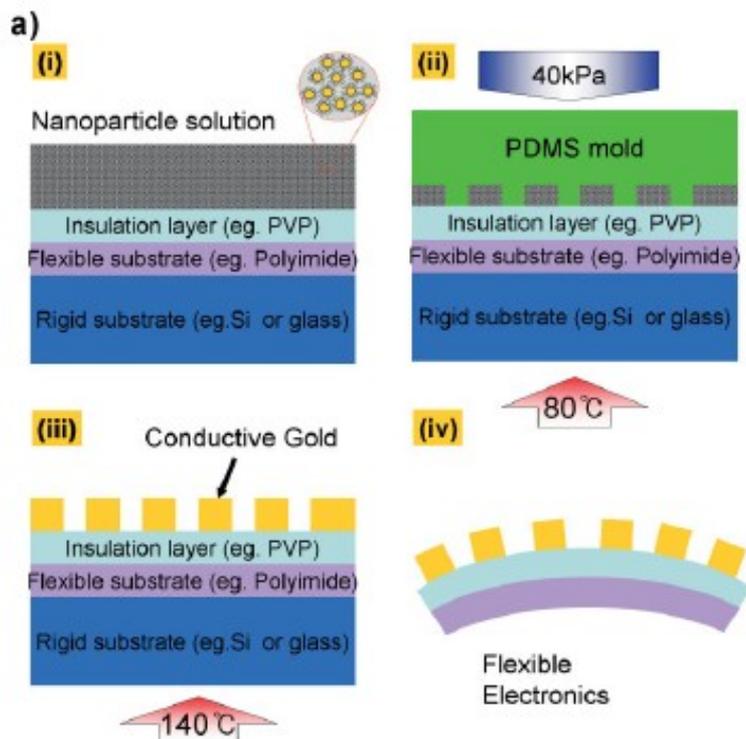


Nanoimprinted gold structures

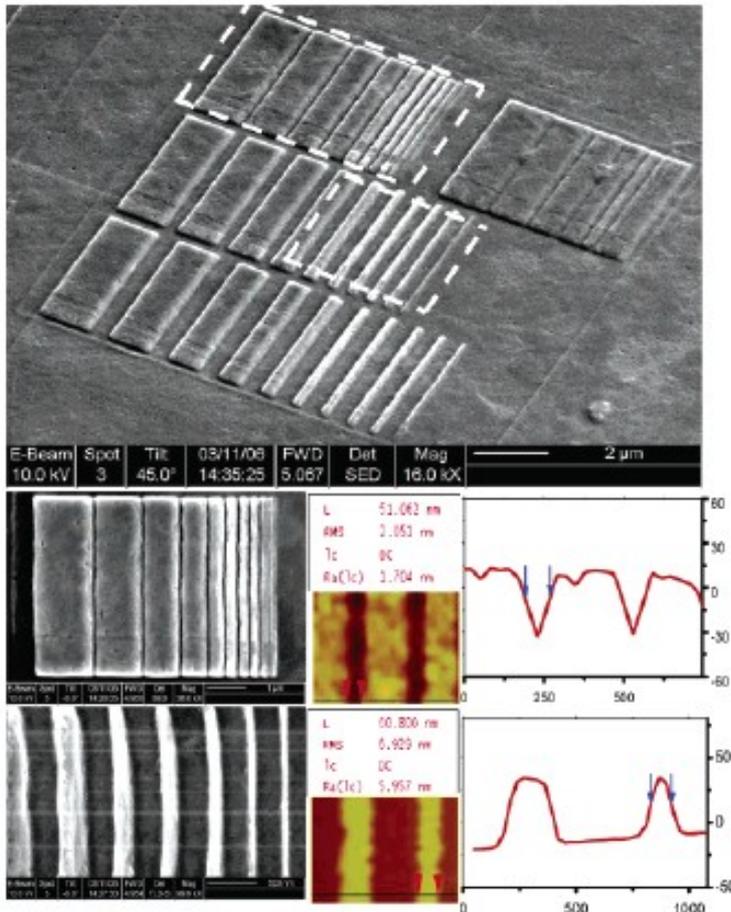


- Nanodots (positive and negative), nanowires,

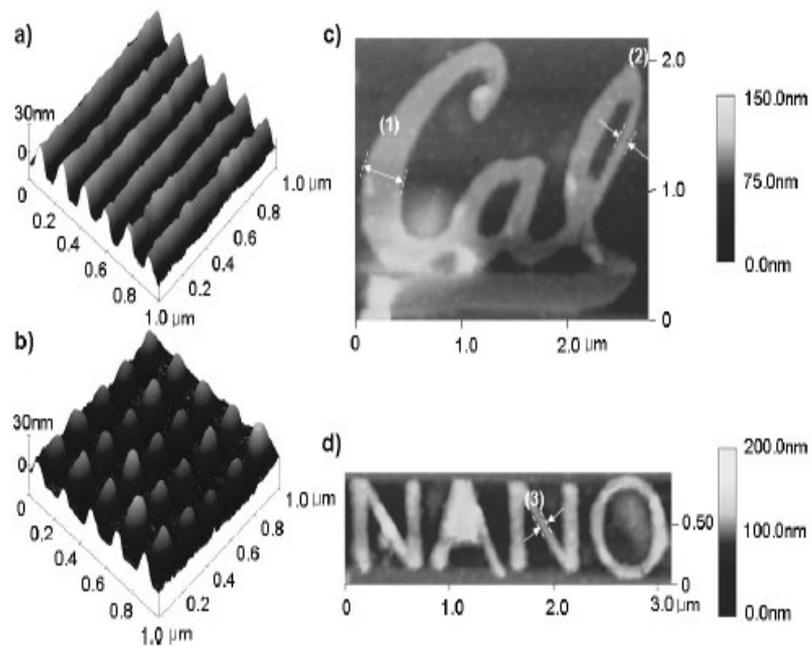
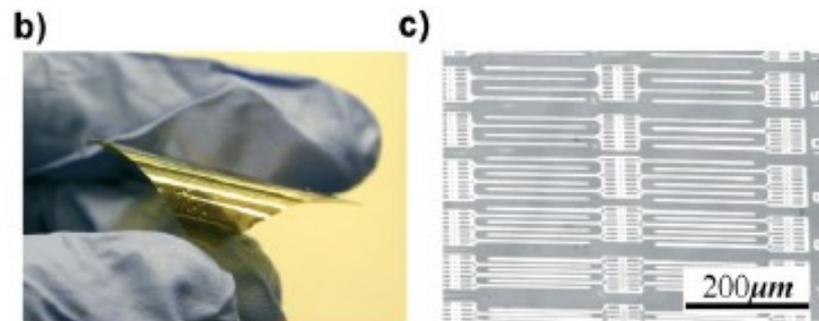
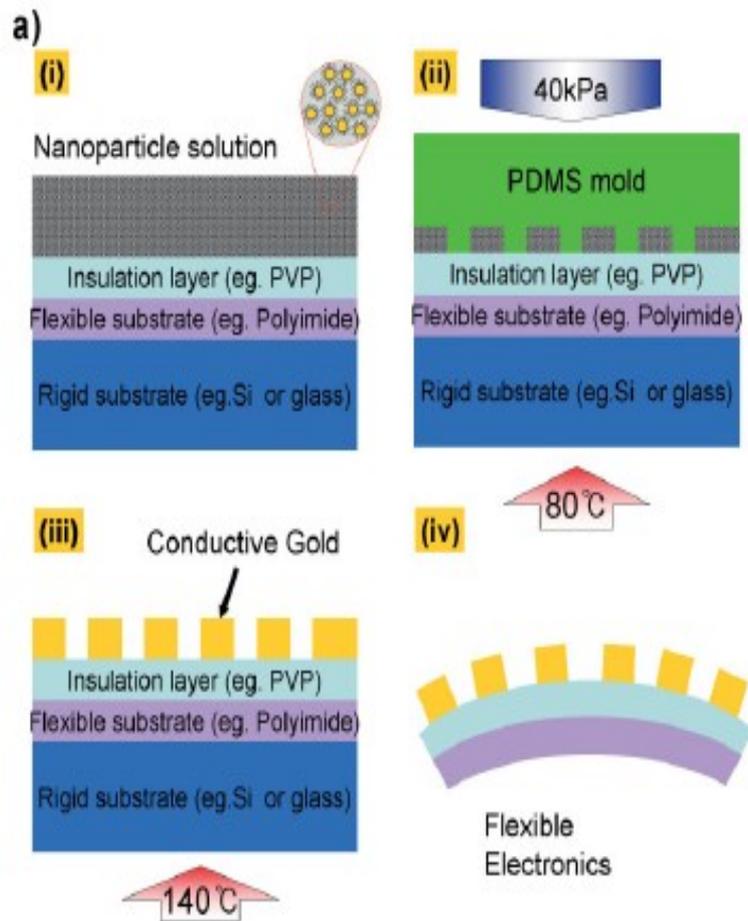
Nanoscale patterning on flexible substrate



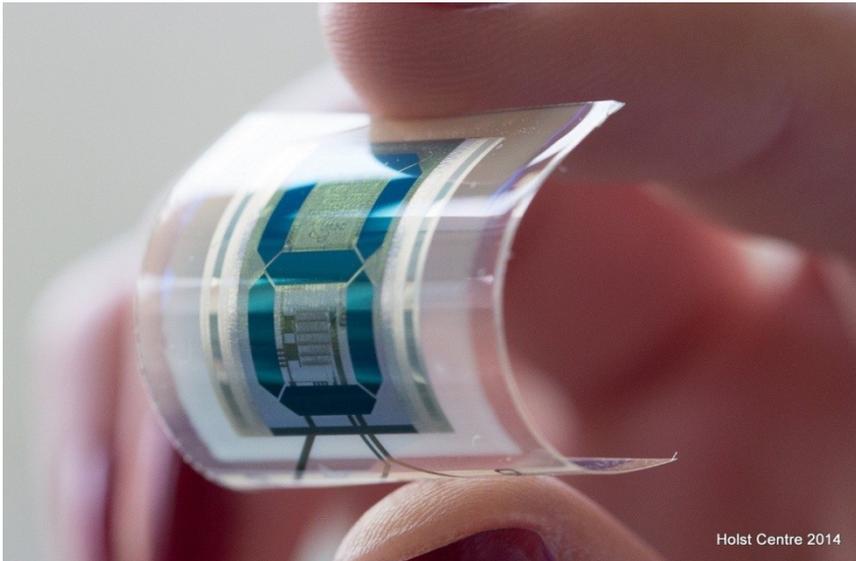
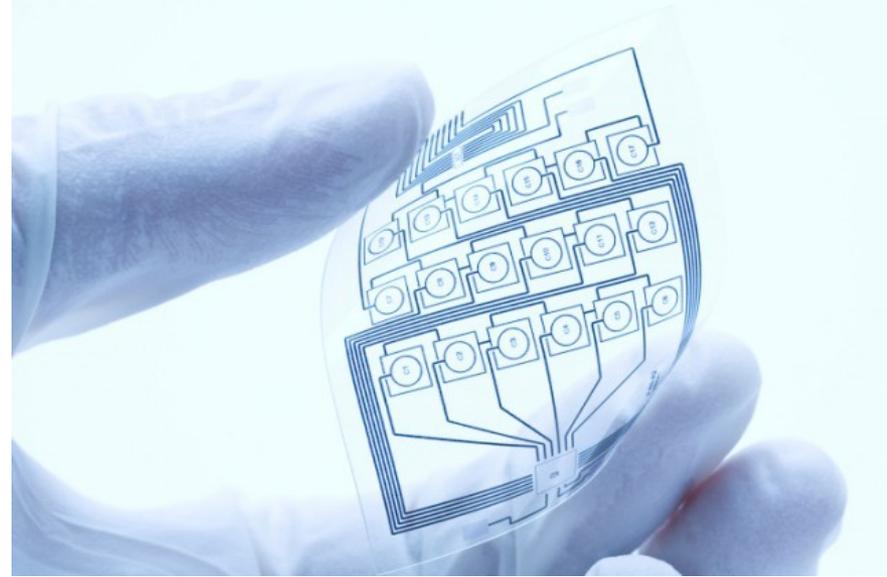
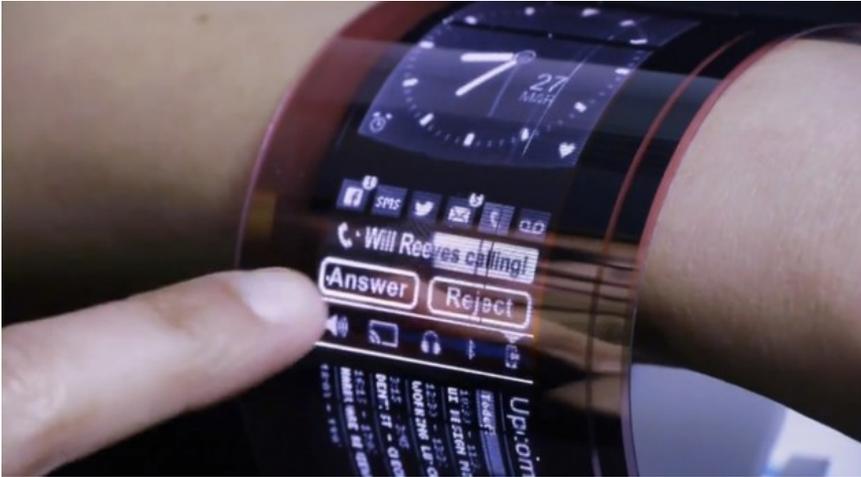
High-resolution transfer of channels and lines



- The smallest line width and spacing is 50nm.
- The feature height is around 100nm for the thicker lines and reduces to 40nm for the last two lines of width 90nm and 60nm.



Flexible electronics



Conclusions

- Nanoimprint lithography is major breakthrough in nanopatterning because it can produce sub-10nm feature size over a large area with a high throughput and a low cost.
- Direct nanoimprinting of metal nanoparticles is successfully demonstrated to high-resolution patterning and low temperature process.
- The solid-state superionic stamping process produces high-resolution nanostructures and represents a new, efficient, and cost-effective avenue for current processes.