Nanoparticle Technology

Lecture 07: 3-D Nanostructures Fabrication

Lecture 07: table of contents

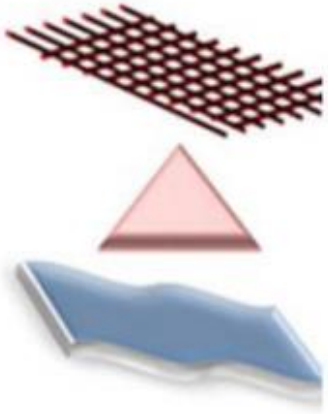
Introduction to 3-D nanostructures fabrication

Classification of nanomaterials

Dimensional classification

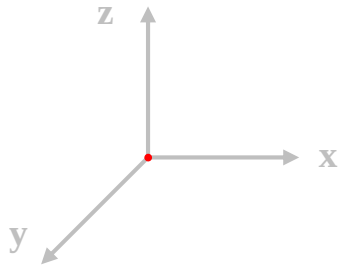
0-D

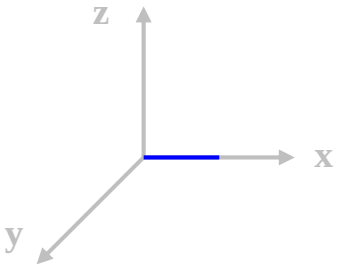
1-D

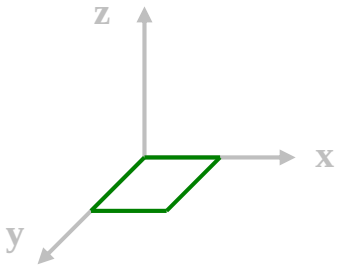


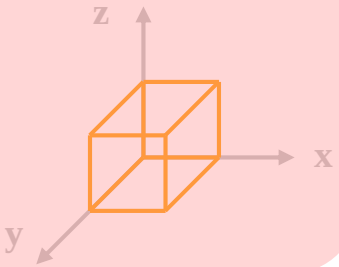
2-D

3-D





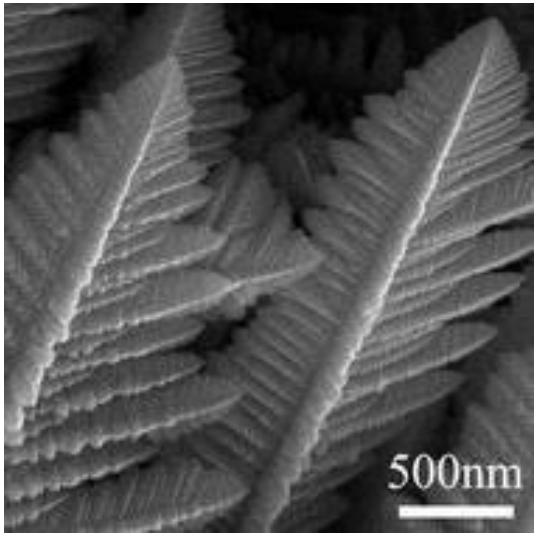




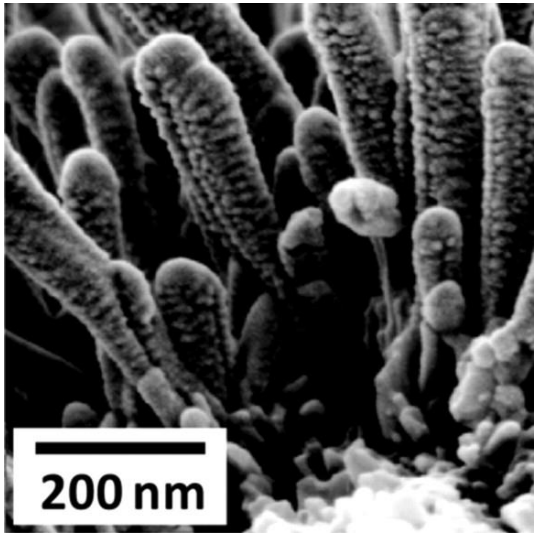
Classification of nanomaterials

Three-dimensional (3-D) structures

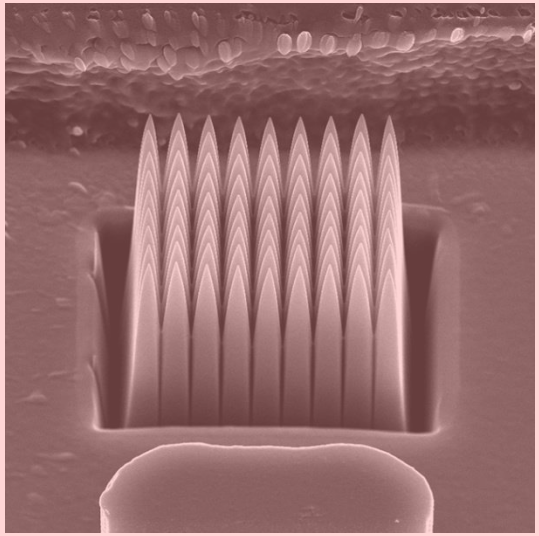
- Dendrite -



- Nanostructured thin film -



- Nanopattering -



Photolithography

Lithography

Lithography process

Lithographic pencil applied

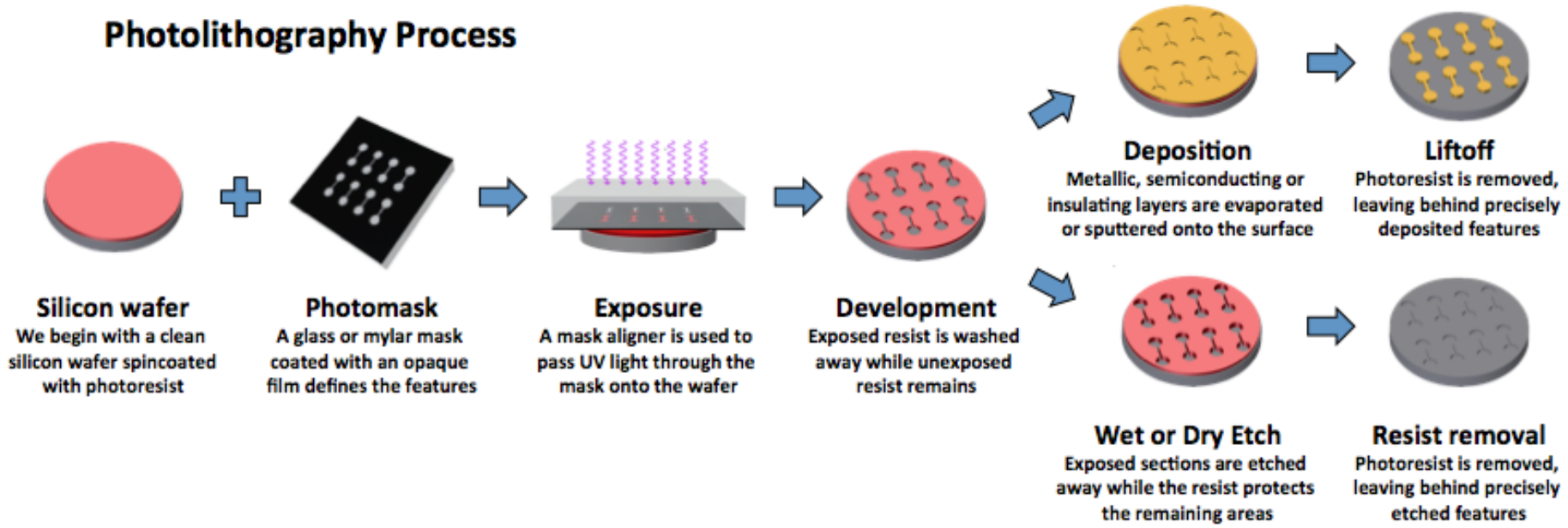
Bitumen applied to surface

Greasy ink rolled on

Paper over inked surface

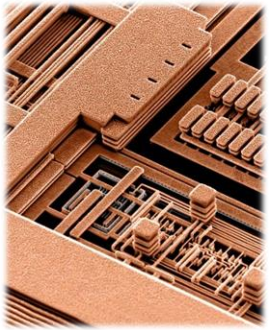
Final result

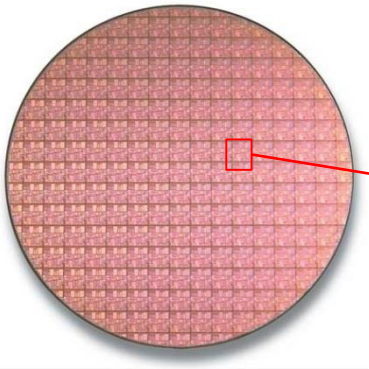
Photolithography

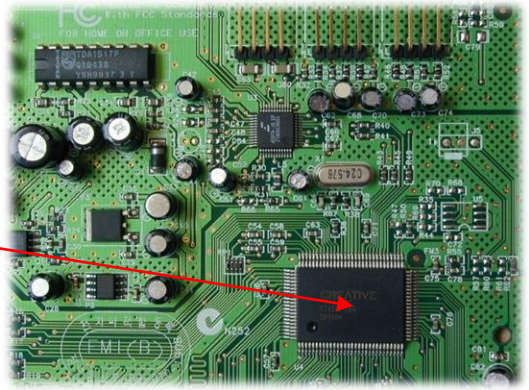


Photolithography: substrate (silicon wafer)

Patterning

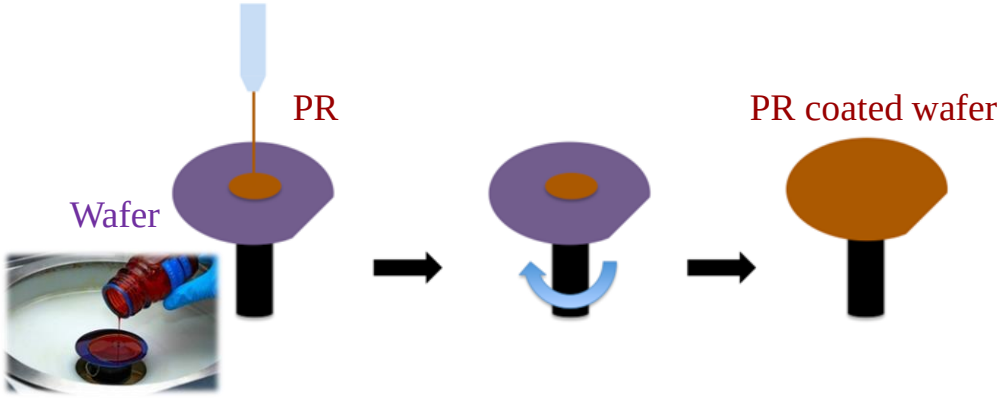


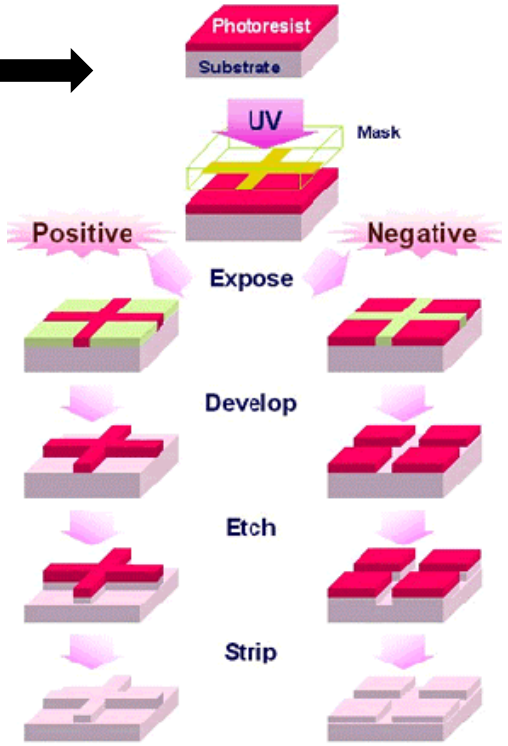




Photolithography: photoresist (PR)

PR spin coating



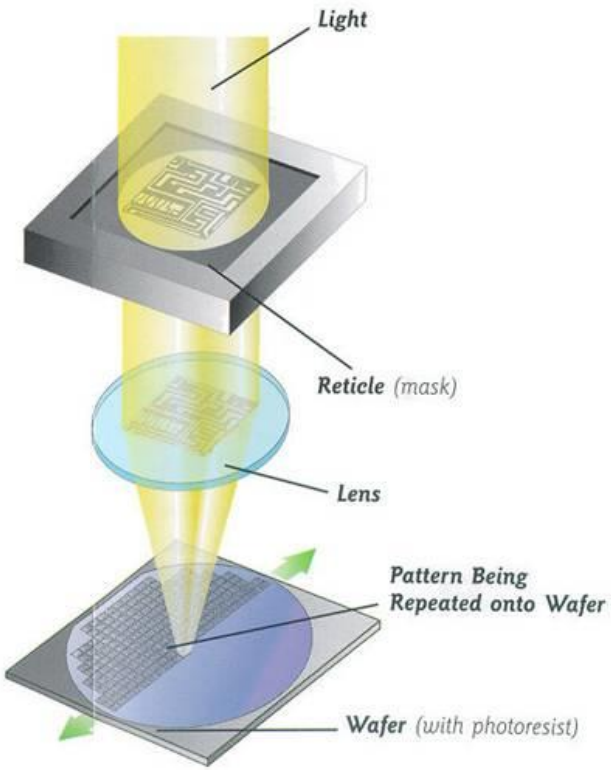


Positive PR vs. Negative PR

Positive PR: Exposure to the UV light changes the chemical structure of the resist so that it becomes more soluble in the develop solution.

Negative PR: Exposure to the UV light causes the negative resist to become more difficult to be dissolved, meaning that the develop solution removes only the unexposed parts.

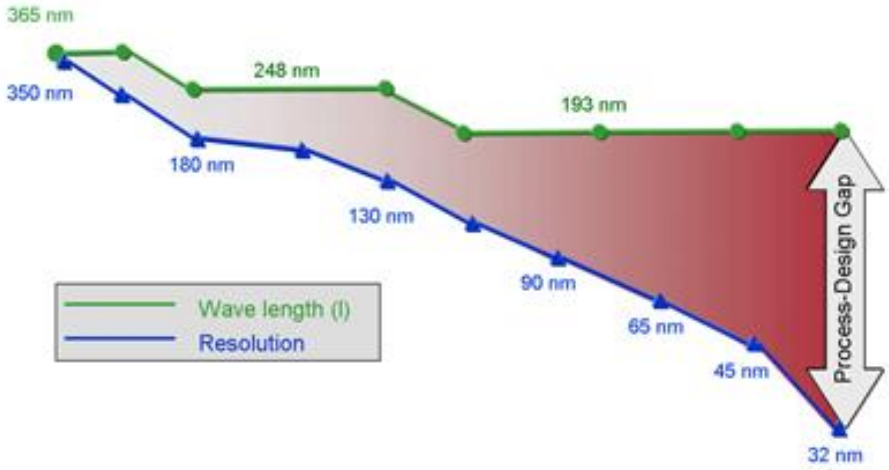
Photolithography: exposure



Resolution:

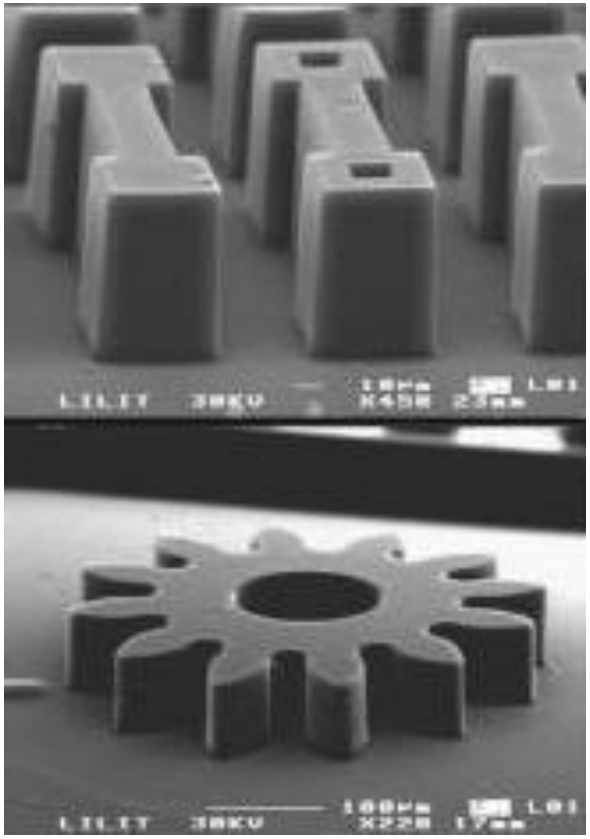
$$R = K \times \frac{\lambda}{n \sin\theta}$$

K: technical limited constant
λ: wavelength (UV: 100 ~ 400 nm)
n: an index of refraction (air = 1)

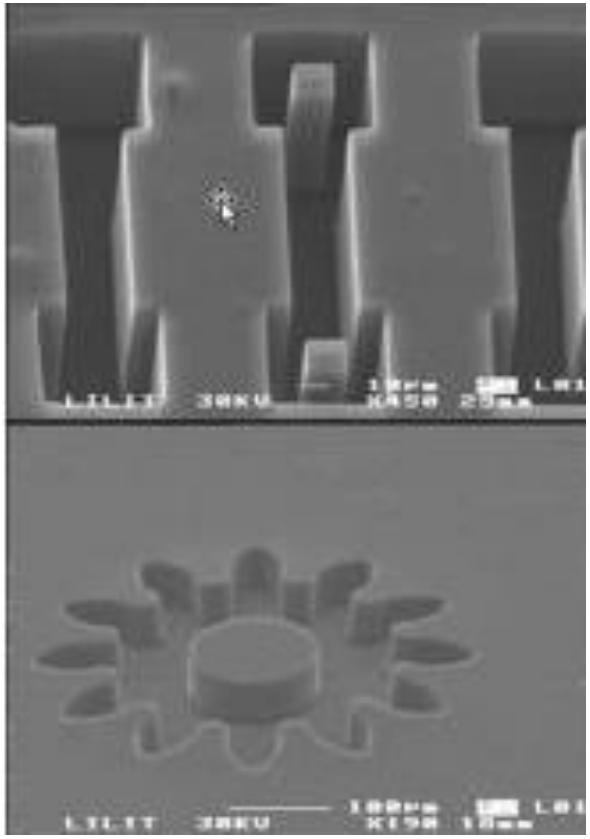


Photolithography: lift off vs. etch

Lift off



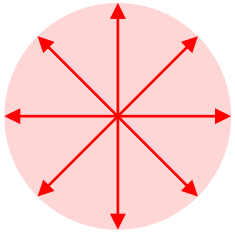
Etch



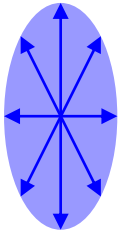
Etch: isotropic vs. anisotropic

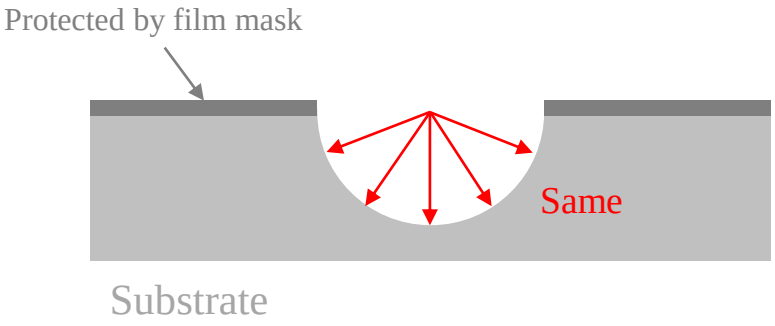
Etch is the process of using strong acid or base to cut into the unprotected parts of a surface to create a design.

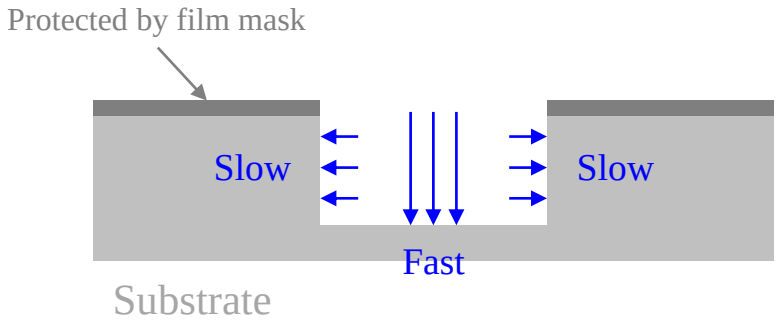
Isotropic



Anisotropic



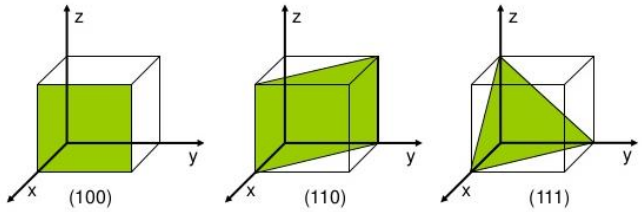




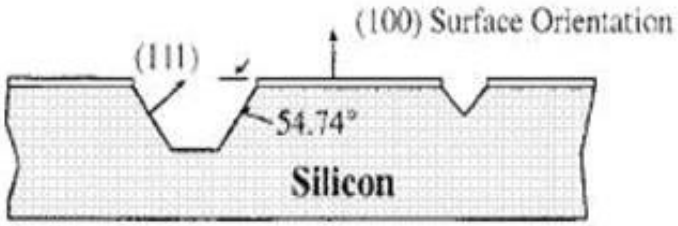
Anisotropic etch: Si orientation

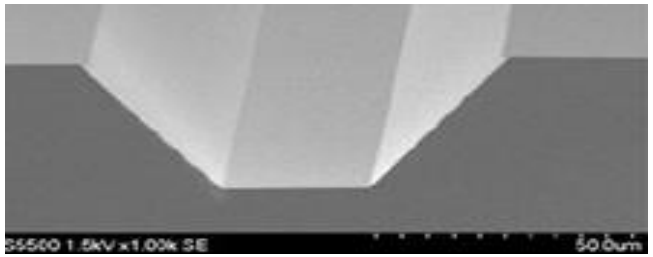
Si (111) shows an extremely low etch rate in KOH solution.

KOH etch on Si: $Si + 2OH^- + 2H_2O \rightarrow \left[SiO_2(OH)_2\right]^{2-} + 2H_2$

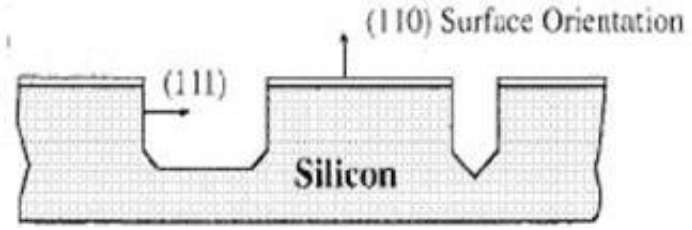


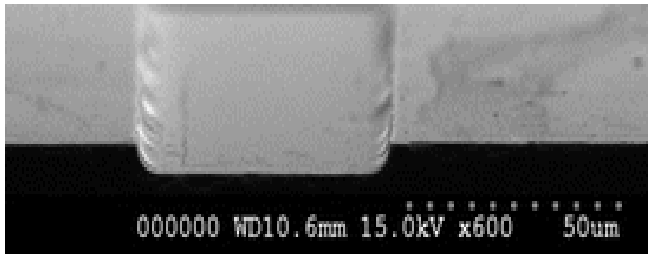
Si (100) anisotropic wet etch



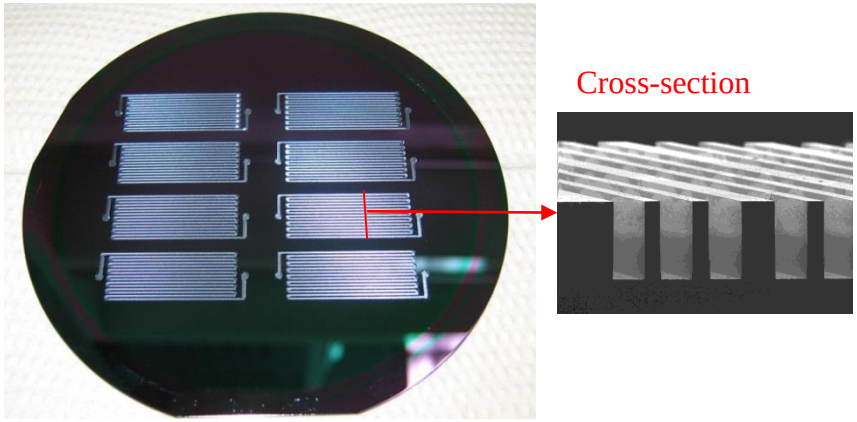


Si (110) anisotropic wet etch





Photolithography: rectangular channels



Substrate: Si wafer (110)
Thickness: 500 μm

SiO_2 formation (thickness: 1 μm)
Thermal oxide was grown onto Si (110) wafer by thermal wet oxidation.

Photoresist (PR) coating
AZ1512, thickness: 1 μm

Film mask
Channel width: 600 μm

Exposure
UV, exposure energy: 15 mW × 4.5 sec

Development
AZ 300 developer

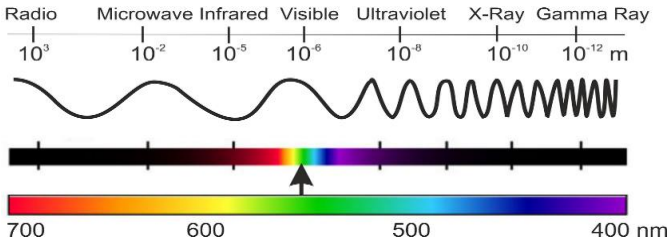
Buffered HF (BHF) etching
NH_4F : HF = 7 : 1

PR strip
H_2SO_4 : H_2O_2 = 4 : 1

KOH wet etching
30 wt% KOH solution, at 80 for 3 hrs

Buffered HF (BHF) etching
NH_4F : HF = 7 : 1

Lithography techniques

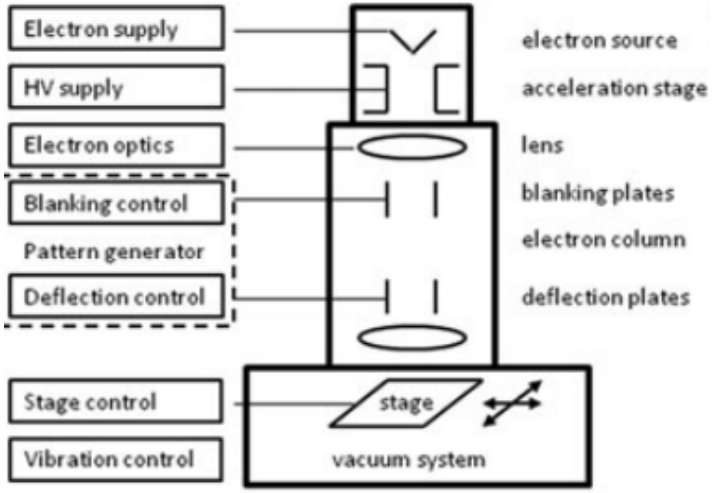


Resolution:

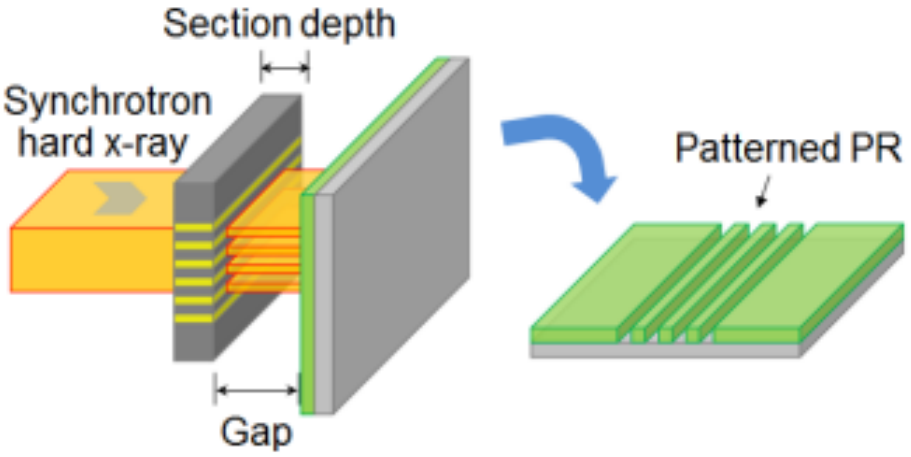
$$R = K \times \frac{\lambda}{n \sin\theta}$$

K: technical limited constant
λ: wavelength
n: an index of refraction

Electron-beam lithography



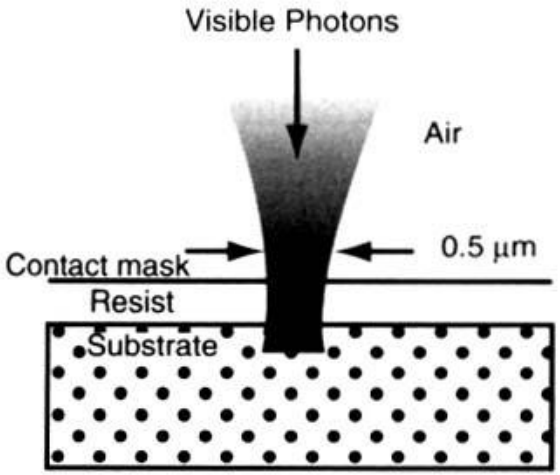
X-ray lithography



Lithography techniques

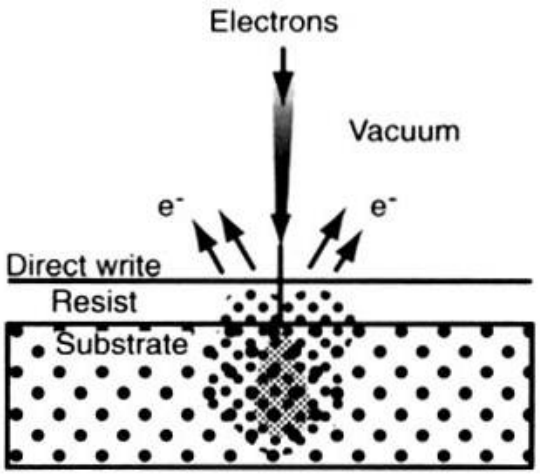
Comparison

Photolithography



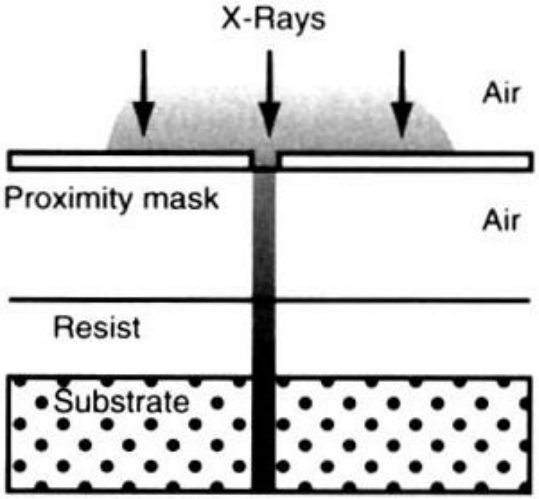
diffraction limits resolution

Electron-beam lithography



Scattering problem

X-ray lithography



Little diffraction, high depth of focus

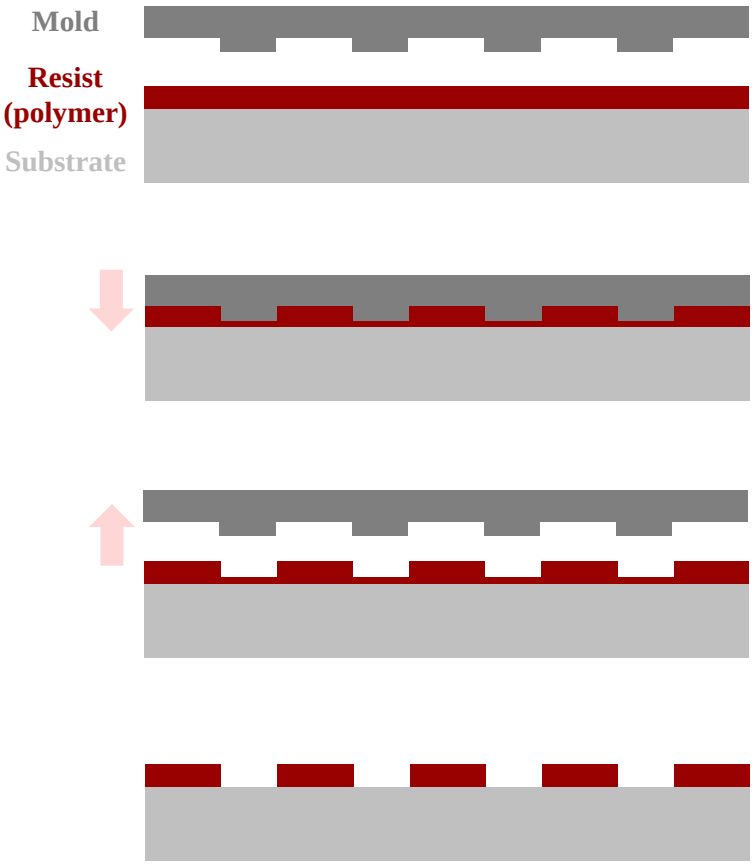
Lithography techniques

Comparison

	Photolithography	Electron-beam lithography	X-ray lithography
Source	Ultraviolet (UV)	Electron	X-ray
Wavelength	100 ~ 400 nm	Depending on voltage	0.4 ~ 4 nm
Resolution limit	~ 125 nm	~ 20 nm	~ 15 nm
Resist	Various polymers	Polymethylmethacrylate	Polymethylmethacrylate
Advantages	Fast process Simple Relatively low cost	Print complex patterns directly on wafers Eliminates the diffraction problem Flexible technique	Utilizes short wavelength of 1 nm Simple: Requires no lenses Allows for small feature size Faster than electron-beam lithography
Disadvantages	Low resolution	Slower than photolithography Expensive and complicated Secondary electrons	Thin lens Cannot be focused through lens Masks are expensive to produce

Nanoimprint lithography

Nanoimprint lithography: process



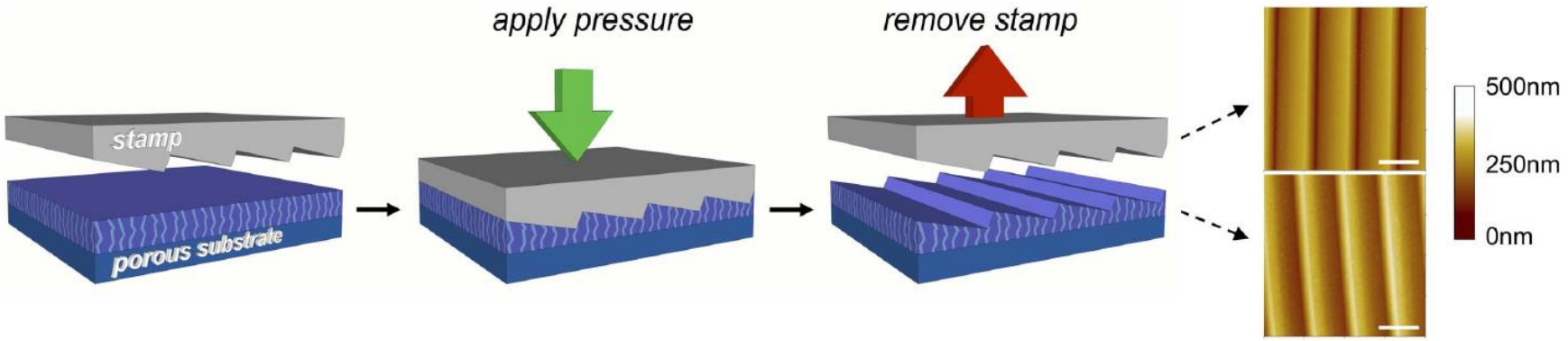
Step 1: Preparation
A mold is fabricated by electron-beam lithography and dry etching.

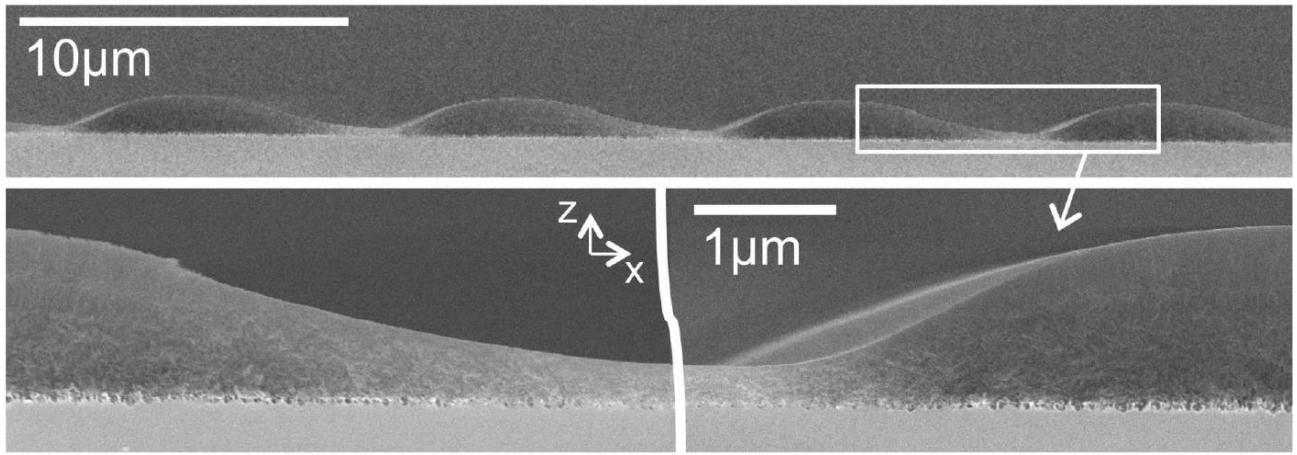
Step 2: Pressing mold
The mold is pressed into a soft thermoplastic polymer on a substrate combined with heating or UV radiation.

Step 3: Removing mold
The polymer is patterned and the mold release from substrate.

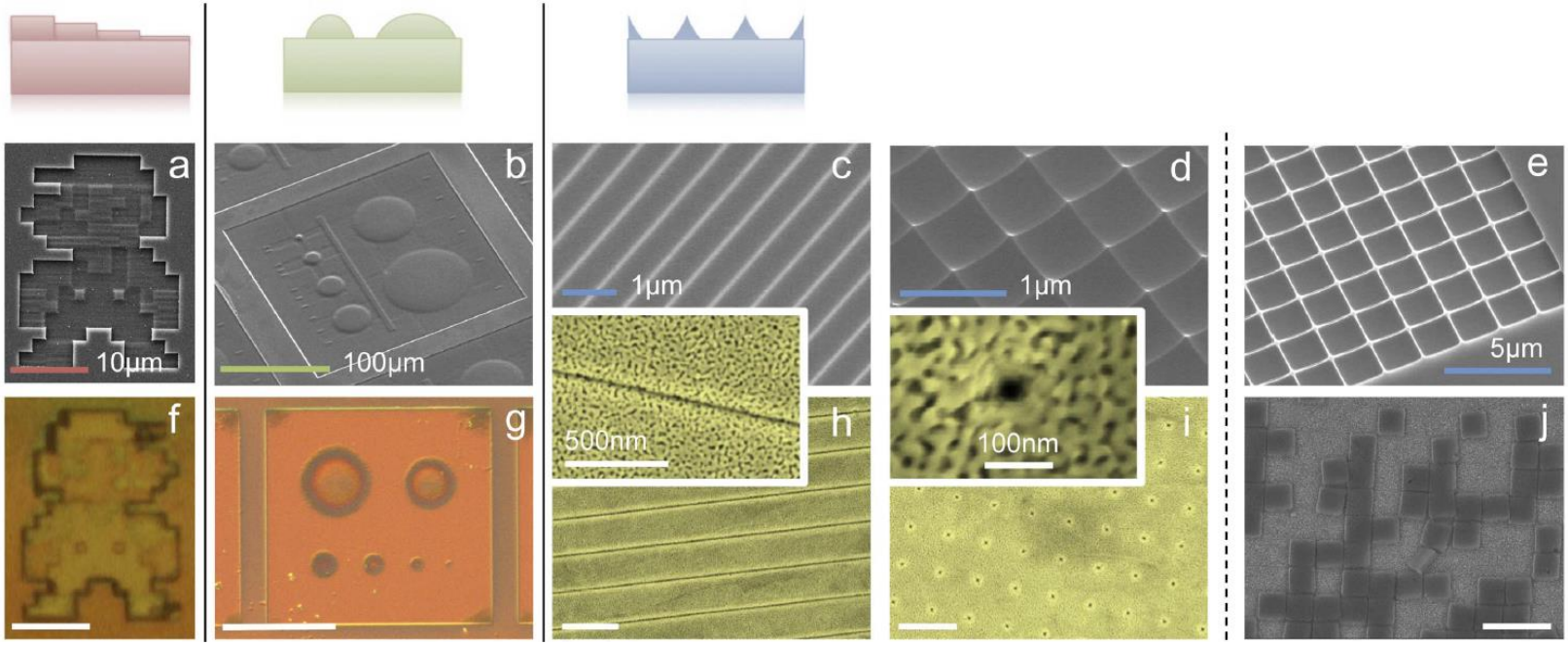
Step 4: Etch
Residual imprint polymer under mold protrusion removed by reactive ion etch (RIE) process

Nanoimprint lithography: process



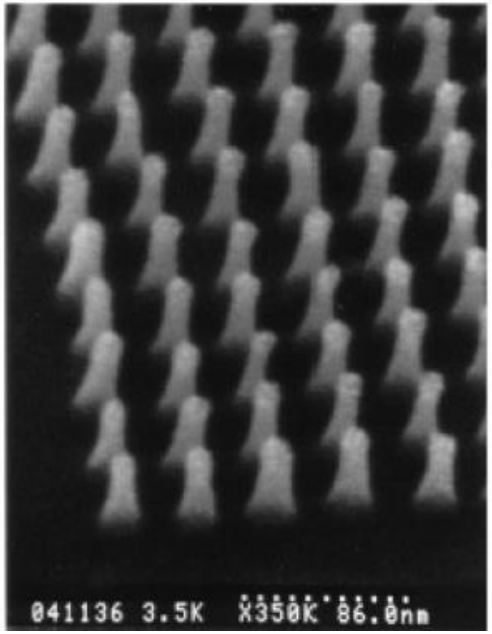


Nanoimprint lithography: examples



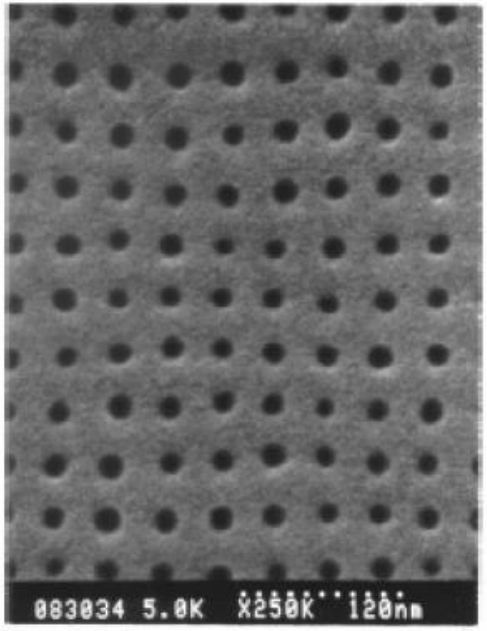
Nanoimprint lithography: examples

Mold



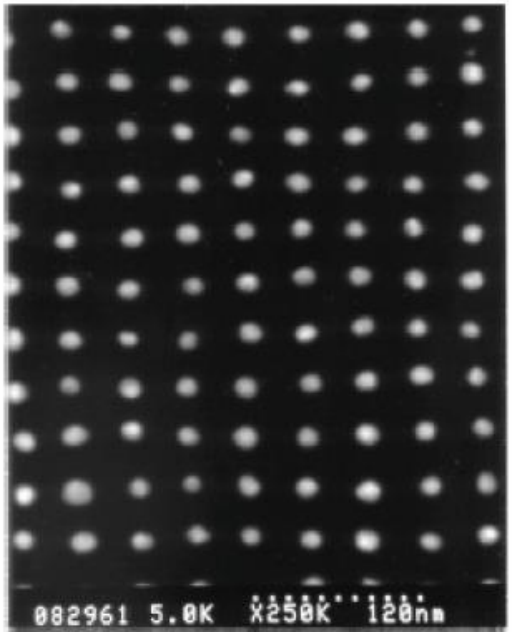
10 nm diameter pillar mold

Resist (after pressing mold)



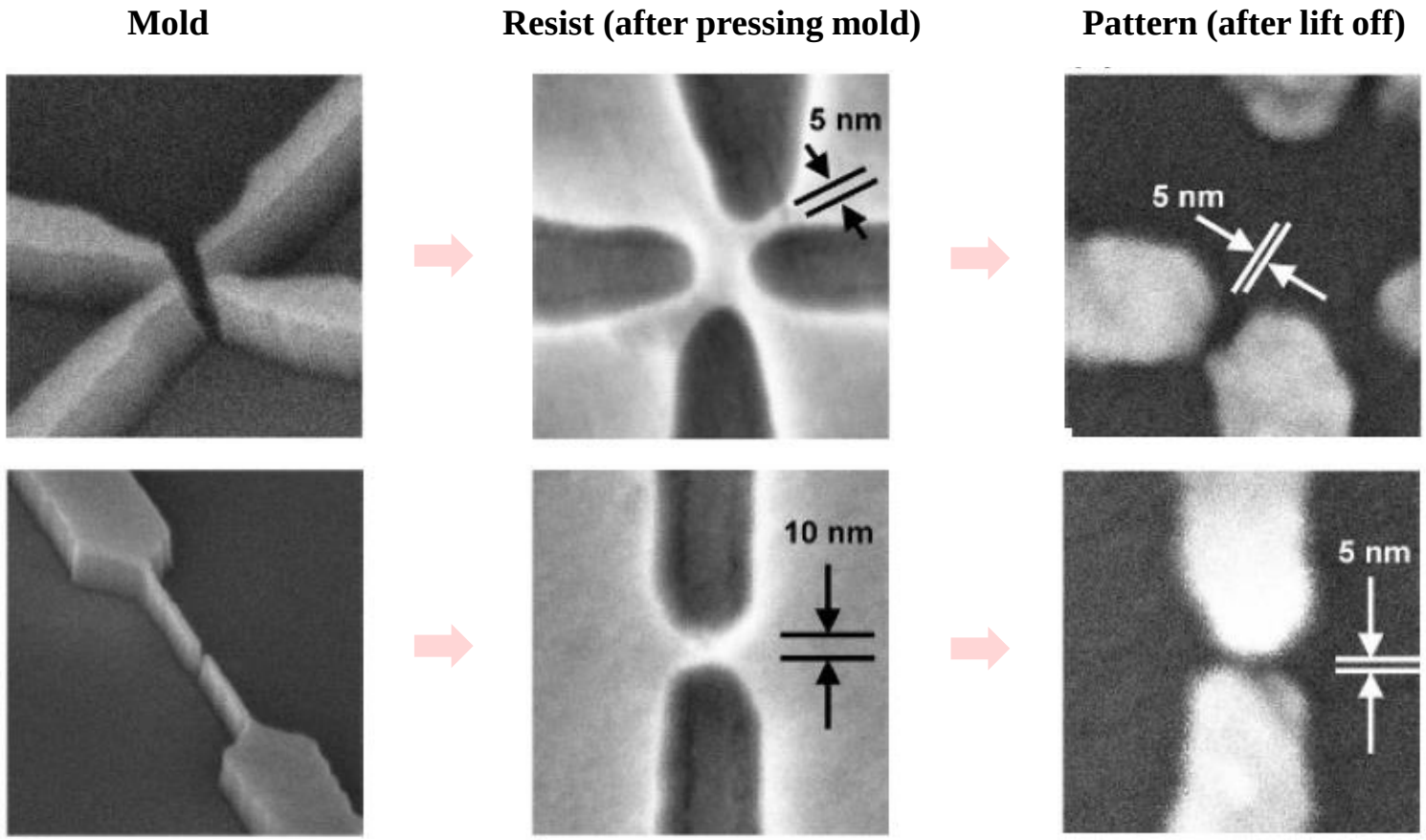
10 nm diameter resist holes by imprinting

Pattern (after lift off)



10 nm diameter metal dots by imprint and lift off

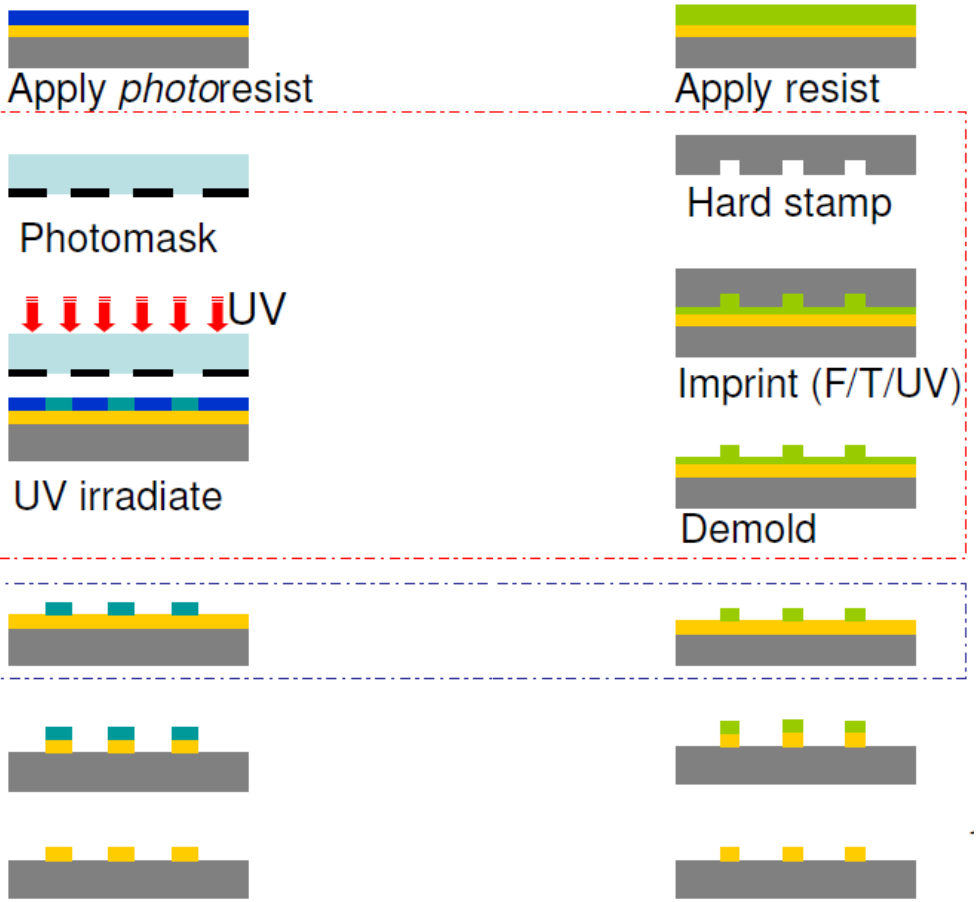
Nanoimprint lithography: examples



Nanoimprint lithography: comparison

Photo lithography

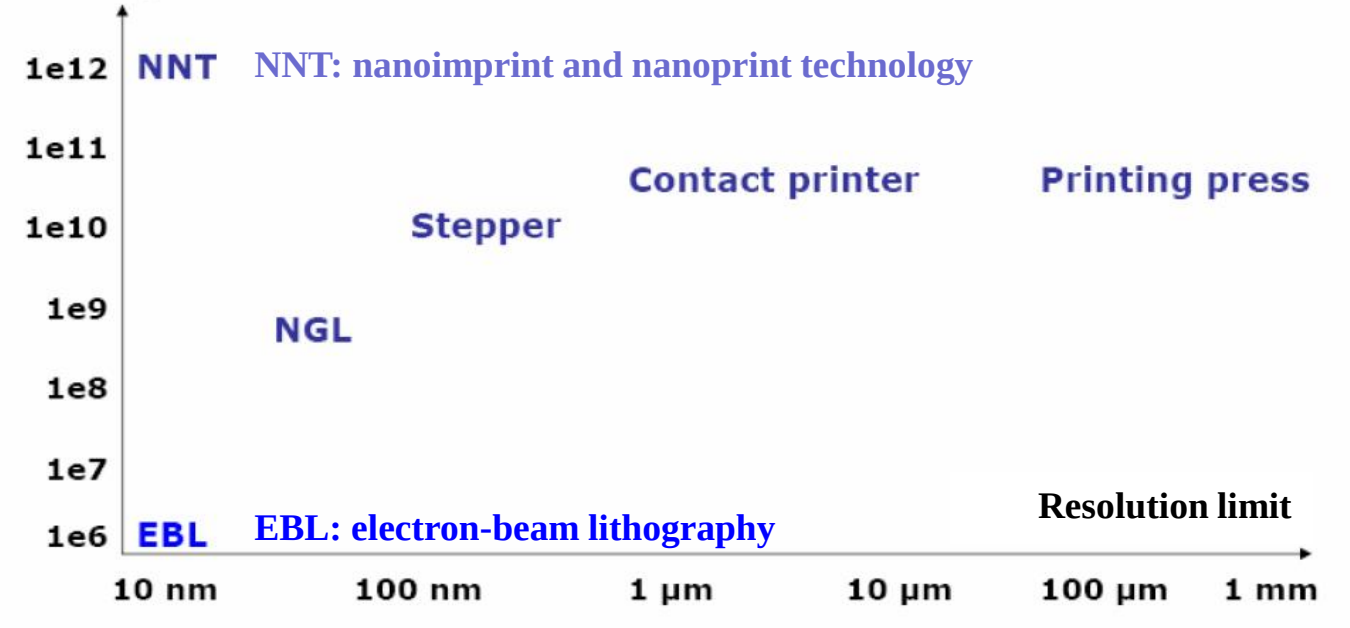
Resolution limit
~ 125 nm



Nanoimprint lithography

Resolution limit
5 ~ 50 nm

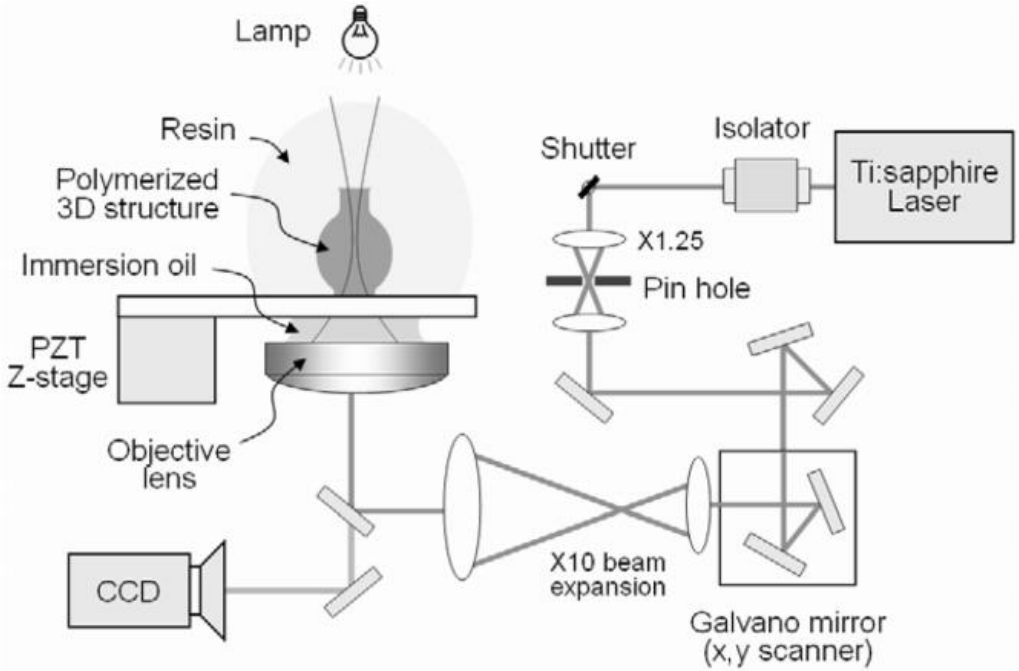
Nanoimprint lithography: comparison



Nanoimprint lithography has an advantages for mass production of nano patterns.

Nano-stereolithography

Nano-stereolithography

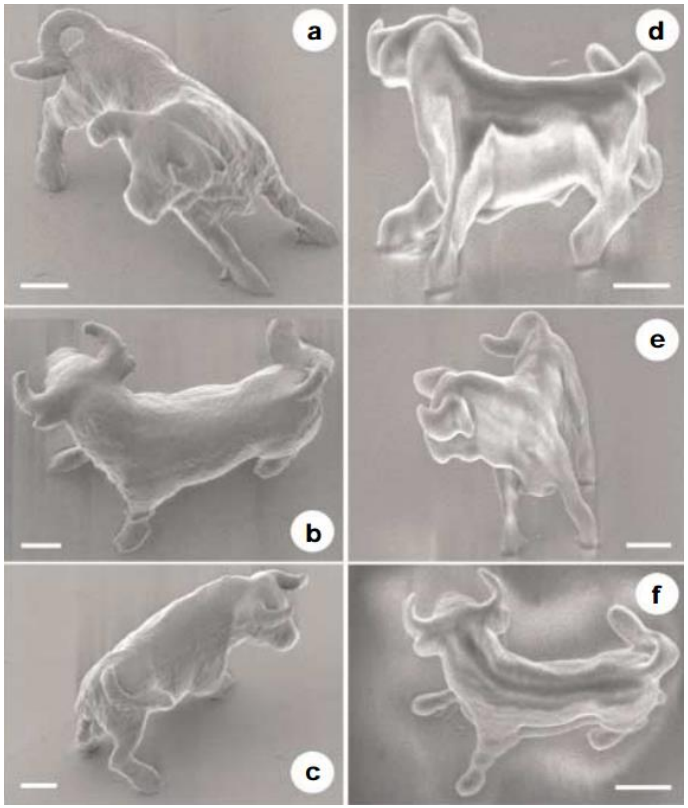


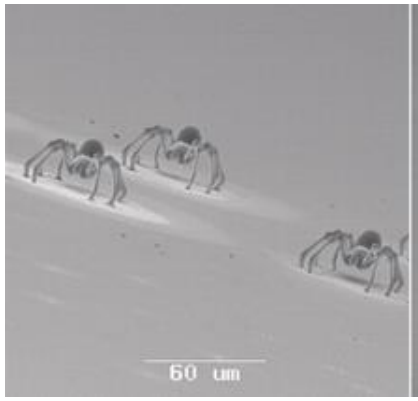
Modeling

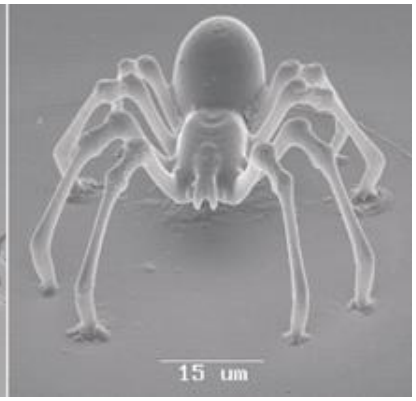
Layer-by-layer deposition

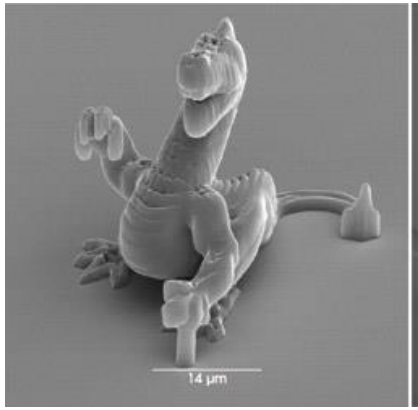
Final object

Nano-stereolithography: examples









Nano-stereolithography: examples