NUFAB
NORTHWESTERN UNIVERSITY
MICRO/NANO FABRICATION FACILITY

Lithography at NUFAB:

For Beginners and the Experienced

Lithography History

- Lithography is the transfer of geometric shapes on a mask to a smooth surface
- In Greek: Lithos: *stone*, graphein: *to write*

Stencils ~ 10,000 BC

Cave paintings
Perito Moreno, Argentina

Royal Seals ~ 3000 BC

Cylinder-seal, Uruk period and its impression,

woodblock book prints ~ 800 AD

the oldest known dated printed book in the world, Tang-dynasty

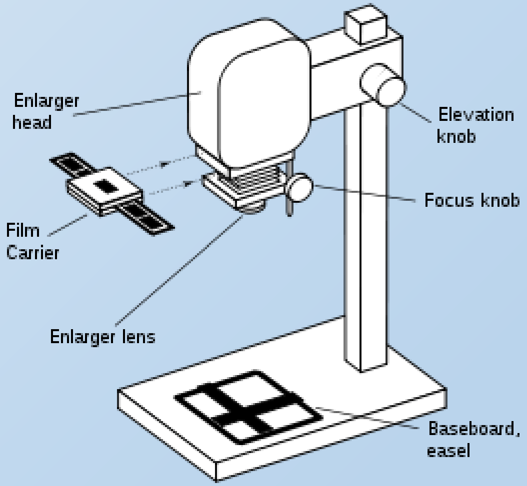
Photo(litho)graphy…

- not the digital one -

- First photographs by a pinhole camera on Silver Nitrate papers ~ 1840s

Anybody remember this?

- Agrandisseur (Enlarger)



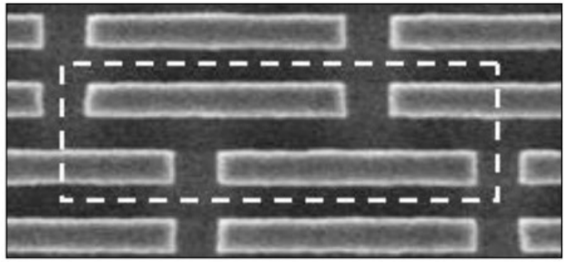
Grandfather of the mask aligners

Chronology of photolithography in industry

Contact Lithography
1^{st} IC's ~ 200 um resolution

Proximity lithography
~ 2 um resolution
Worse than contact but less defects and prolonged mask life

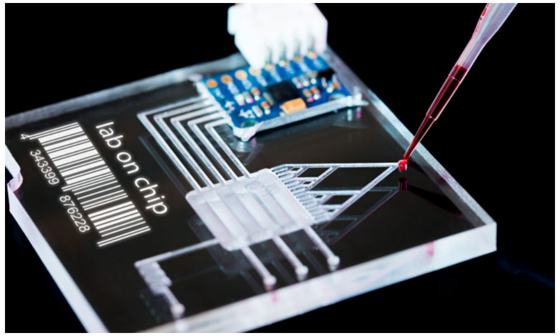
22 nm Process



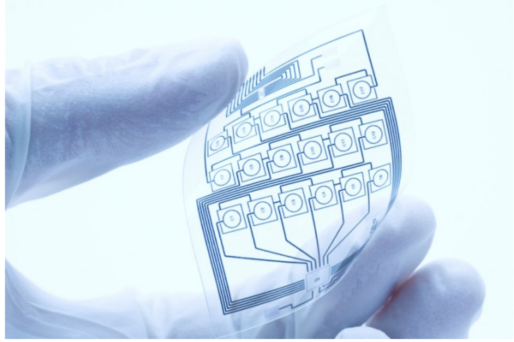
Step and repeat
submicron resolution with image reduction
No contacts with the sample so long mask life

Contact lithography is still commonly practiced today, mainly in applications requiring thick photoresist and/or double-sided alignment and exposure. Advanced 3D packaging, optical devices, Microfluidics and MEMS applications..

Lithography Applications

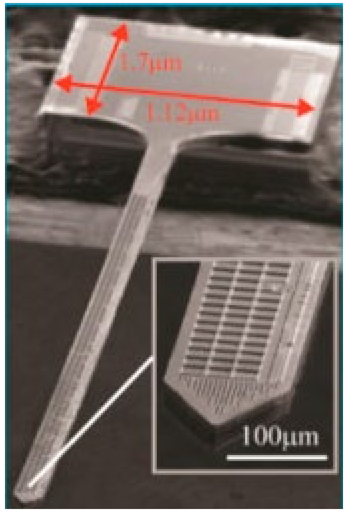


Micro/Nano fluidics

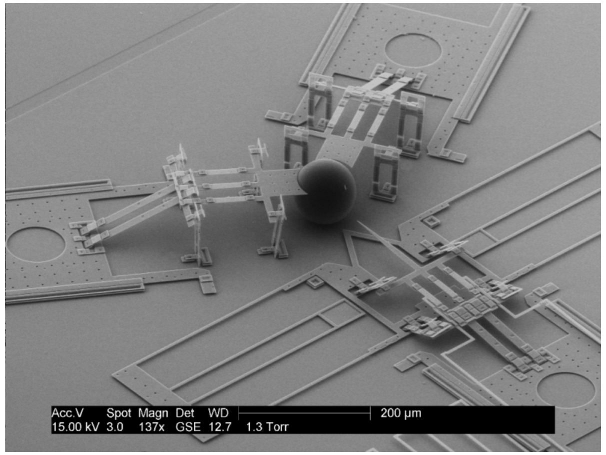


Flexible Electronics

Bioelectronics and implantables



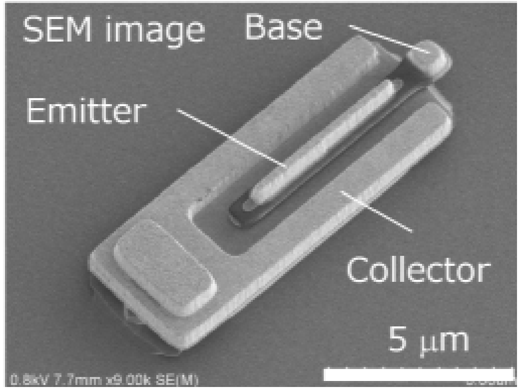
Biosensors



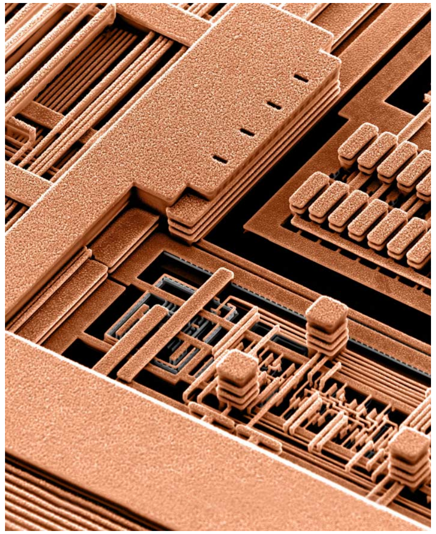
NEMS - nano injector

Lithography Applications contd.

Solar Cells

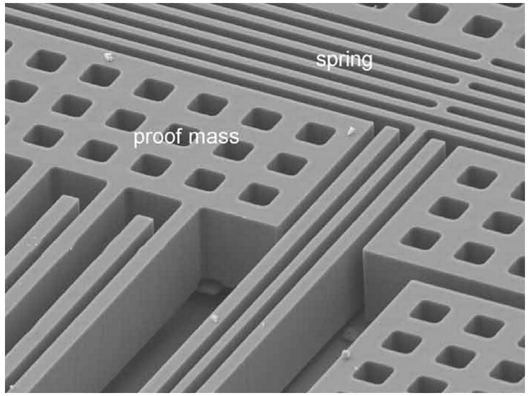


Electronic Devices



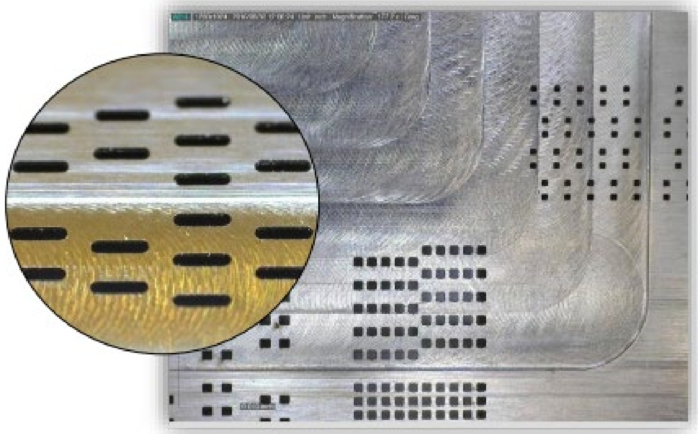
Integrated Circuits

MEMS

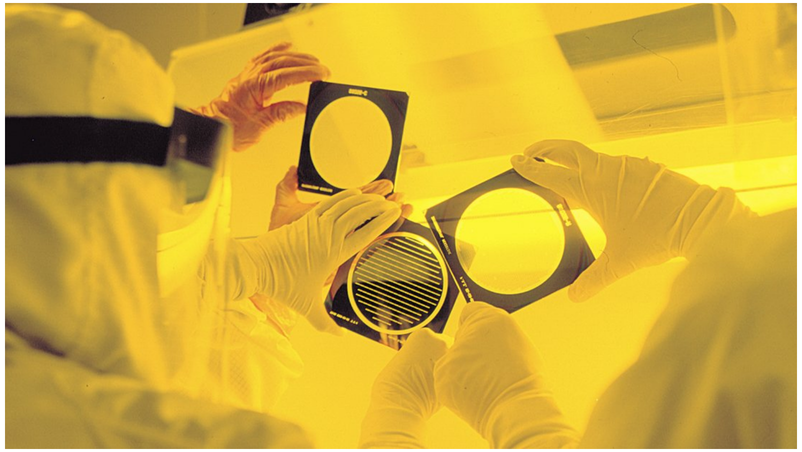


Fitbit Accelerometer

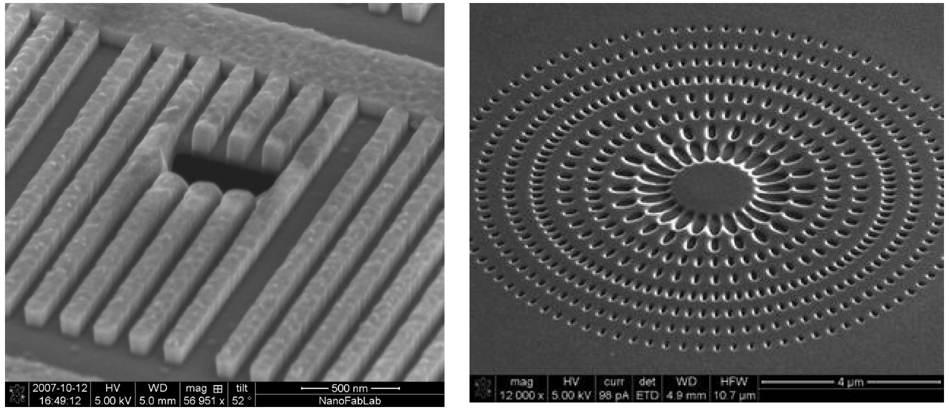
Types of lithography



Stencil/Hard Mask
~ 50 um



Photolithography:
UV, EUV, Xray
~ 0.2 um



Ebeam Lithography
and Focused Ion
Beam milling
~ 0.01 um

Photolithography ----- How it works

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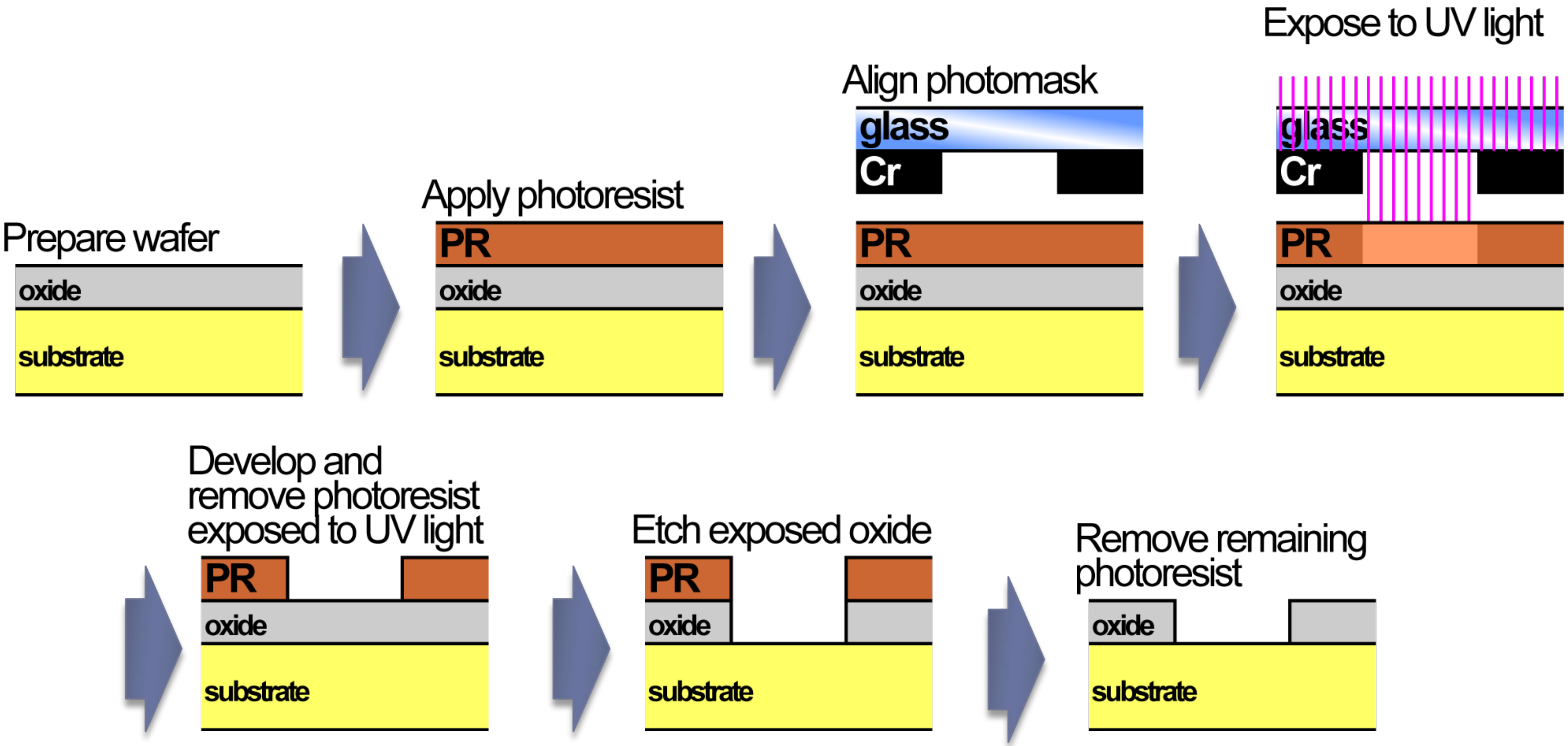

Prepare wafer

Apply photoresist

Align photomask

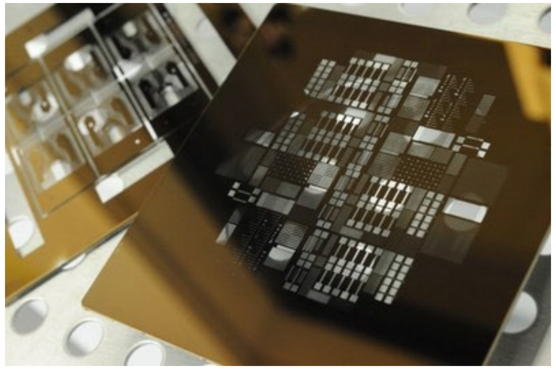
Expose to UV light

Develop and remove photoresist exposed to UV light

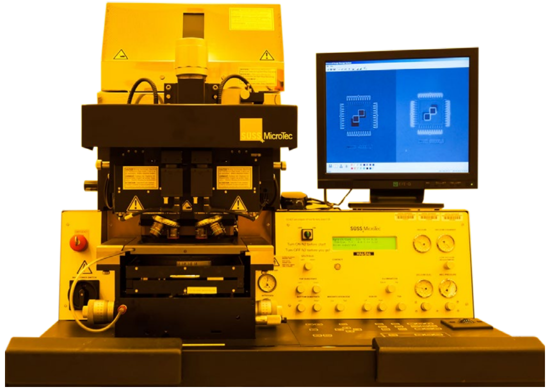
Etch exposed oxide

Remove remaining photoresist

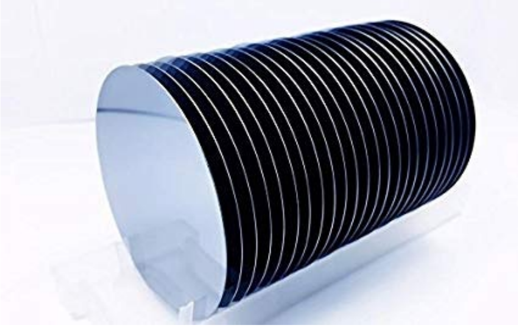
Required tools



Masks: Chromium or Iron oxide plates



Mask aligner: typically has a UV source such as Hg lamp or UV LED



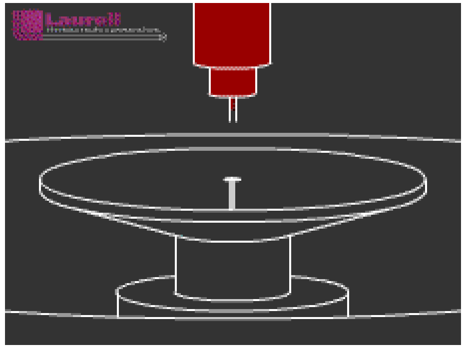
Substrates: Si wafers, glass slides, metal foils

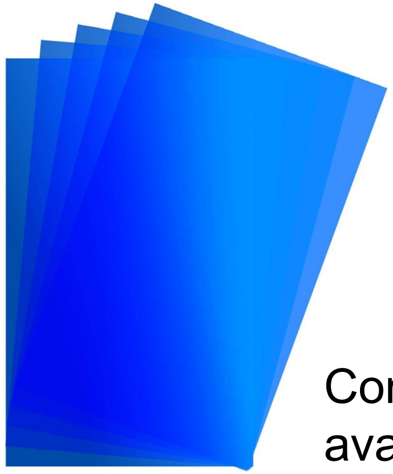
Photoresists

Developers:
Alkaline or Solvent solutions

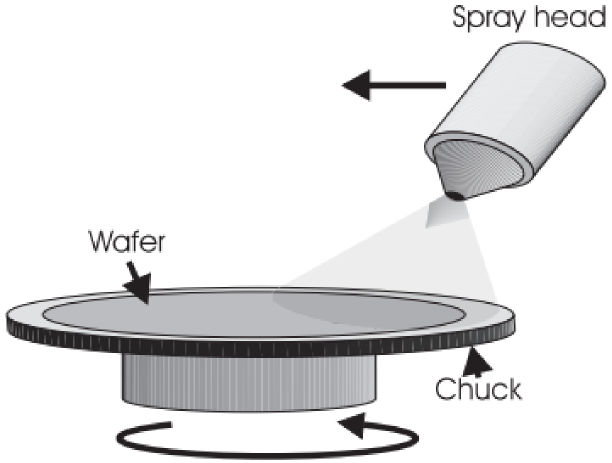
Photoresist application techniques

- Spin coating
  - NUFAB has multiple spinners available for both standard photoresists and specialized resins



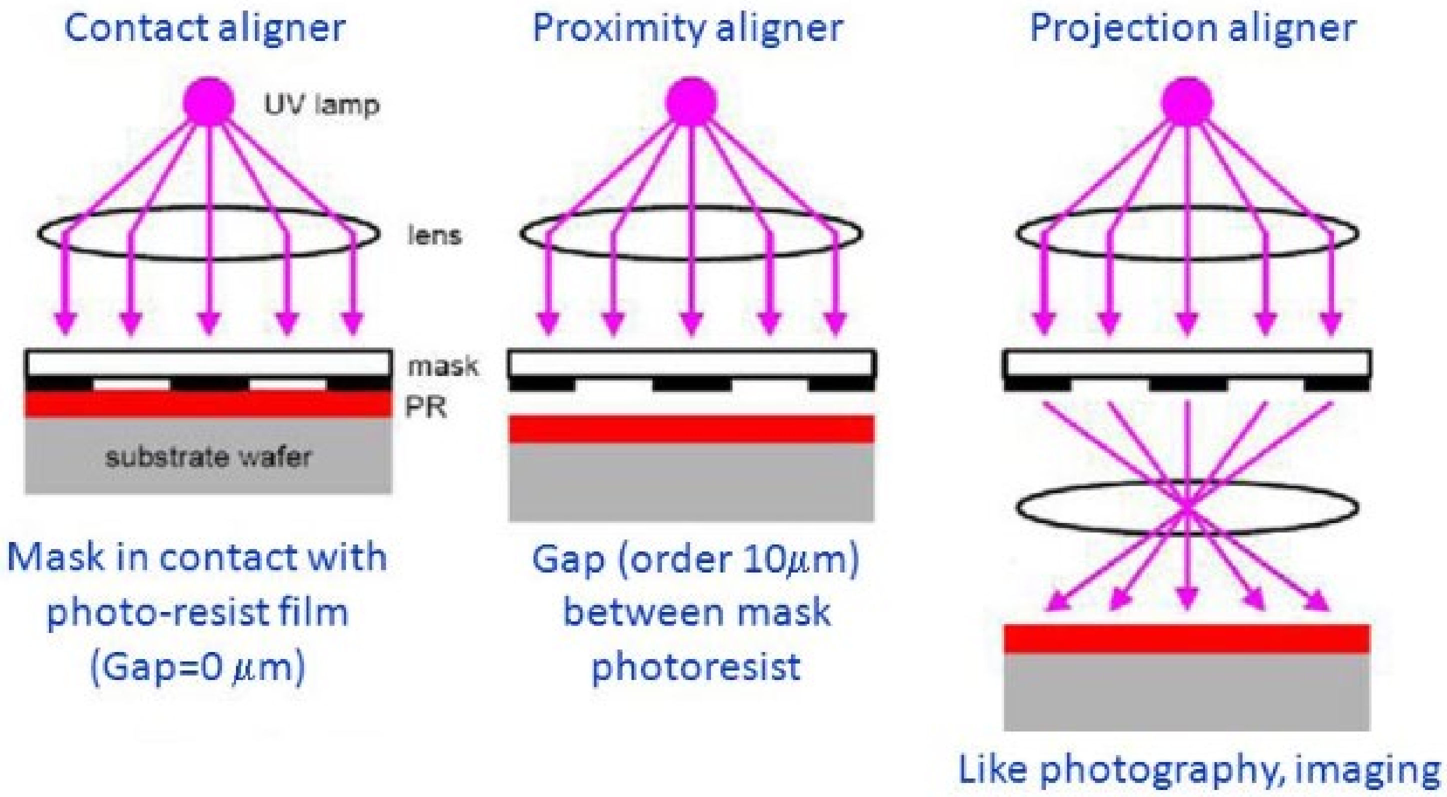


Commercial dry film tapes are available for coarse processes



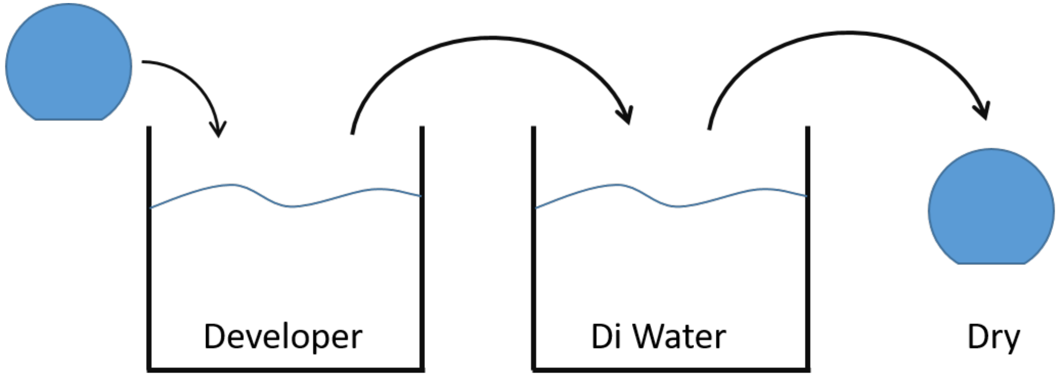
Spray coating for mass production

Photolithography types explained

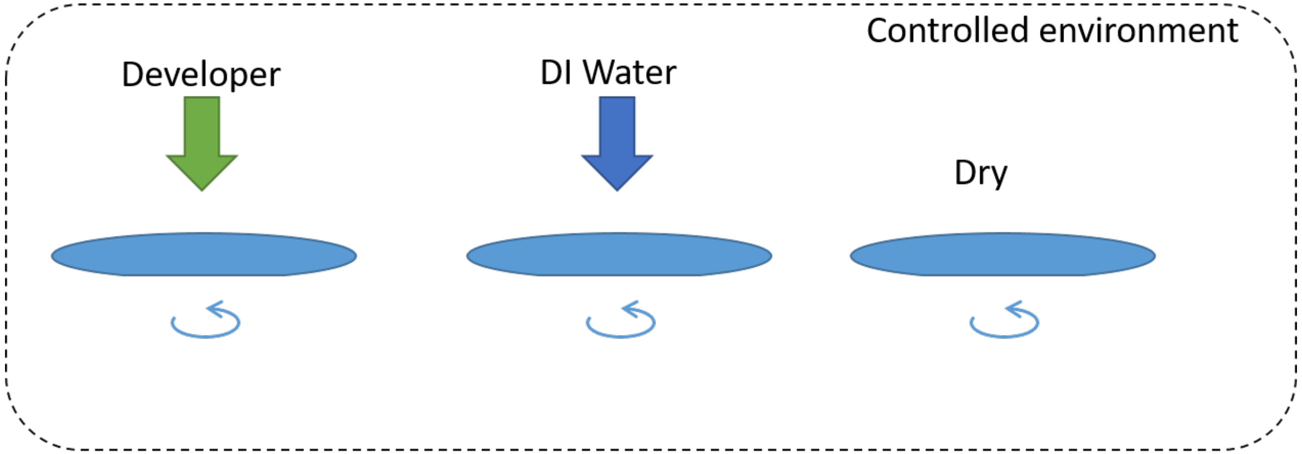


Resolution	0.7 um	5 um	0.3 um

Photoresist developing techniques



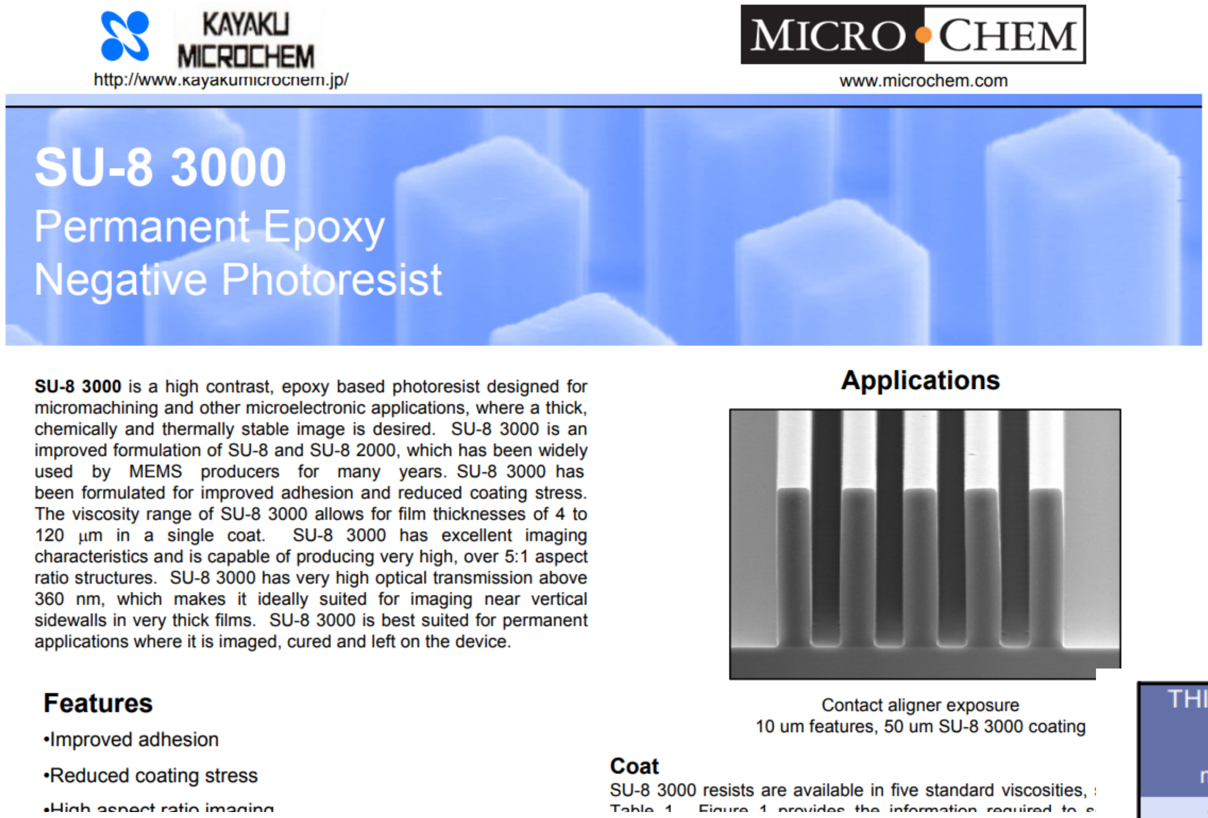
Immersion Developing



Spray/Puddle Developing

NUFAB's proposed automatic spin developing station

Datasheets are good resources for recipes



KAYAKU MICROCHEM
http://www.kayakumicrochem.jp/

MICRO•CHEM
www.microchem.com

SU-8 3000
Permanent Epoxy
Negative Photoresist

SU-8 3000 is a high contrast, epoxy based photoresist designed for micromachining and other microelectronic applications, where a thick, chemically and thermally stable image is desired. SU-8 3000 is an improved formulation of SU-8 and SU-8 2000, which has been widely used by MEMS producers for many years. SU-8 3000 has been formulated for improved adhesion and reduced coating stress. The viscosity range of SU-8 3000 allows for film thicknesses of 4 to 120 µm in a single coat. SU-8 3000 has excellent imaging characteristics and is capable of producing very high, over 5:1 aspect ratio structures. SU-8 3000 has very high optical transmission above 360 nm, which makes it ideally suited for imaging near vertical sidewalls in very thick films. SU-8 3000 is best suited for permanent applications where it is imaged, cured and left on the device.

Applications

Contact aligner exposure
10 um features, 50 um SU-8 3000 coating

Features

- Improved adhesion
- Reduced coating stress
- High aspect ratio imaging

Coat

SU-8 3000 resists are available in five standard viscosities, Table 1. Figure 1 provides the information required to s

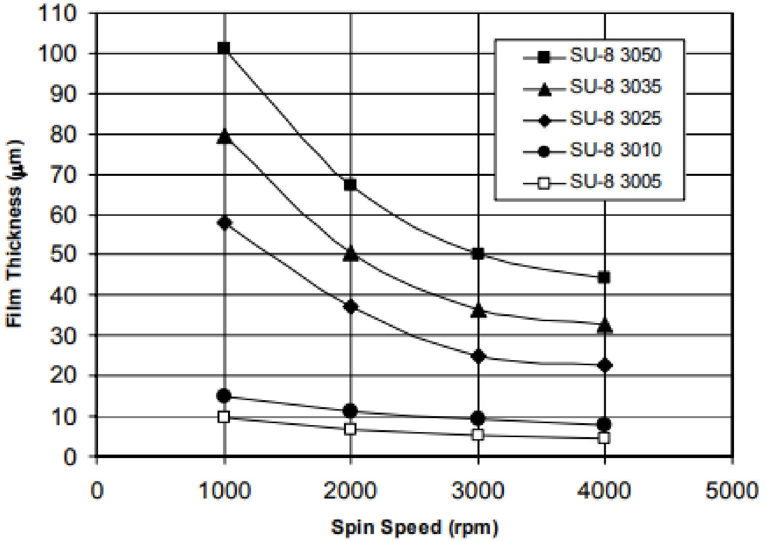
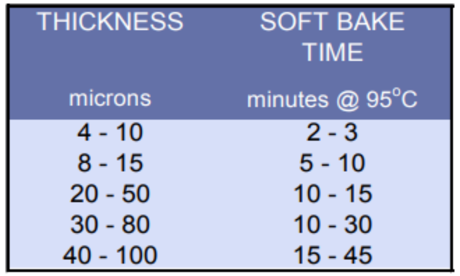
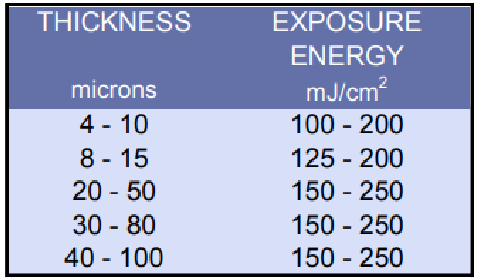


Figure 1. Spin speed vs. Thickness
for SU-8 3000 resists (21°C US & EU)



THICKNESS microns	SOFT BAKE TIME minutes @ 95°C
4 - 10	2 - 3
8 - 15	5 - 10
20 - 50	10 - 15
30 - 80	10 - 30
40 - 100	15 - 45

Table 2. Soft Bake Times

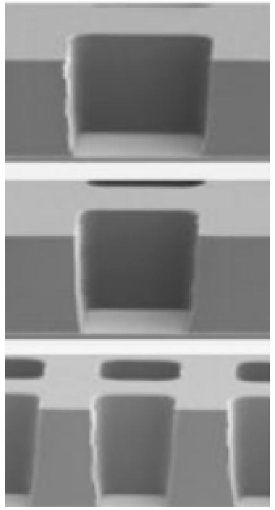


THICKNESS microns	EXPOSURE ENERGY mJ/cm^2
4 - 10	100 - 200
8 - 15	125 - 200
20 - 50	150 - 250
30 - 80	150 - 250
40 - 100	150 - 250

Table 3. Exposure Dose

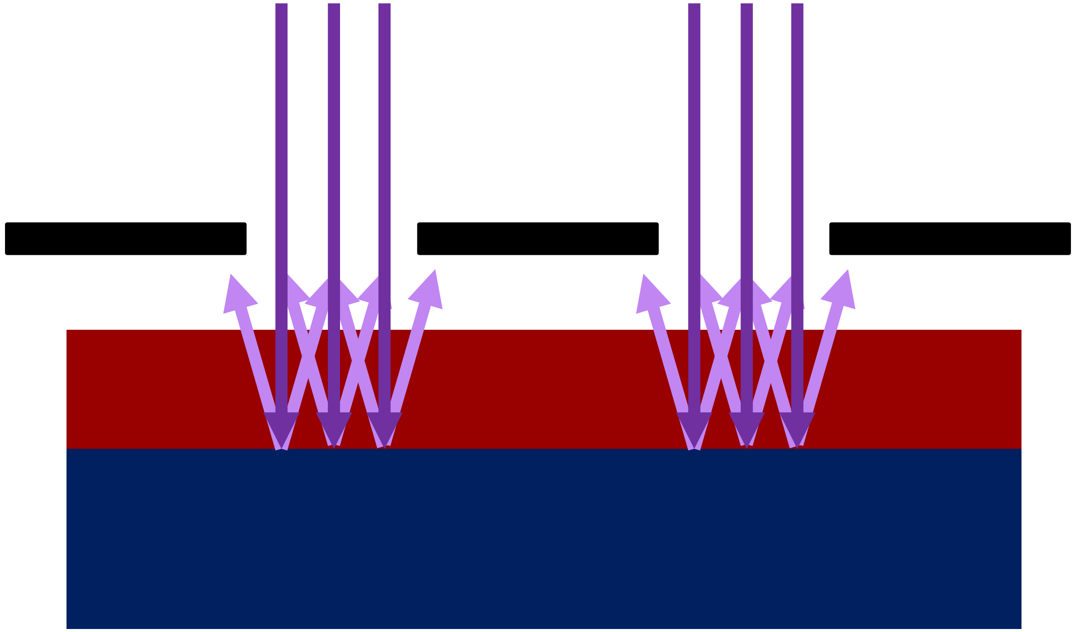
There are two kinds of PR

Positive Photoresist



Negative/IR Photoresist

What determines the wall profile?



Light collimation, Diffraction, refractive index gradient, interference

Exposure

Contact Separation

- Particles on the sample
- Edge bead
- WEC

Developer

- Type MIF/MIB
- Concentration

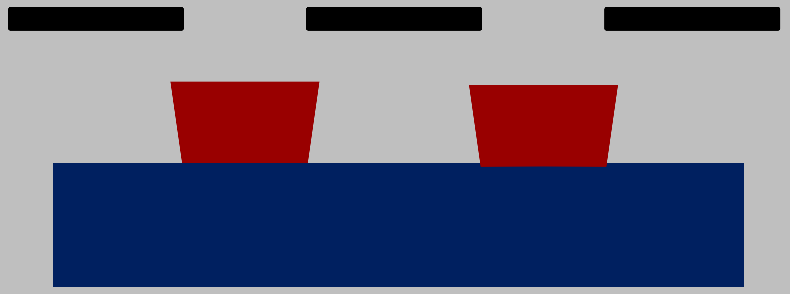
Development time

How to choose the correct type of PR

Positive Photoresist

- ✓ Wet/Dry Etching
- ✓ Electroplating
- ✓ Air bridges

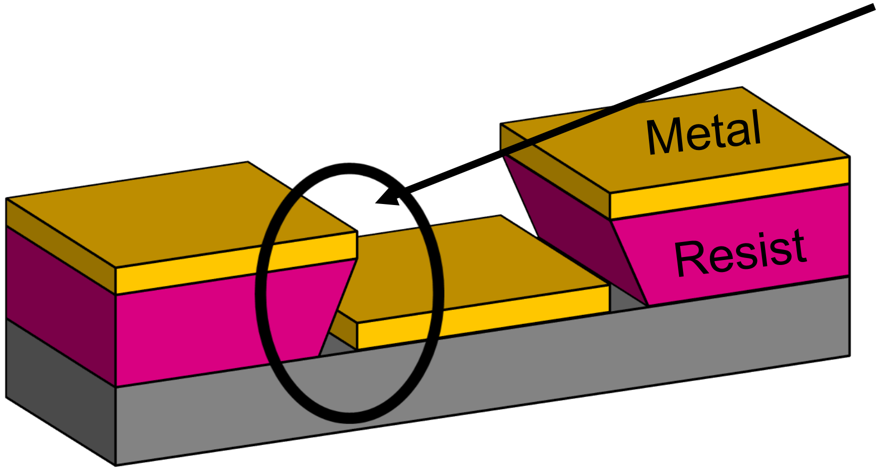
Negative/IR Photoresist



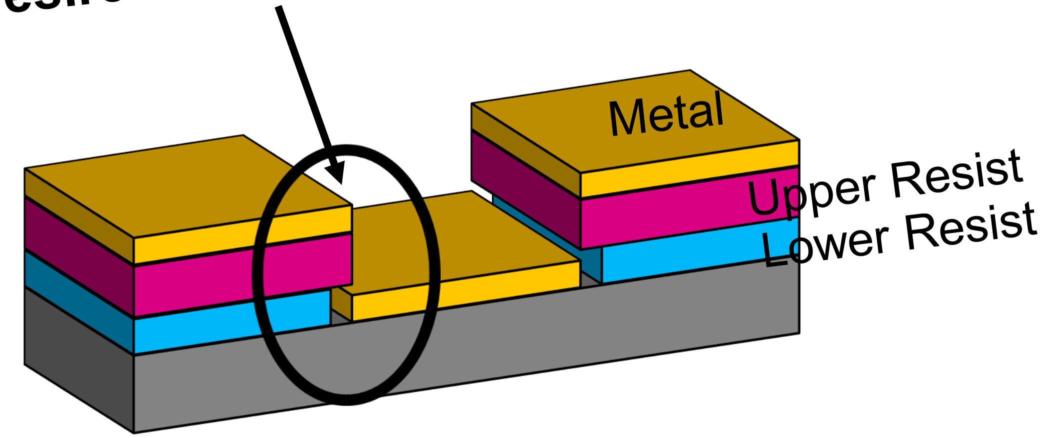
- ✓ Lift-off

Lift-off process

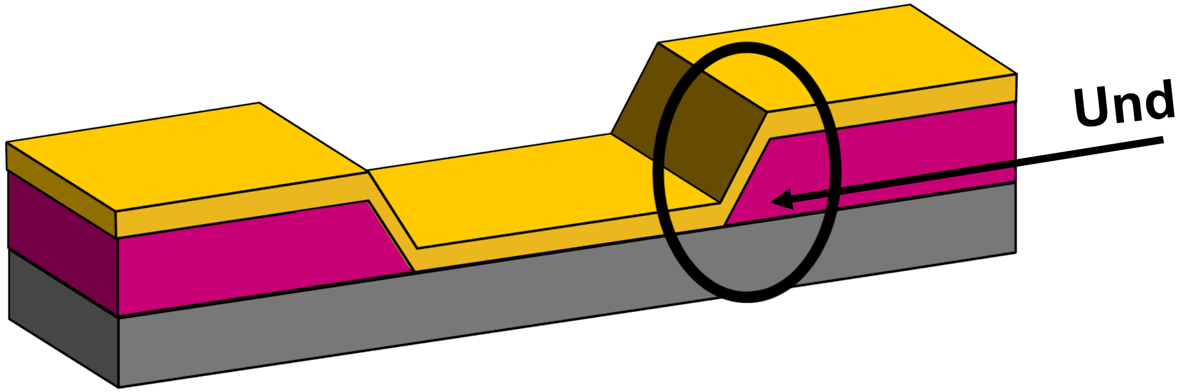
Desired undercut profile



Good negative or IR resist process



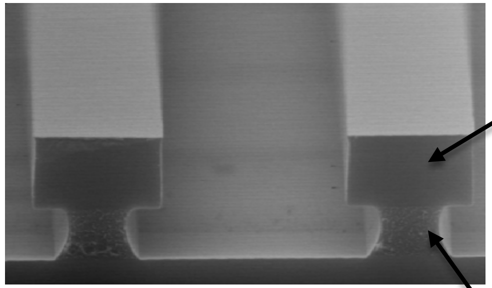
Bilayer process



Undesired resist wall profile

Lift-off – How it works

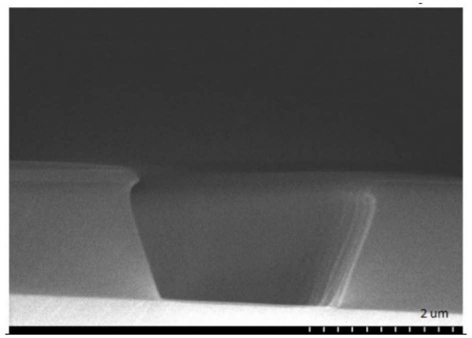
Bilayer process



A positive PR
S1805, S1813 etc.

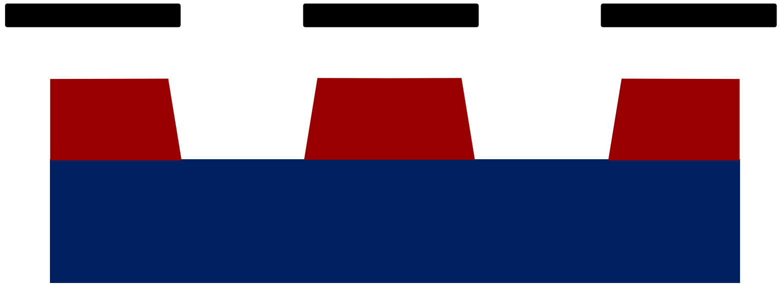
LOR 1A, 5A

Toluene or Chlorobenzene soaking



NUFAB's inventory

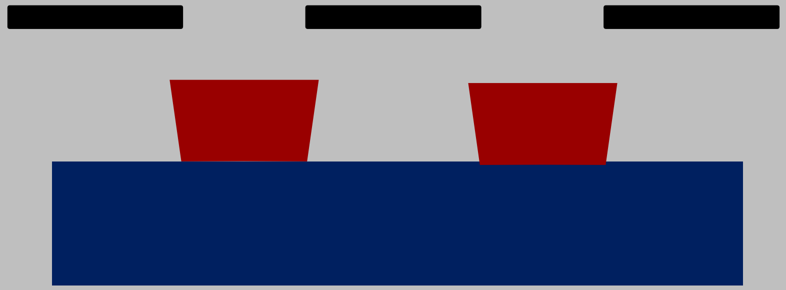
Positive Photoresist

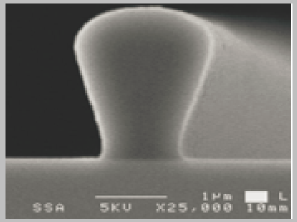


S1805
S1813

AZ P2640
SPR 220-7.0

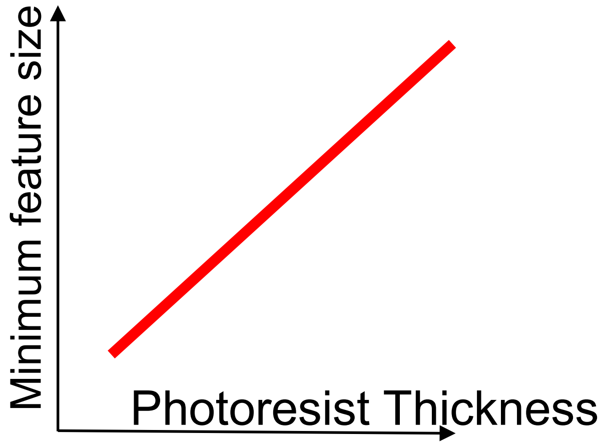
Negative/IR Photoresist

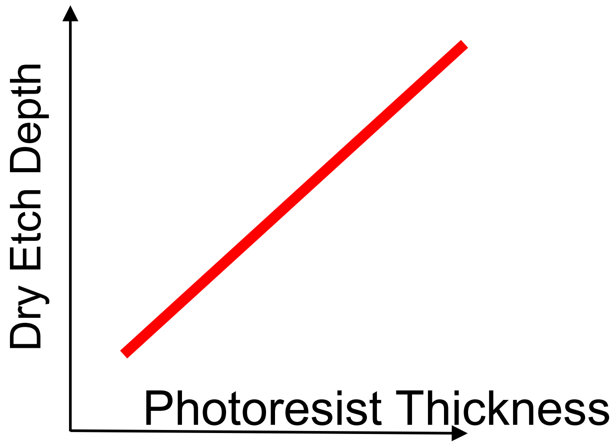


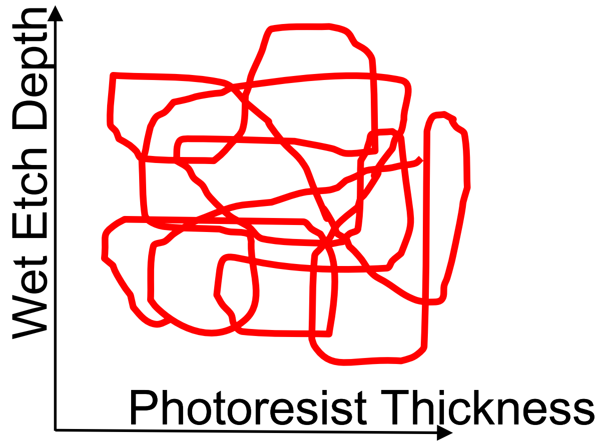


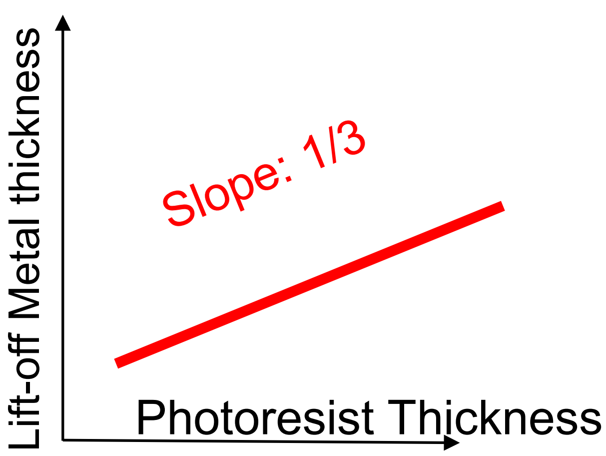
AZ 5214E
nLof 2035
All SU8s

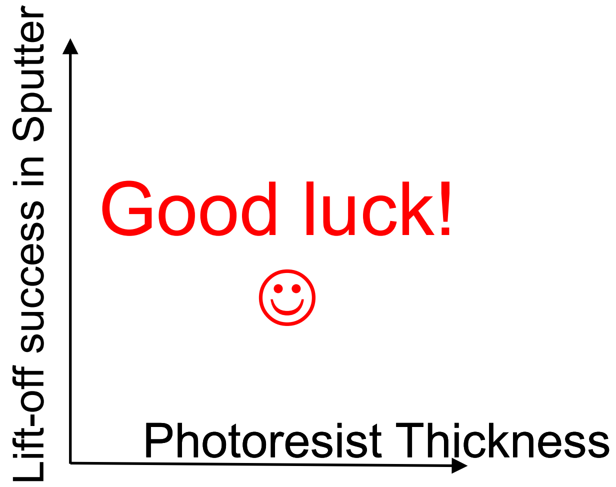
In general . . . **





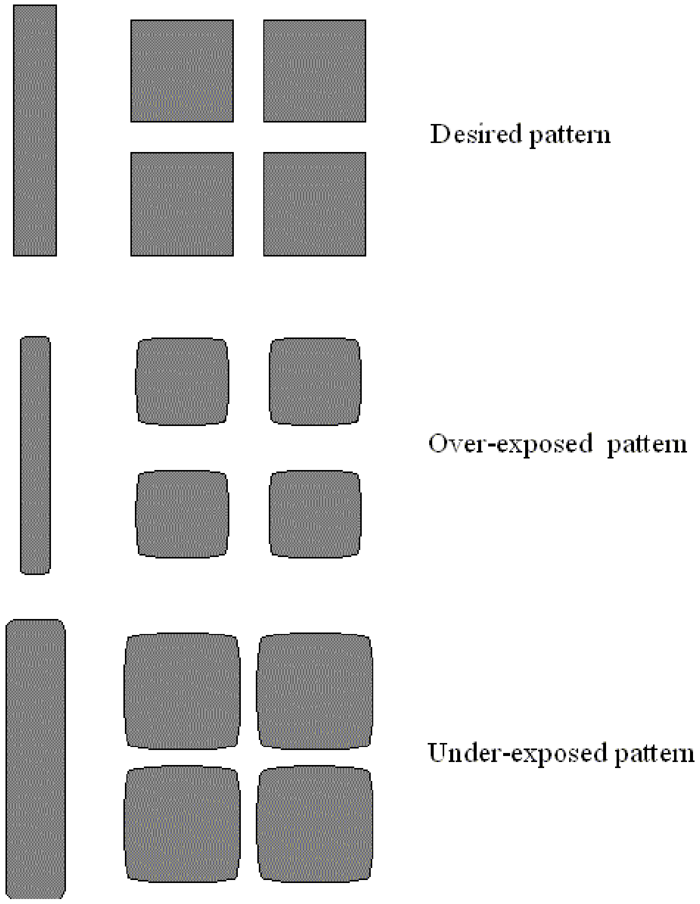


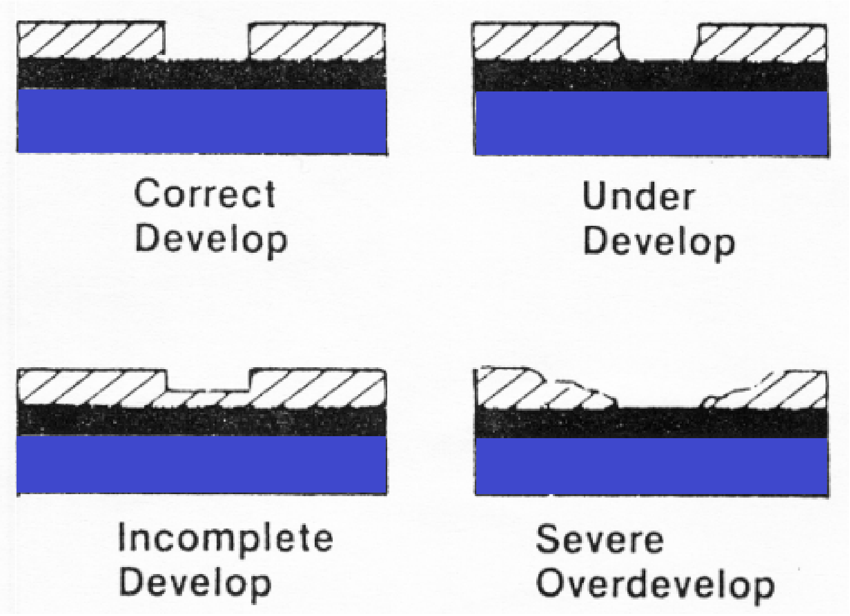




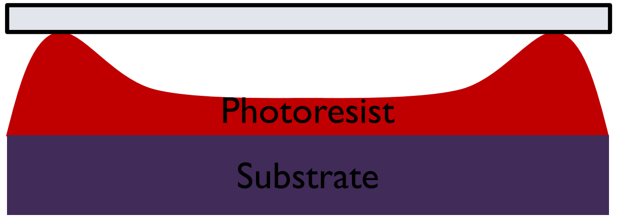
** Assuming superb lithographic practices

Exposure/ Develop Problems

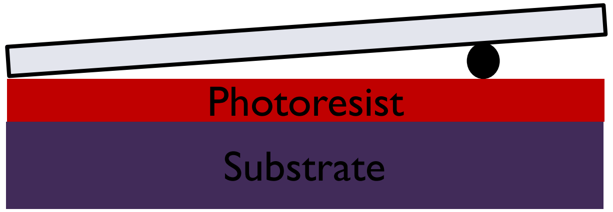




Contact Problems

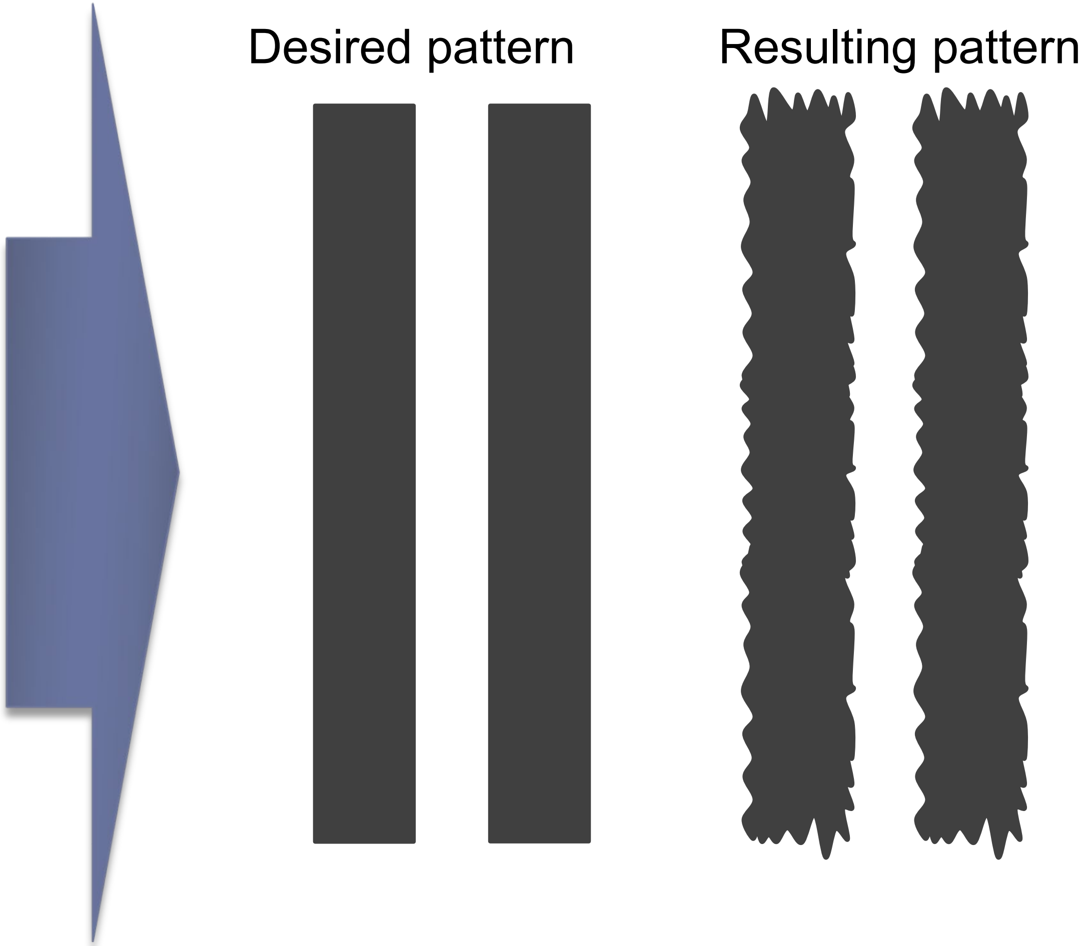


Severe edge beading



Dirty mask/substrate

Wrong operation of the mask aligner



Designing Masks

- DXF – AutoCAD
  - Free for educational use
  - widely available
  - python/matlab friendly

  - Too complicated
  - Not all tools are supported
  - Resource heavy
  - Lacks basic Boolean operations

- GDSII – Ledit, Klayout, Layout editor
  - *De facto* standard for photolithography masks
  - Fool proof
  - Everything is supported
  - Resource friendly

  - Decent editors are expensive
  - Lacks circles

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Mask materials

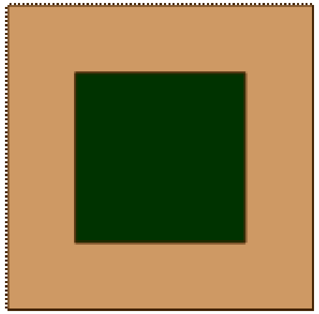
- Chromium
  - Opaque
  - Better resolution
  - Cheaper
  - Requires careful alignment mark design

- Iron Oxide
  - Transparent above 600 nm
  - Acceptable resolution
  - Forgiving to alignment mark design errors
  - Expensive

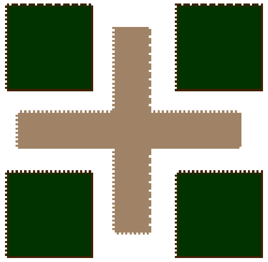
Alignment marks are required for overlay exposures

Simple marks for coarse alignment

Complex marks for fine alignment

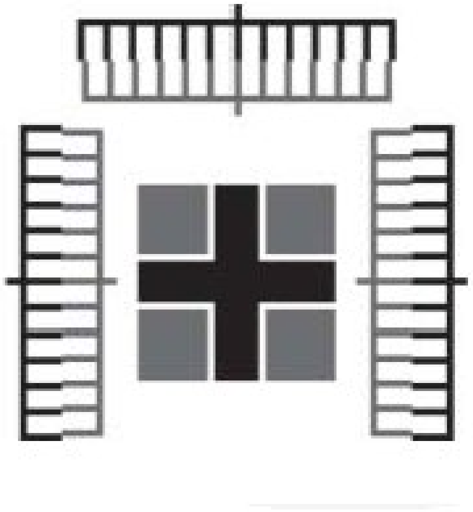


Box in Box alignment mark



Cross alignment mark

2 um Accuracy 0.2 um



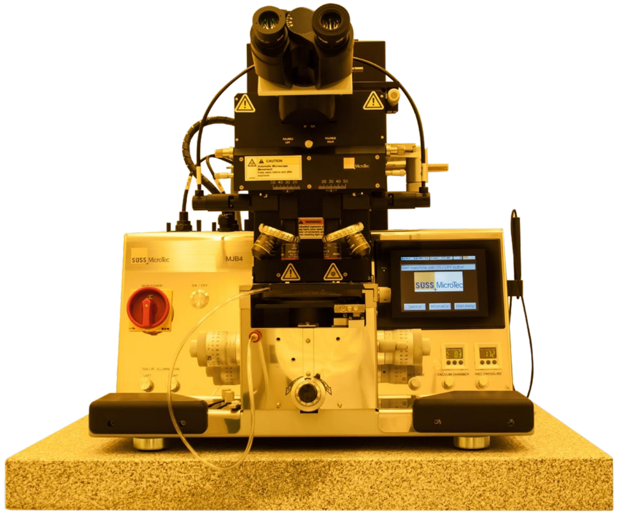
Vernier mark

Microscope magnification, resolution and depth of field affect accuracy

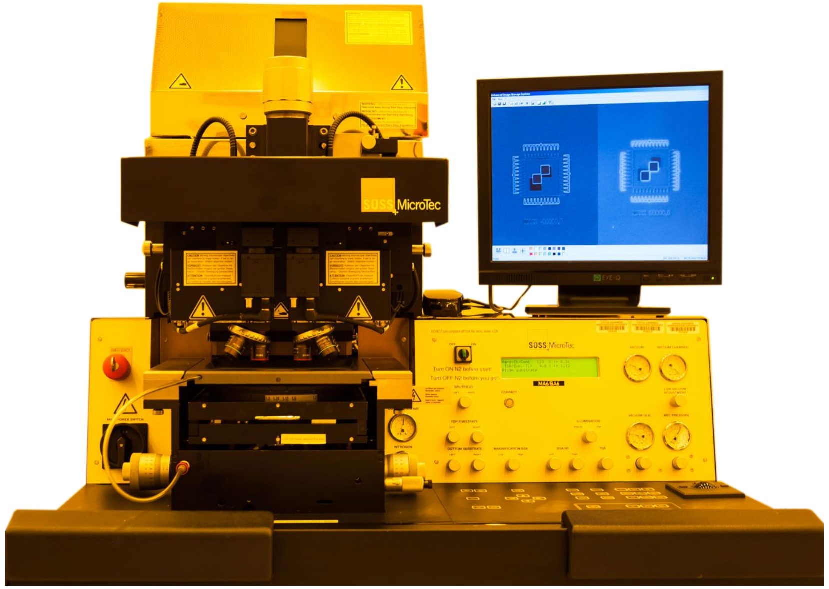
NUFAB tools : Contact Aligners

- Advanced contact modes
- UV lamp – 365 nm and 405 nm (h, i-line)
- Up to 6 inch wafer process
- Backside alignment

Suss MJB4

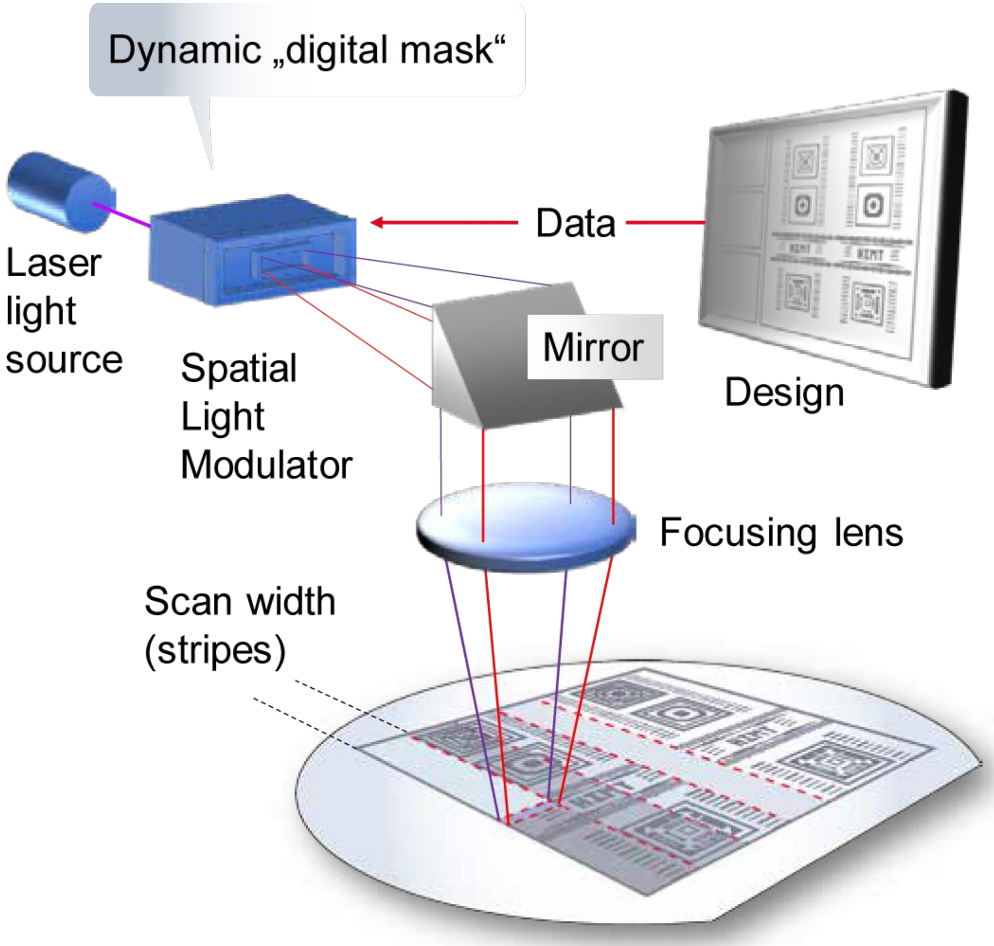


Suss MABA6



Digital age – “film to digital photography”

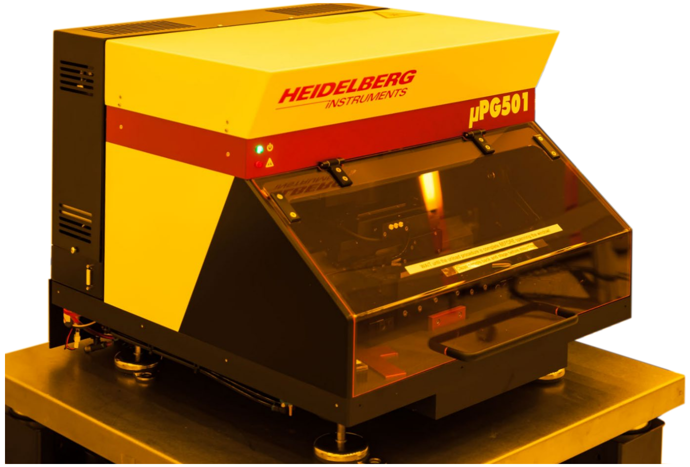
- Maskless lithography
  - Eliminates the need of fabrication of a mask
  - Fast and dynamic
  - Suitable for prototyping and rapid optimization



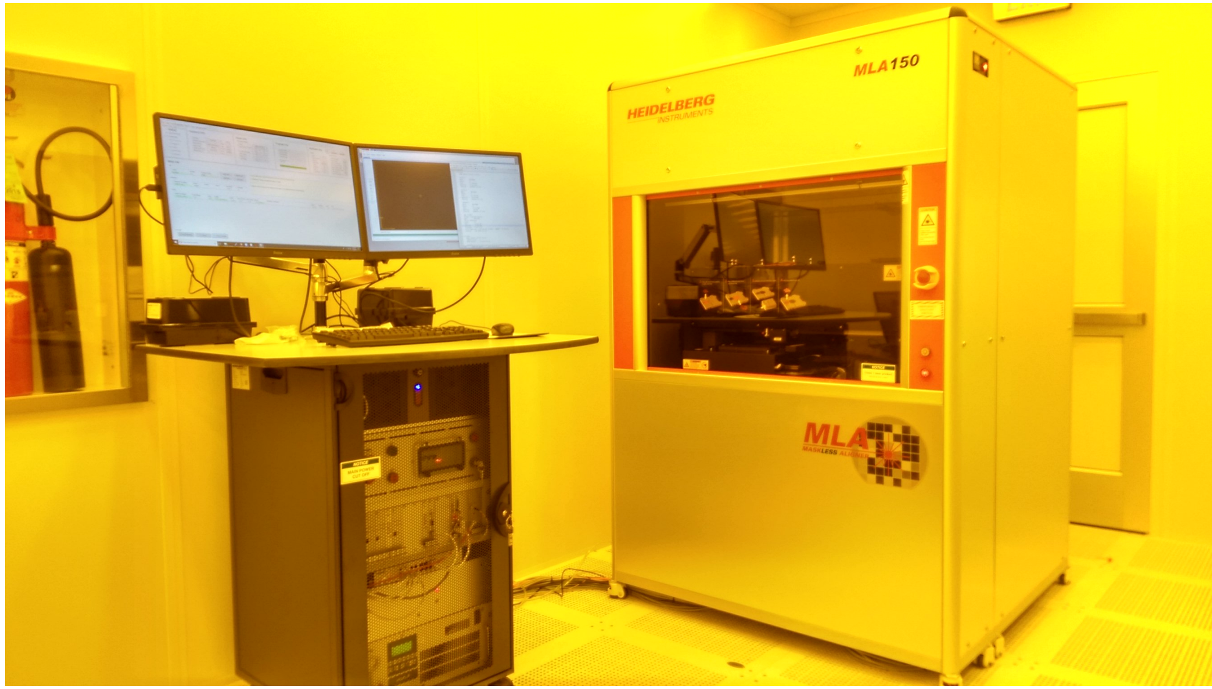
NUFAB tools: Maskless Aligners

- 375, 395 and 405 nm lasers
- Up to 150 x 150 mm writing area
- Backside alignment

Heidelberg uPG 501



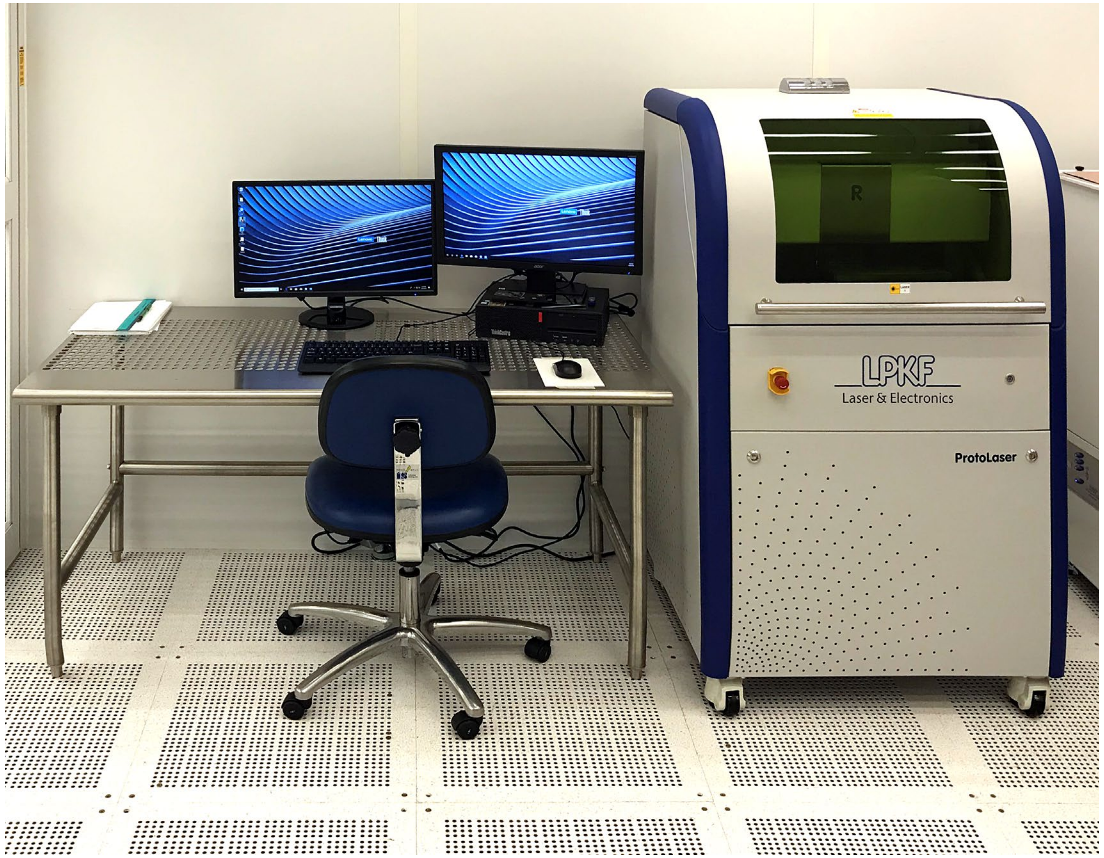
Heidelberg MLA150



NUFAB tools: Laser Cutter

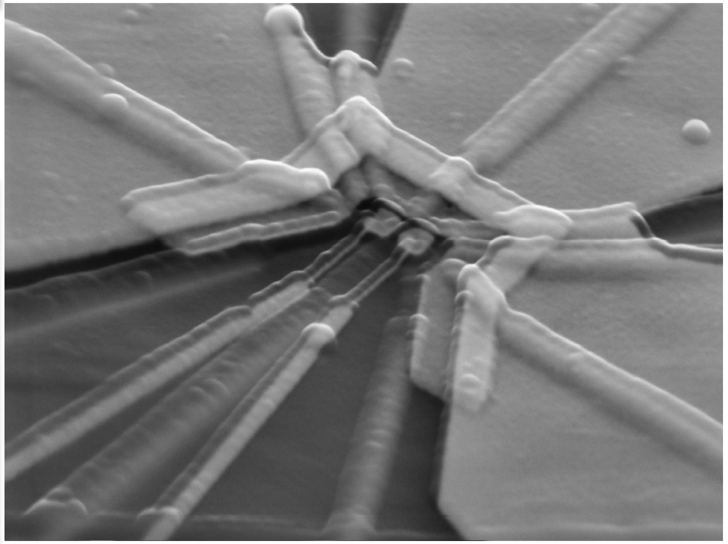
- Virtually anything can be cut
- ~20 um spot size
- 15 um lines can be cut depending on the material thickness

LPKF R Protolaser

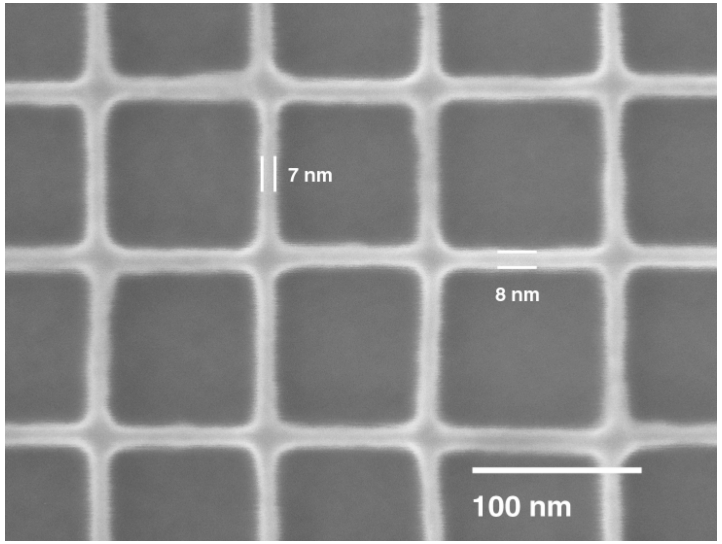


E-Beam Lithography

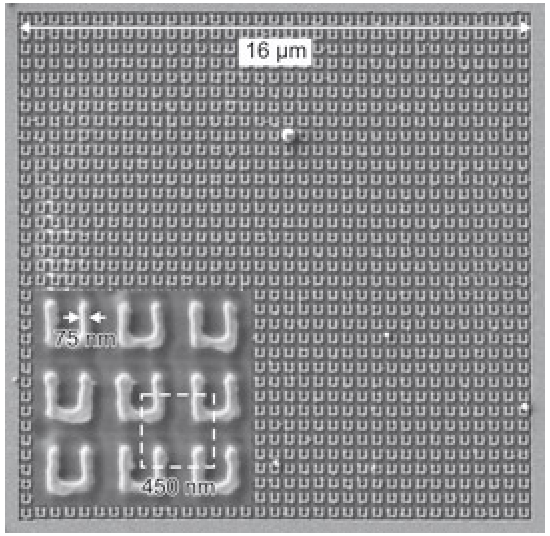
- Write using electrons
- Less than 10 nm resolution
- E-beam resist instead of photoresist: PMMA, ZEP



Quantum electronics



Plasmonics



Metamaterials

E-beam Lithography

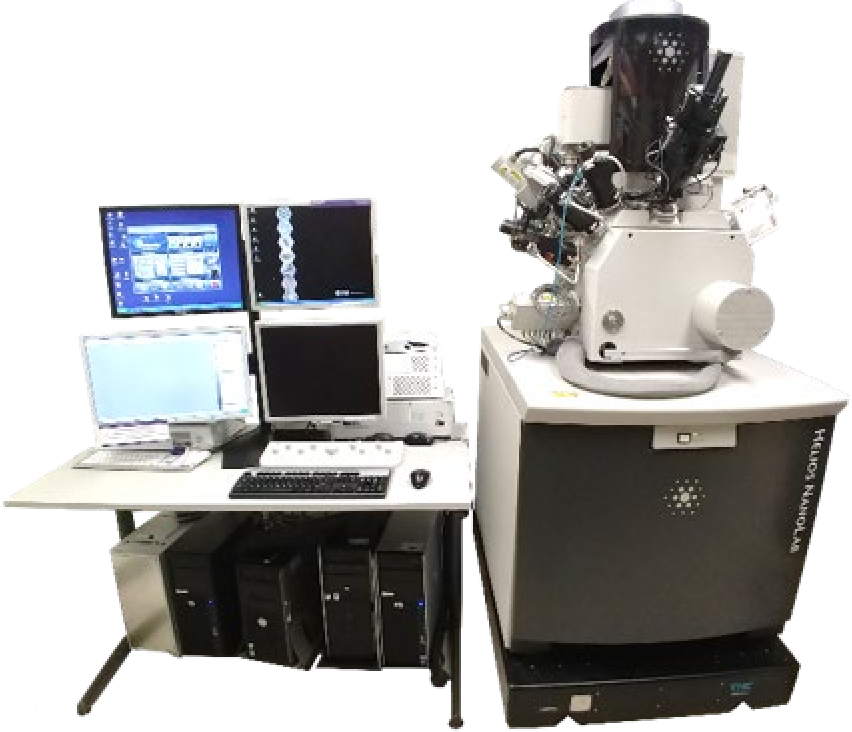
FEI Quanta with NPGS in EPIC Facility

NUFAB's Prospective Direct Write EBL system

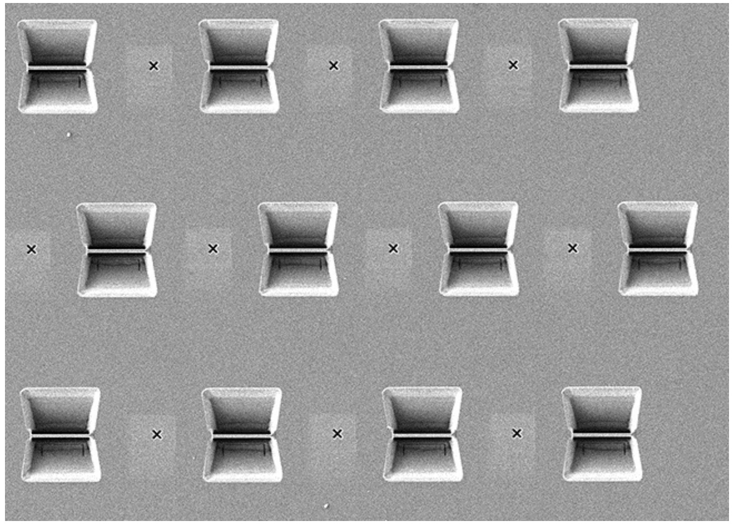
eBL
MRI Funded
Coming Soon ….

Focused Ion Beam Milling

- Scribes using ions
- High resolution etching

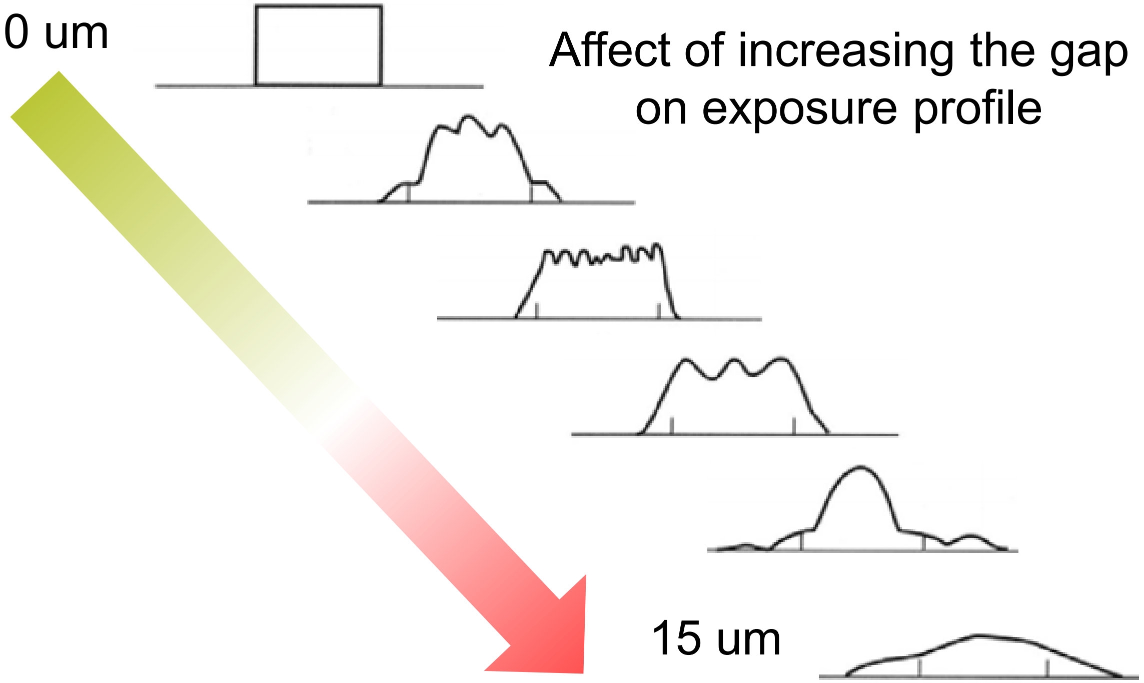


FEI Helios FIB
in EPIC facility



Advanced topics: Optical limit

- Diffraction is the main limiting factor for better resolution



Affect of increasing the gap on exposure profile

$$Min\ Feature\ Size \propto \sqrt{k \times \lambda \times gap}$$

k: constant
λ: wavelength

Minimum size (um)	Gap (um)
2.7	20
1.9	10
1.35	5
0.6	1

Advanced topics: Material limit

Not all photoresists produce the same resolution due to different polymerization/crosslinking.

- Each photoresist has different aspects ratio capability
  - Most have at least aspect ratio of 2, Shipley S1800 series, AZ 5200 series
  - Some have larger than 5, such as SU8 variants

NUFAB recommends using a photoresist thickness of at most half of the required minimum feature size to beginners and for most R&D applications as there are other factors involved.

Remarks

- The fundamental limit of optical lithography is not determined by the optical system/lithography technique alone but rather is an overall contributions from the **optics, resist, develop and etching processes.**
- **Process window**: Capability of printing small features does not always guarantee a good quality and a repeatable and controllable patterning.
- **Alignment**: Alignment to the underlying layer is equally as important as the optics.

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Questions?

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