Outline

1 Introduction

2 Basic IC fabrication processes

3 Fabrication techniques for MEMS

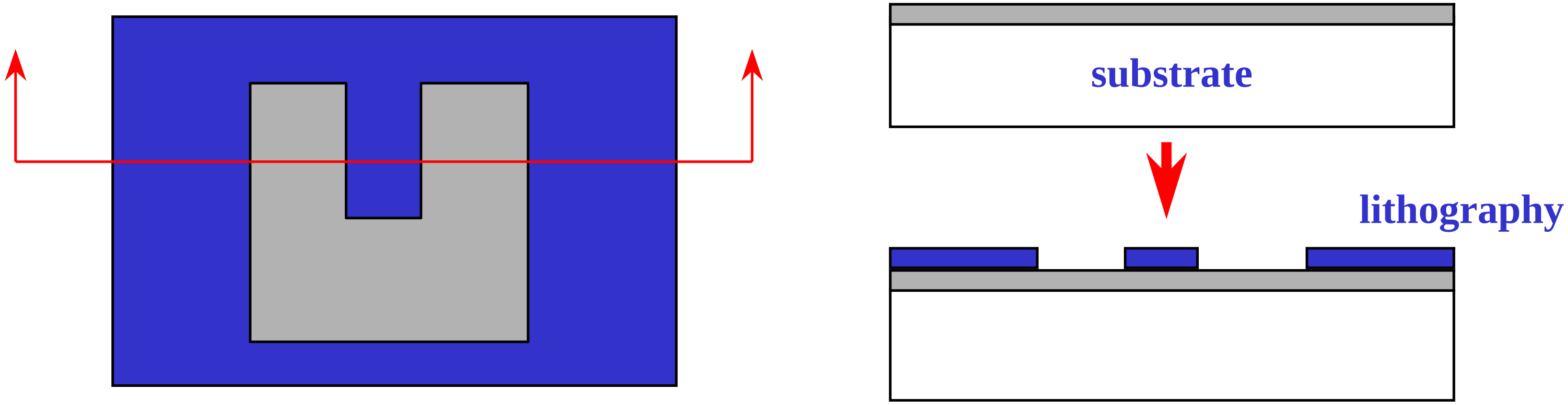
4 Applications

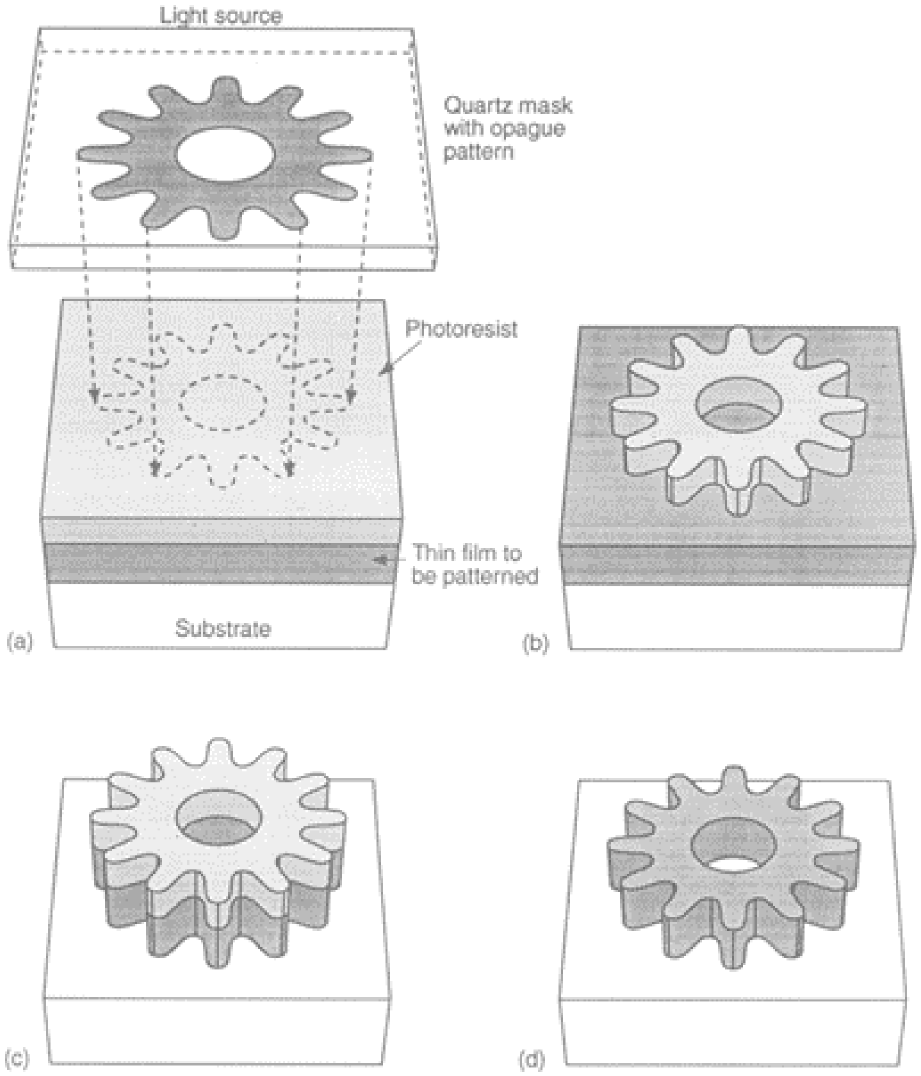
5 Mechanics issues on MEMS

2.2 Lithography

Reading: Runyan Chap. 5, or 莊達人 Chap. 7, or Wolf and Tauber Chap12~14

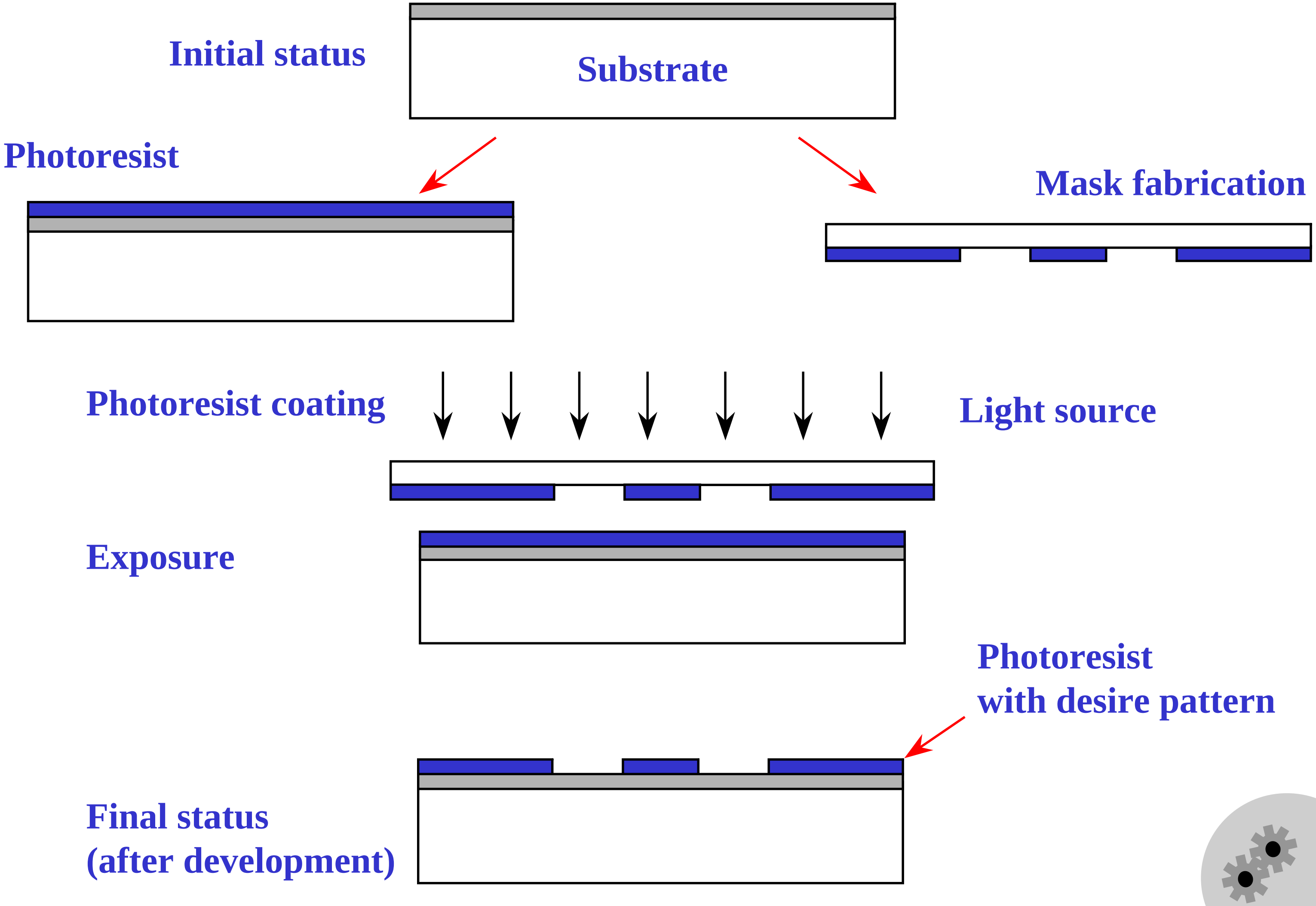
- Lithography is the process to define the desired pattern on thin films or substrates





Semiconductor sensor edited by S.M. Sze, 1994

Basic steps of lithography



Initial status

Substrate

Photoresist

Mask fabrication

Photoresist coating

Light source

Exposure

Photoresist
with desire pattern

Final status
(after development)

2.2.1 Photoresist (PR)

- The PR is a photosensitive organic material which contains three ingredients

  + resin - solvable in aqueous developer

  + sensitizer - photosensitive but insolvable in aqueous developer

  + solvent - keep the resist in liquid state until it is coated to the substrate

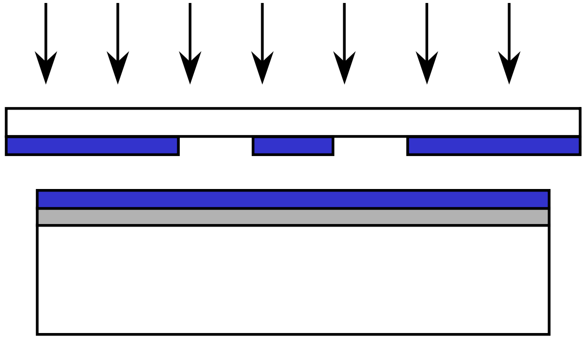
- The major functions of PR are

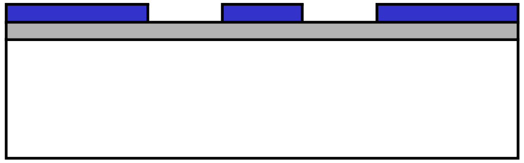
  + Precise pattern transformation

  + Protection of the thin film (or substrate) underneath during etch

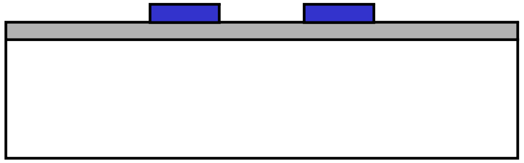
- **Positive and negative resist**
- **The following discussions are mainly focused on the positive photoresist**

Exposure





Positive photoresist



Negative photoresist

Basic Steps in PR Processing

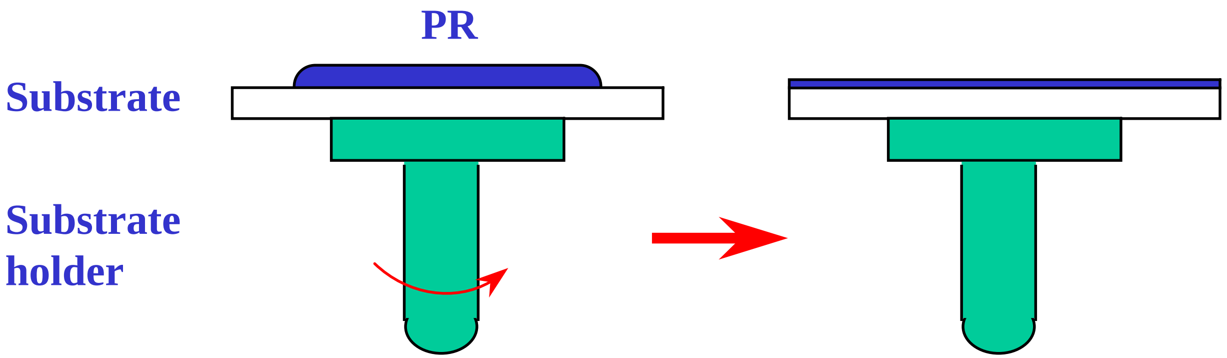
Step 1 Dehydration baking

Dehydration baking is to remove the moisture absorbed by the substrate from the atmosphere. Therefore the adhesion can be improved.

Step 2 Coating photoresist

The PR is spin coated on the substrate surface. The thickness of the PR is determined by the spin rate and the viscosity of the PR.

In order to improve adhesion, hexamethyldisilazane (HMDS) is also spin coated onto the substrate before the PR.



Step 3 Soft bake

The substrate is baked near 90^{o}C to drive solvent out of the PR (from 20 ~ 30% to 4 ~ 7%) so that it can be properly exposed

Step 4 Exposure

The PR is exposed to a light source (usually Ultraviolet light) to define its pattern

Step 5 Development

After the PR is exposed, the regions without protecting by the mask will be removed by developer

Step 6 Hard bake

The substrate is baked at 90~120 C to

(1) Improve PR adhesion

(2) Increase the etch resistance of the PR

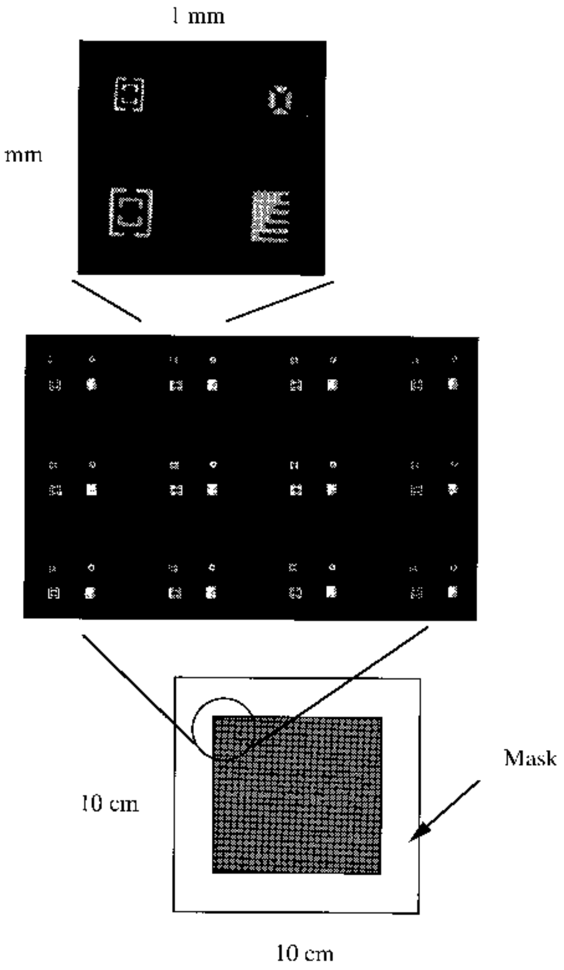
(3) Remove the solvent remain in the PR to prevent solvent-burst effect in the vacuum environment

* The PR will be very difficult to be removed if its post bake temperature is too high

2.2.2 Mask Fabrication

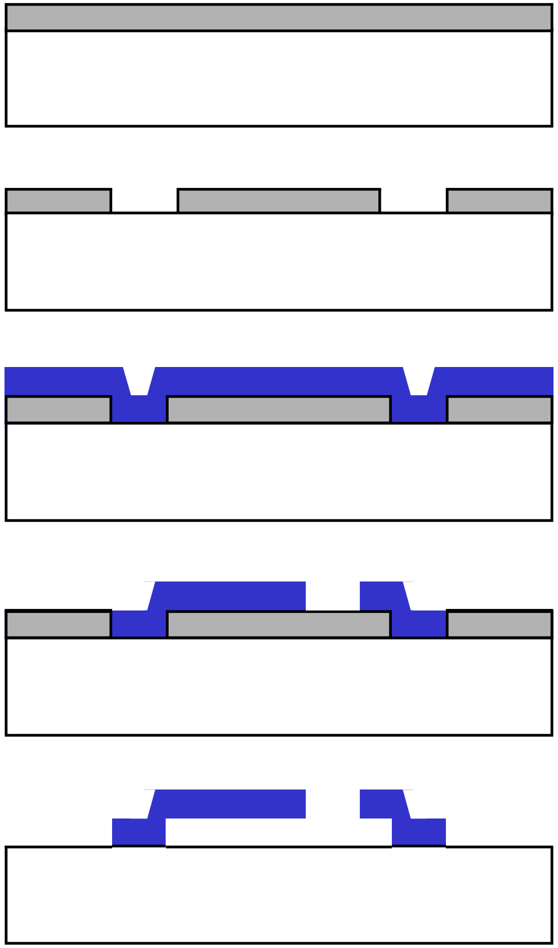
- Mask - a mask is defined as a pattern tool which contains patterns that can be transferred to an entire wafer in one exposure (Wolf and Tauber, 1986)

- Mask for single exposure process



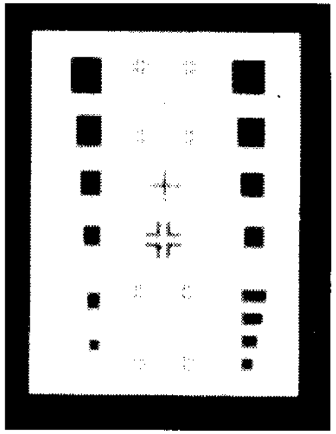
W. Fang, Ph.D. Thesis, 1995

- **Mask for multiple exposure process - alignment marks are necessary**

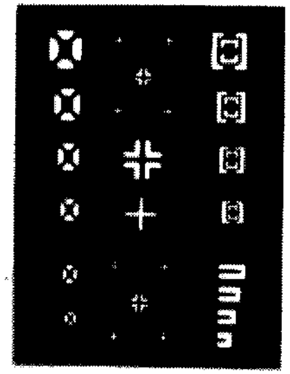


structure patterned by mask1

structure patterned by mask2

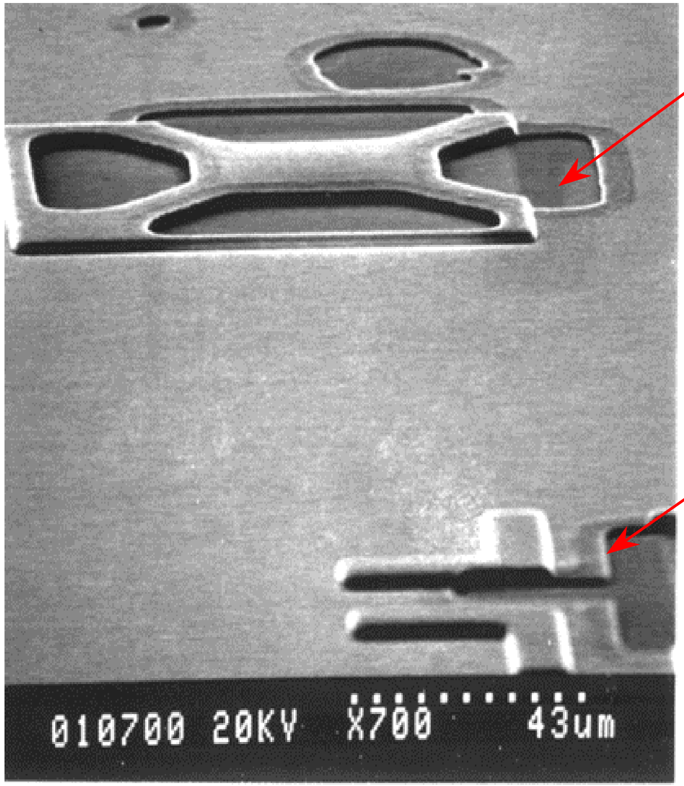


Mask 1



Mask 2

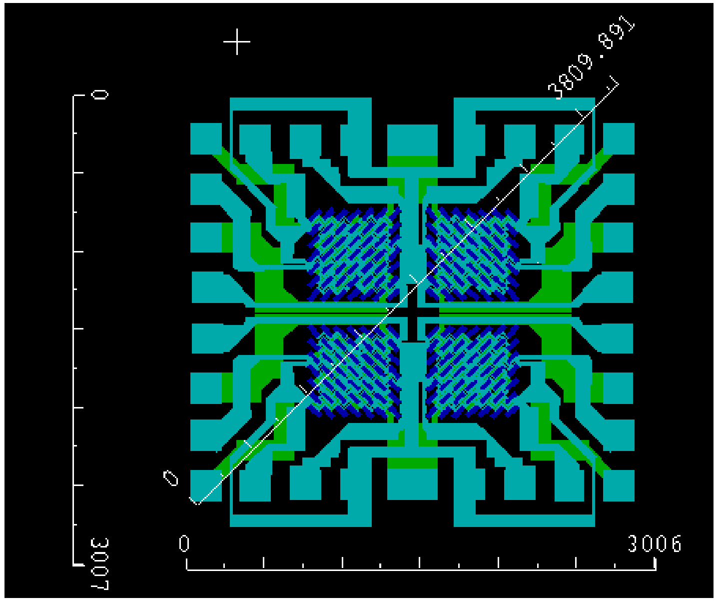
- **Misalignment of a surface micromachined suspension**



misaligned suspension

alignment key

W. Fang and J.A. Wickert, DSSC annual report, Carnegie Mellon University, 1993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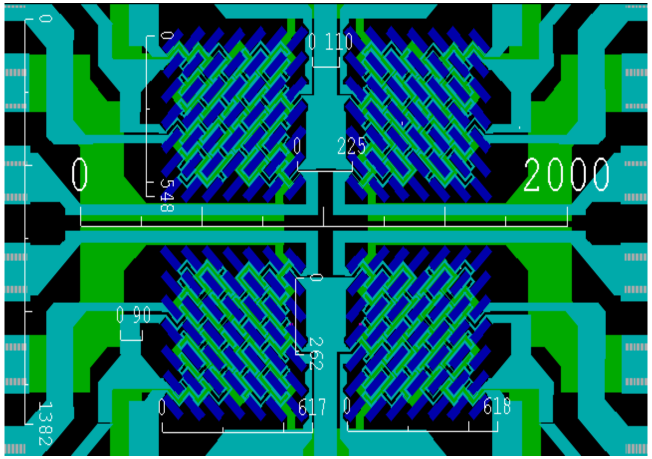
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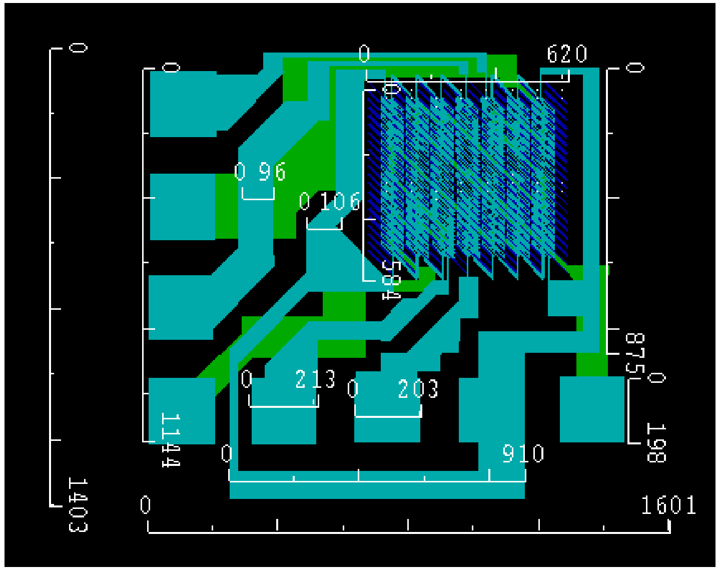
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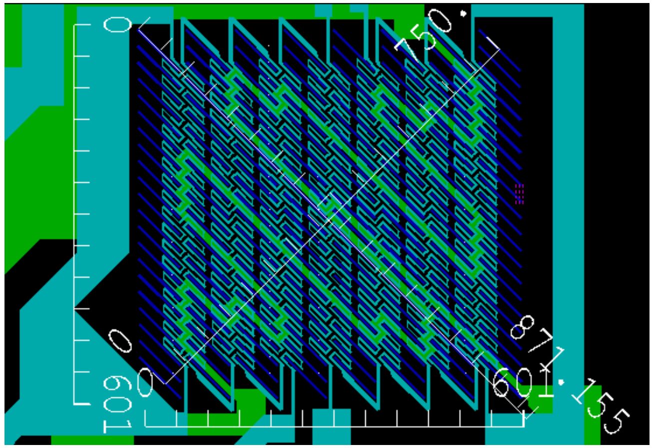
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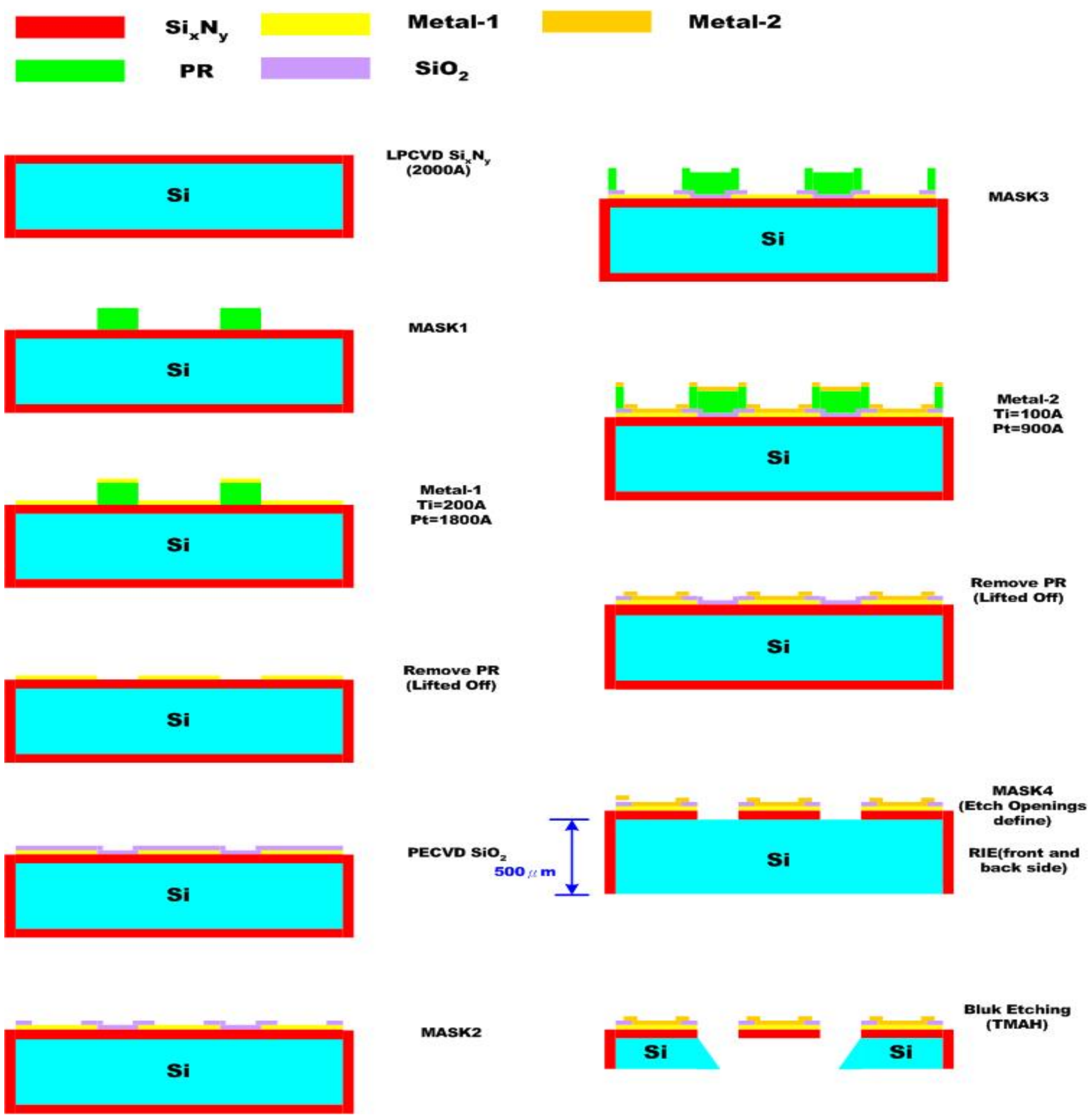
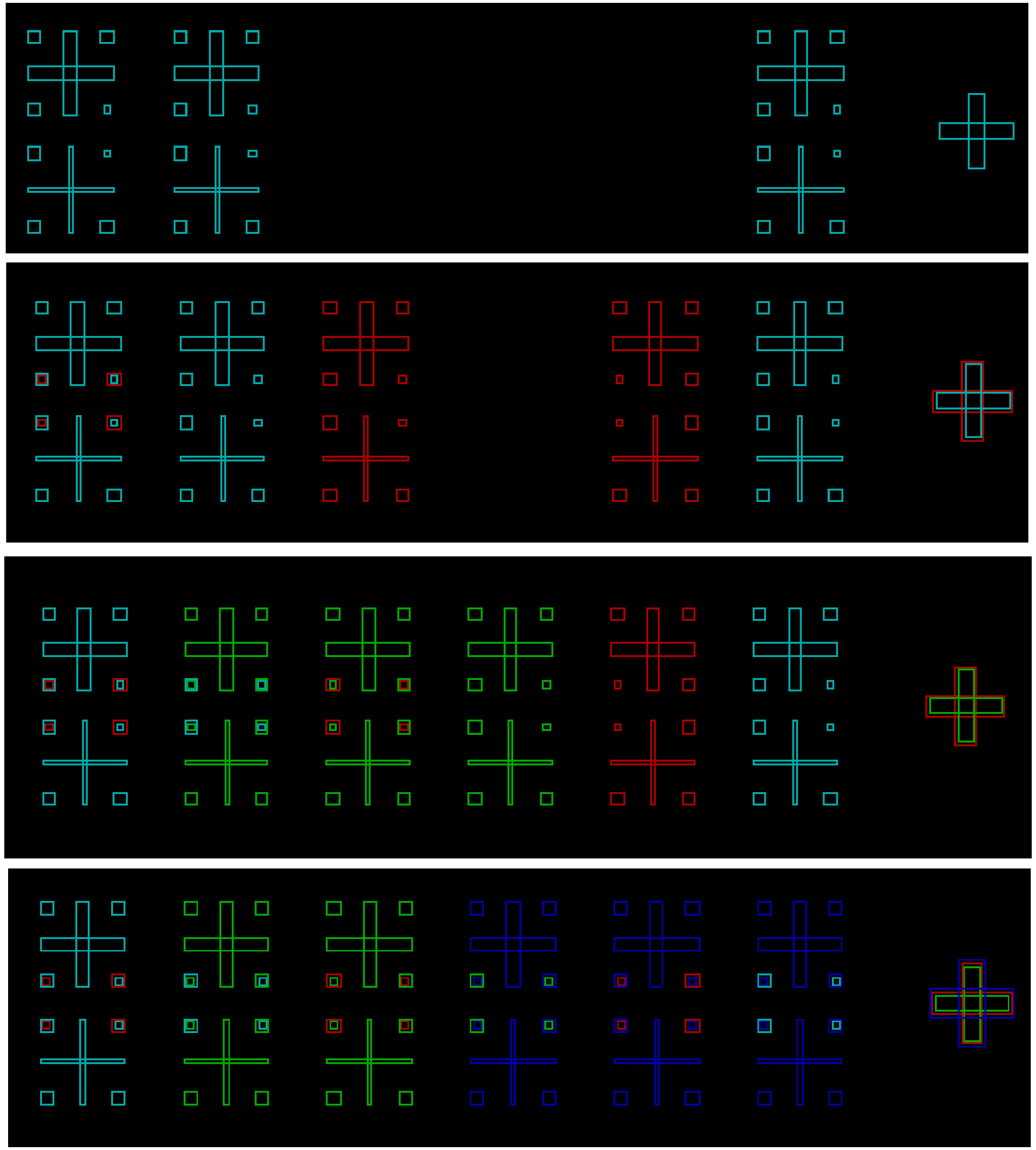
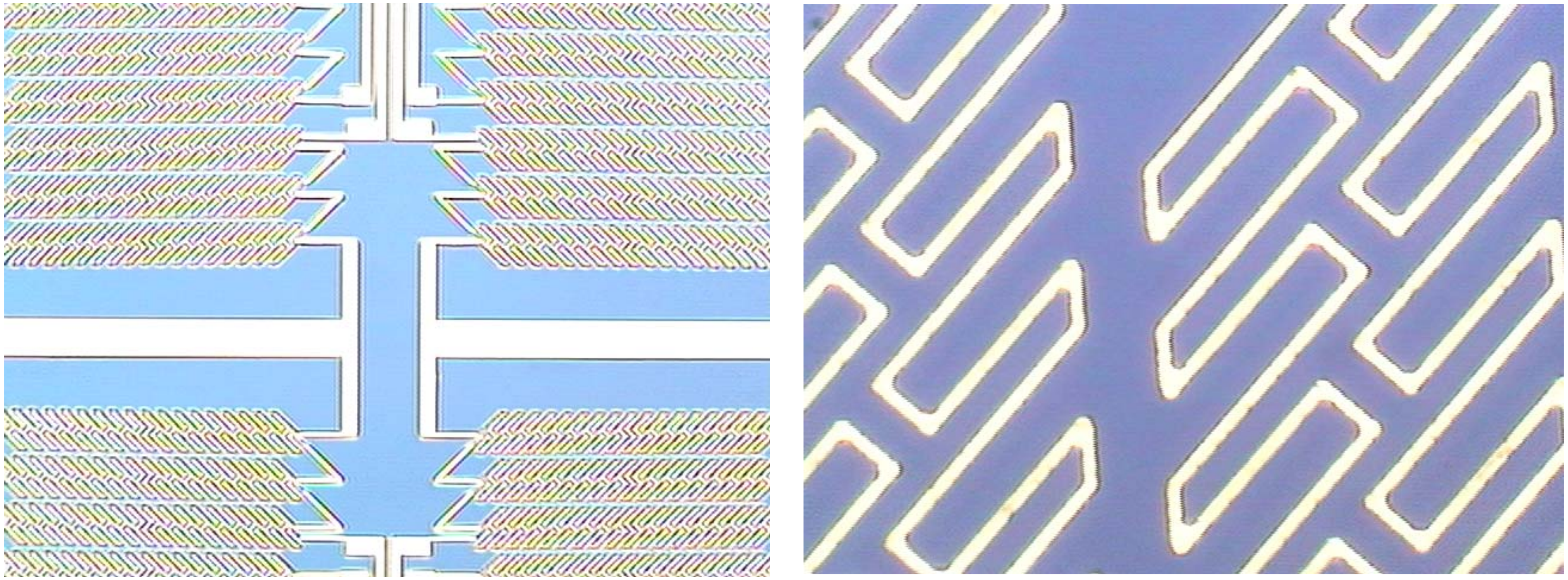
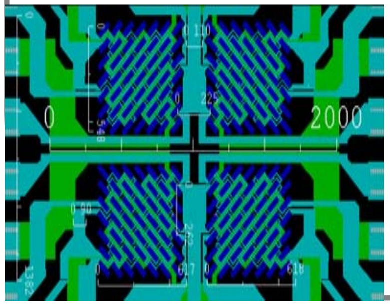
Microthermal Sensors Process Flow Chart





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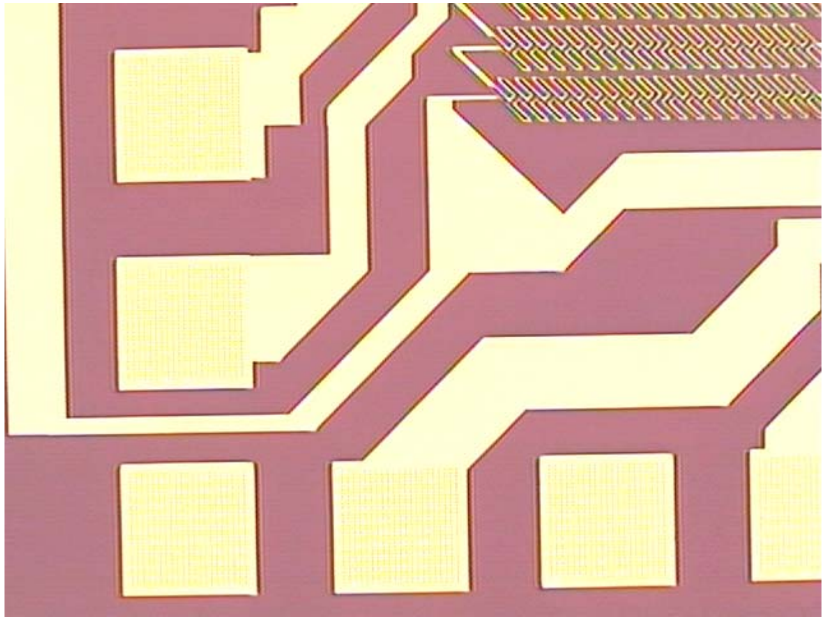

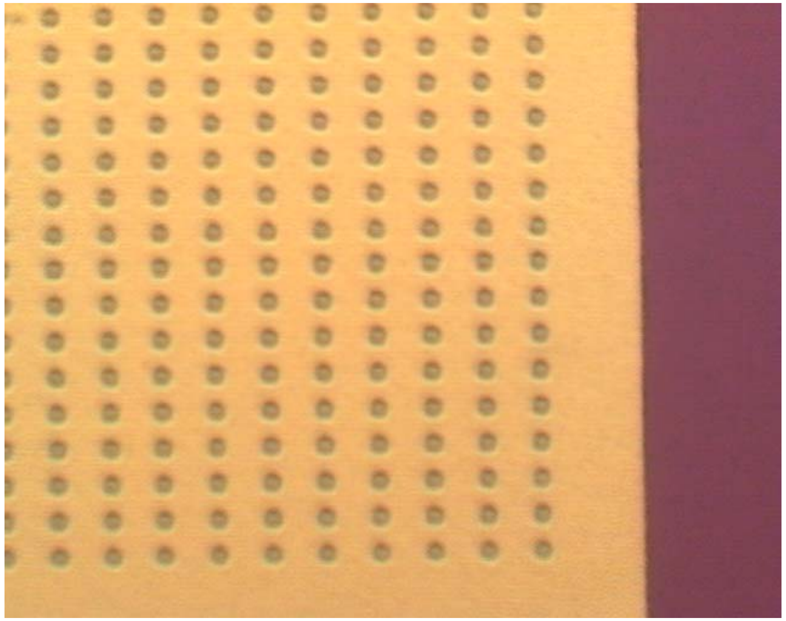

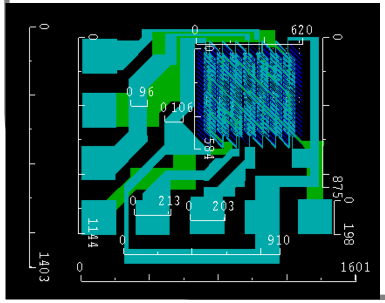
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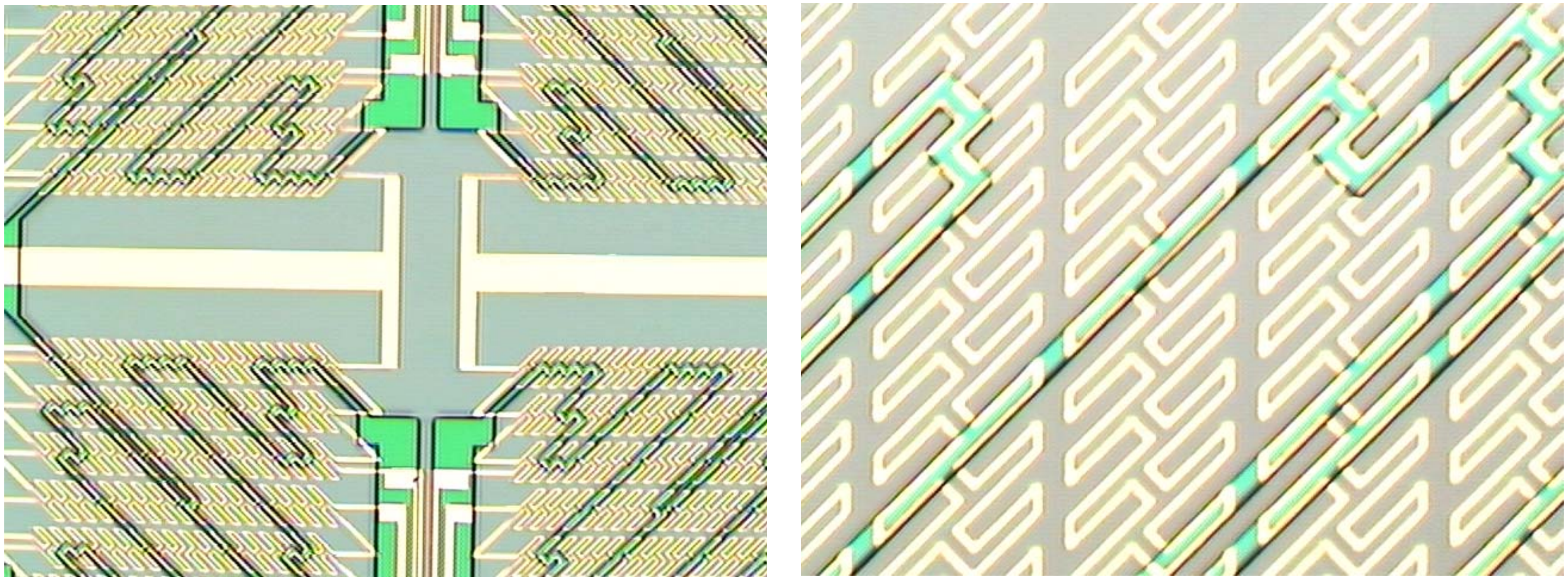

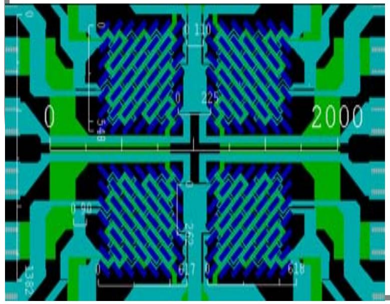
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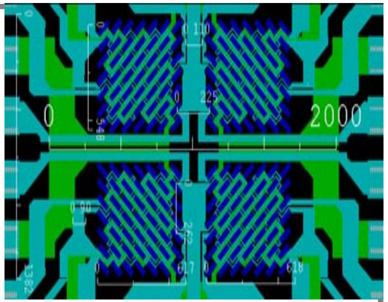
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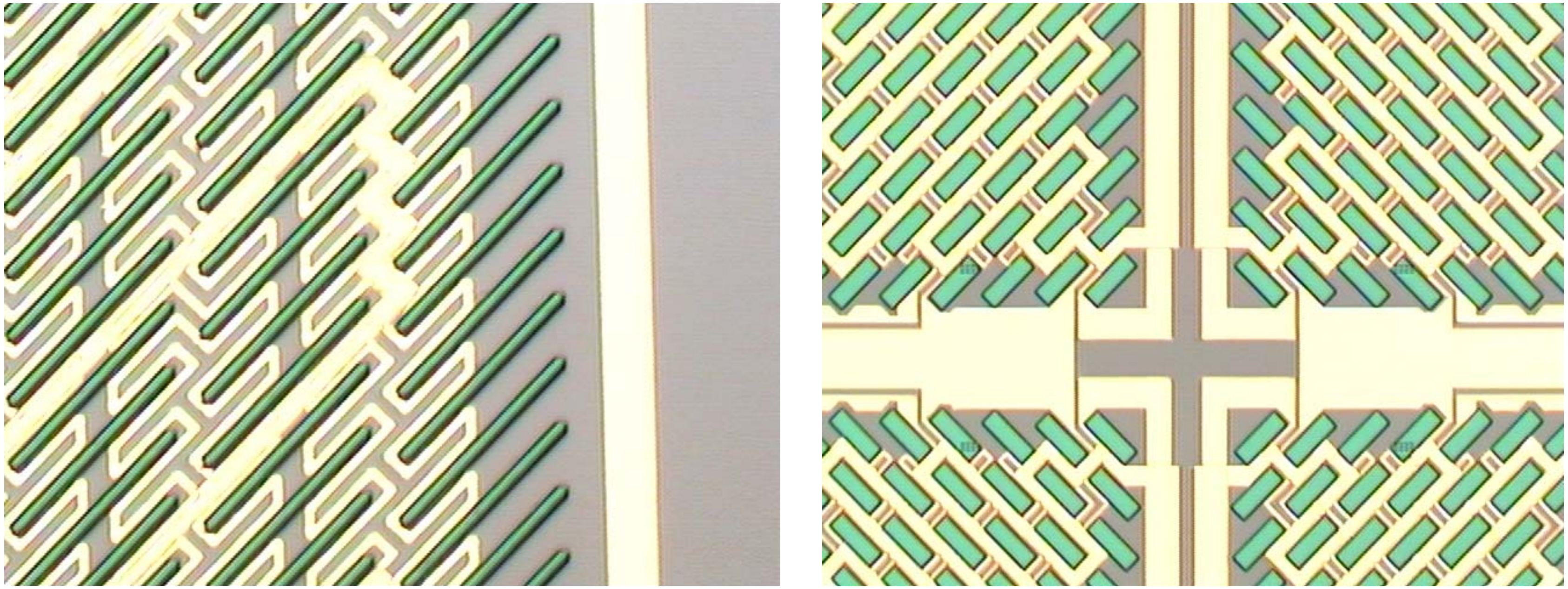

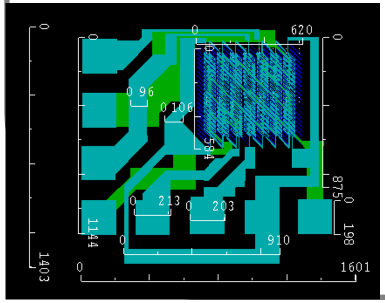
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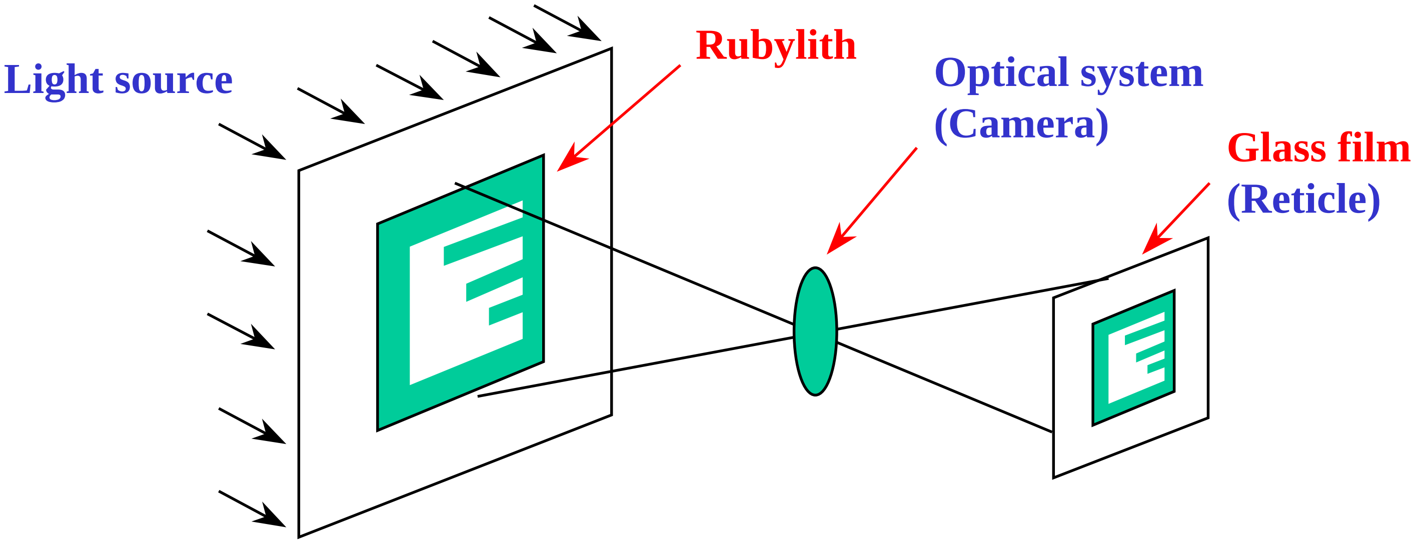
Photo reduction technique

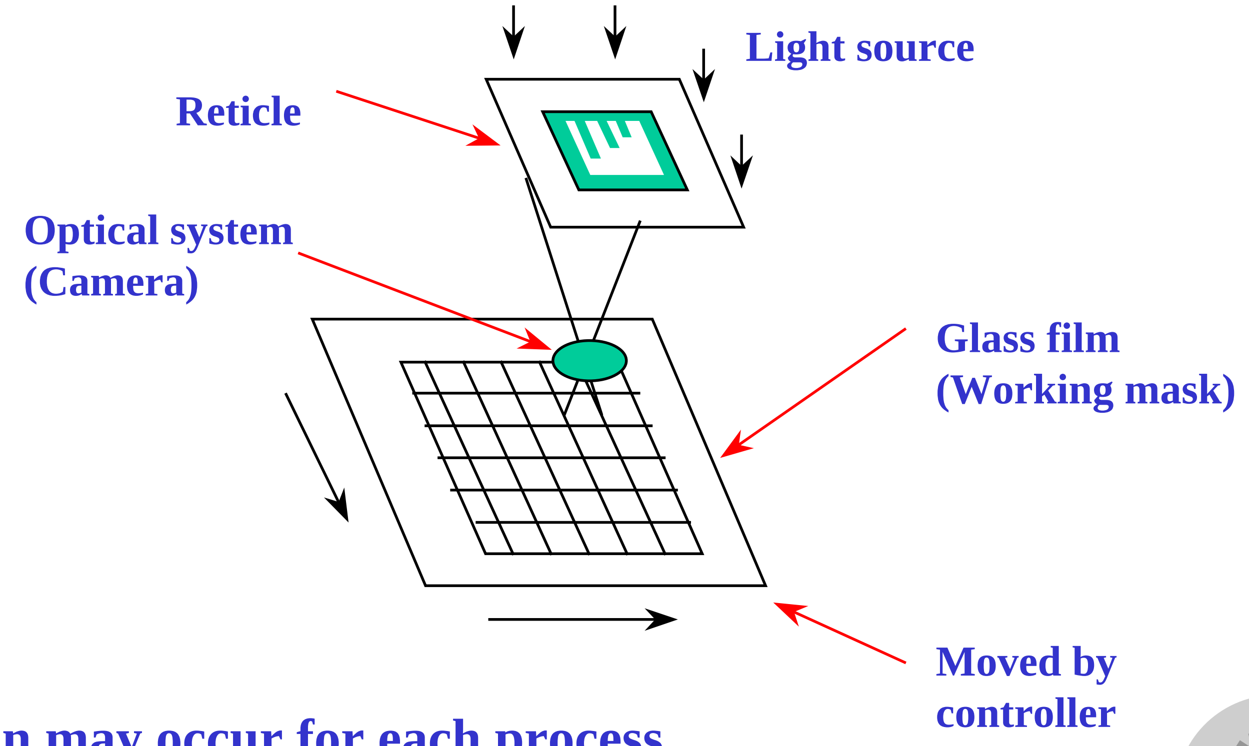
- Drawing the pattern
- Cut the desired pattern on **rubylith**
- Make the **reticle** by **photography**

+ The film of the camera is the mask

+ The size of the pattern is reduced after taking pitchure on the rubylith



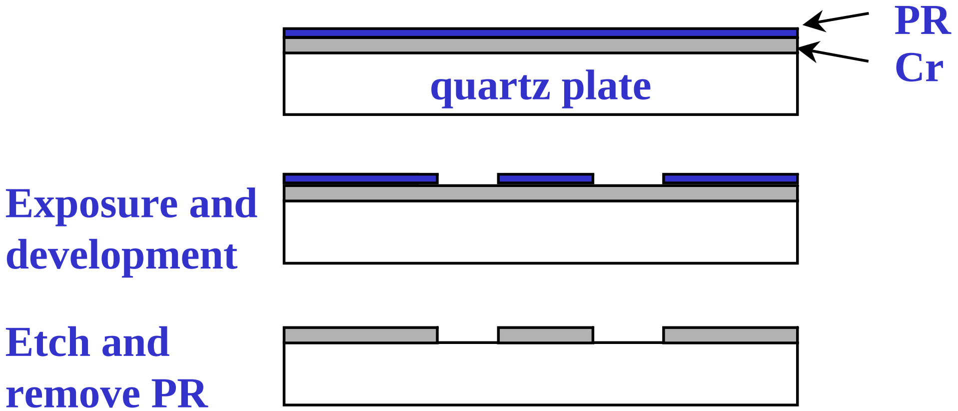
- The working mask is made by a step-repeat equipment (stepper)
  - + Place the first mask into the stepper
  - + The stepper will shrink and duplicate the pattern on the reticle

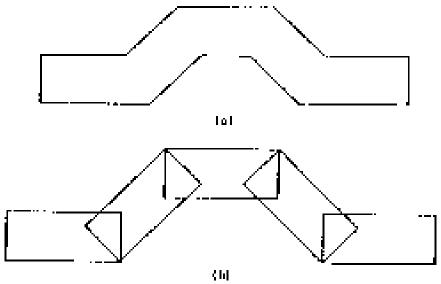


- Distortion may occur for each process

Optical pattern generation technique

- The mask fabricated through this technique is a glass (or quartz) plate with chromium (Cr) pattern on its surface
- The pattern is generated, stored, and transferred to a mask making machine by computer
- The desired pattern is decomposed into rectangles before transferred to the mask making machine

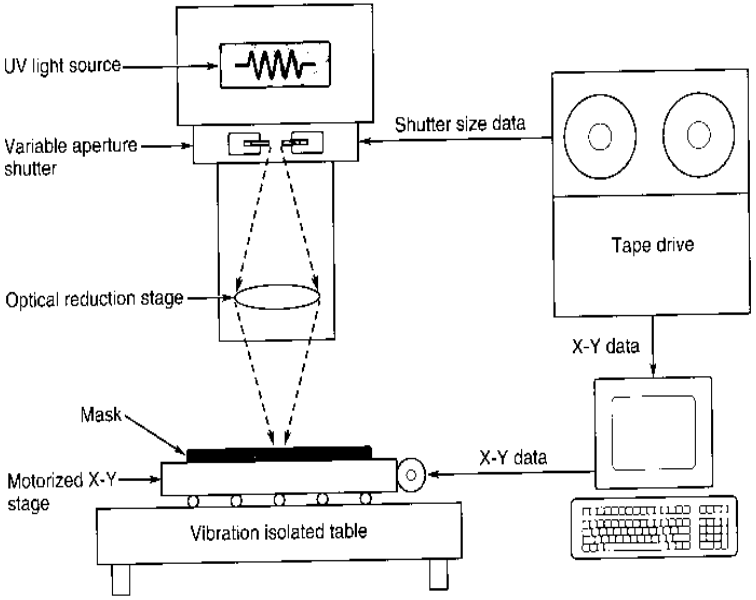




Wolf and Tauber, Silicon Processing for the VLSI Era Vol.1, 1986

- The dimension of rectangle is defined by the shutter. In addition, the shutter is able to give a desired angle for the rectangle by rotating
- The rectangles are positioned by a motorized X-Y stage
- The throughput of this technique depends on the complexity of the desired pattern
- The technique is applied to make reticle

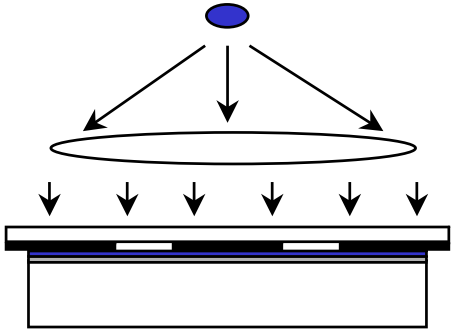
- The mask making machine



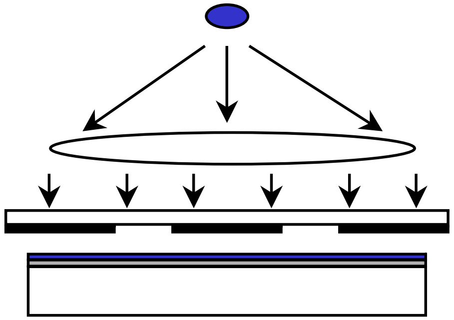
Semiconductor sensor edited by S.M. Sze, 1994

2.2.3 Exposure

- Contact exposure
  - + The earliest method
  - + The mask contacts with the substrate during exposure
  - + This method gives the most reliable transferred image
  - + The mask will be worn or contaminated after frequently contacting with the substrate



contact

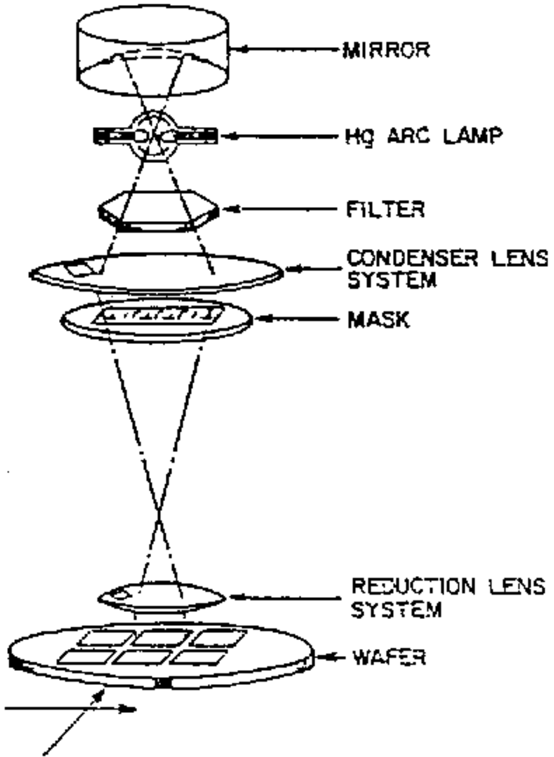


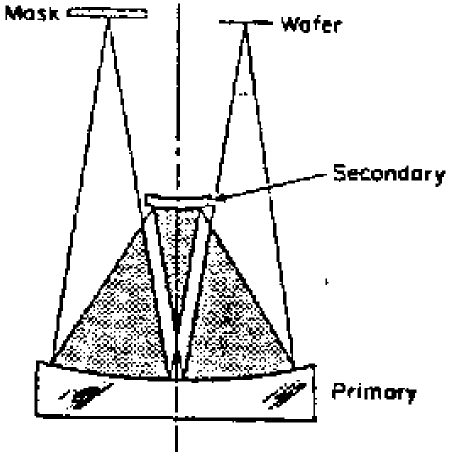
proximity

- Proximity exposure
  - + The mask and substrate is close to each other but not contact
  - + The resolution is decreased as the separation is increased

- **Projection exposure**

  - **+ The mask and substrate is not contact**
  - **+ The resolution is outstanding**
  - **+ Multiple exposure is required to expose the whole substrate**

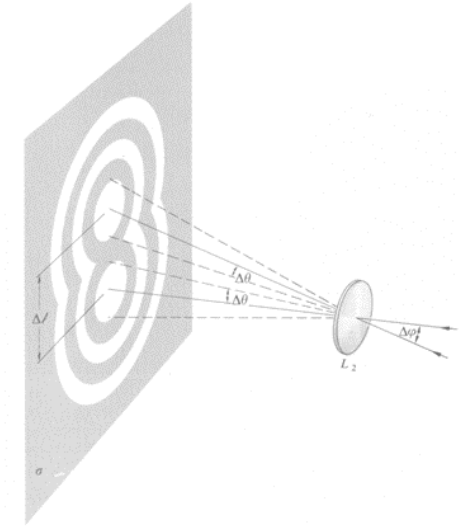


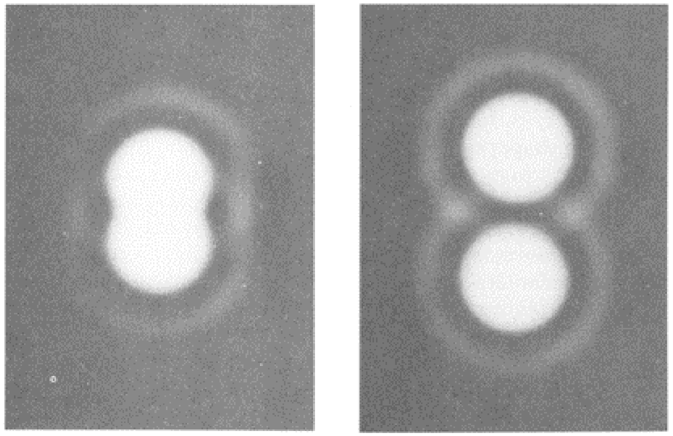


Wolf and Tauber, Silicon Processing for the VLSI Era Vol.1, 1986

- **Important issues**

+ **Resolution : In general, the term resolution describes the ability of an optical system to distinguish closely spaced objects**





Hecht, Optics, 1987

- Here we refer to the minimum resolution of a lithography machine as the **minimum line width** or space that the machine can precisely print

The minimum line width:

1. For **contact** and **proximity** approaches:

$$L_m = \sqrt{\lambda g}$$

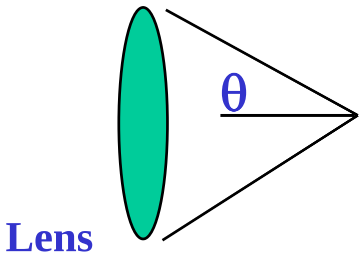
distance between mask and substrate

2. For **projection** approach:

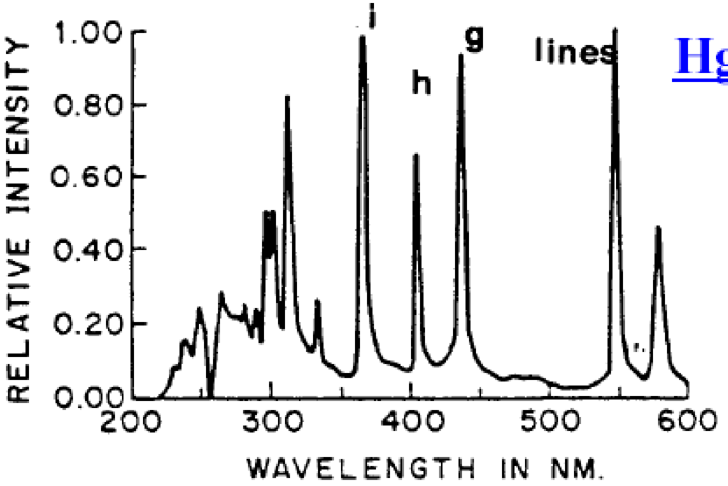
$$L_m = \frac{\lambda}{NA} = \frac{\lambda}{n\sin\theta}$$

numerical aperature

index of refraction



- **Optical sources**



Hg Lamp Spectrum

- Current lithography systems use the **high pressure Hg lamp** which has several lines with high intensity.
  - g-line (436 nm)
  - h-line (405 nm)
  - i-line (365 nm)
- The optical source being contemplated for future lithographic systems use **Excimer Lasers**
  - deep UV (308 nm -157 nm)
    - KrF (248 nm) - current generation
    - ArF (193 nm) - next generation

+ Contrast

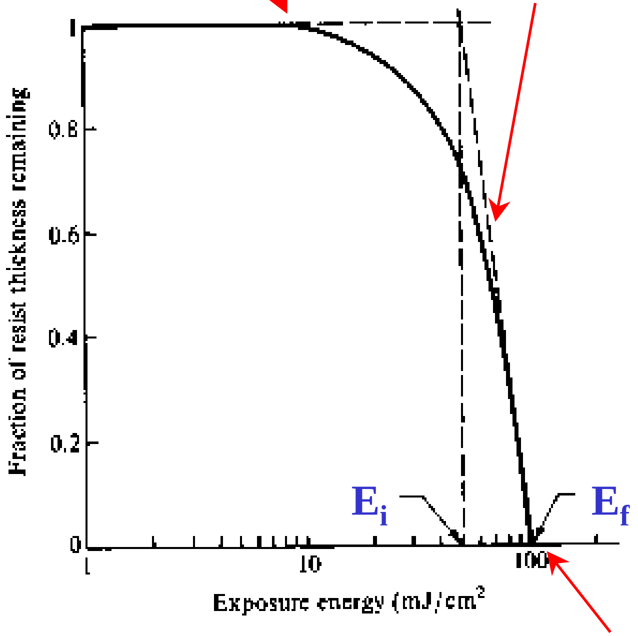
Resist contrast is a measure of the sharpness of the transition from exposure to non-exposure

E_i : the amount of energy required for the positive resist to just begin to break down (ideal case)

E_f : the minimum energy required for the positive resist to be completely removed

non-exposure

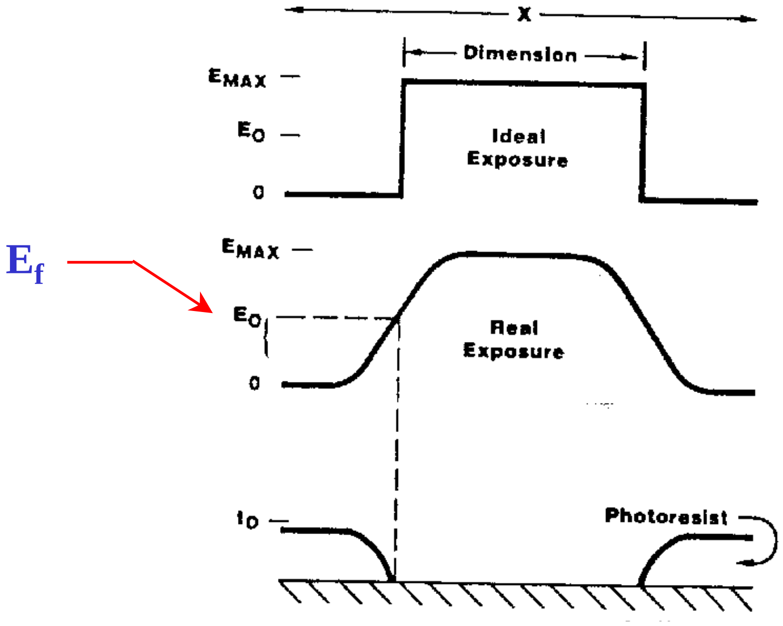
$$slope = \frac{1}{\log E_f - \log E_i}$$



fully exposure

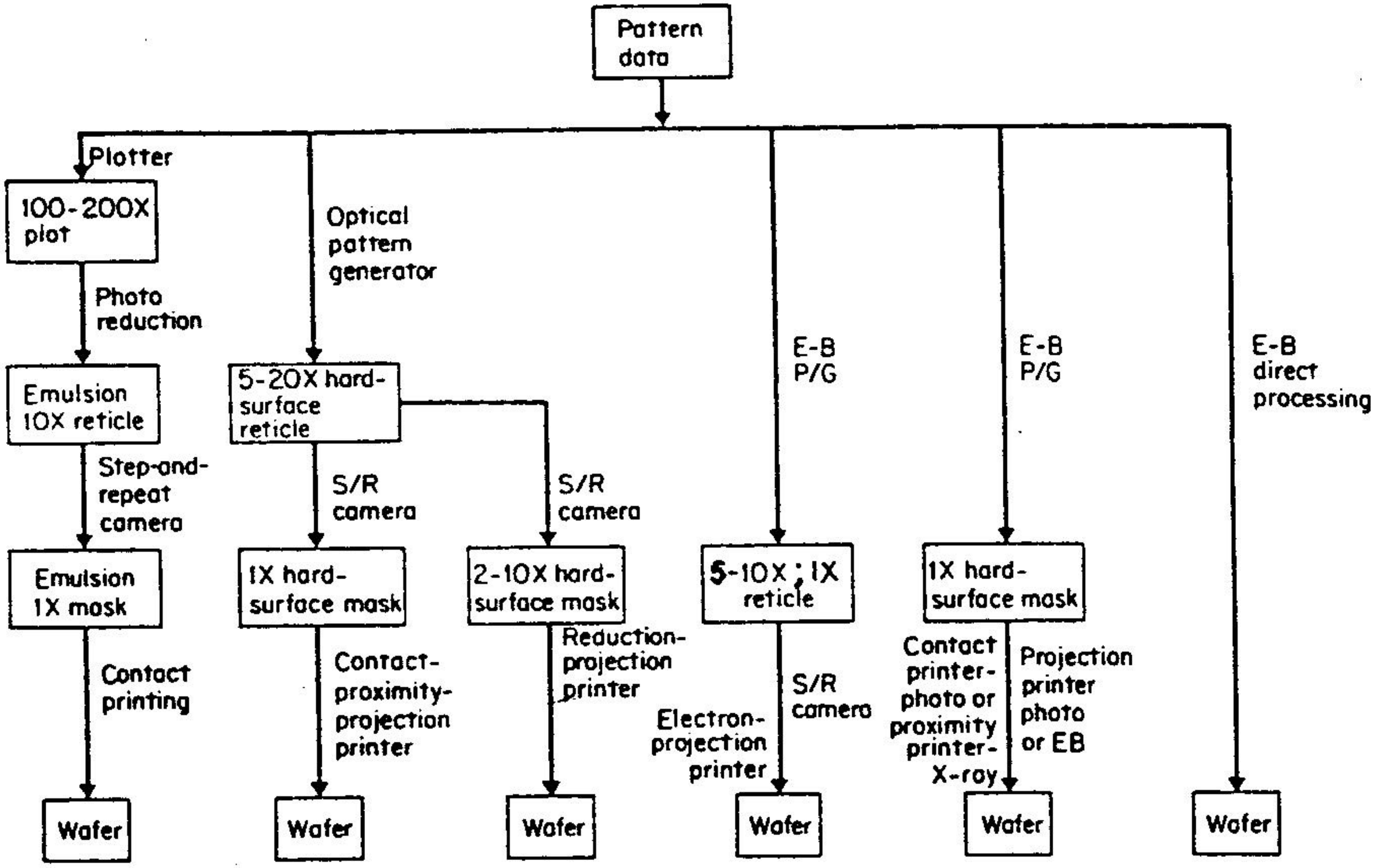
Runyan and Bean, Semiconductor Integrated Circuit Processing Technology, 1990.

+ The actual dimensions and slope of an exposed and developed resist



Wolf and Tauber, Silicon Processing
for the VLSI Era Vol.1, 1986

+ Adhesion : If the adhesion of thin film and photoresist is poor, the thin film protected by the photoresist will be attacked in the etching process



Wolf and Tauber, Silicon Processing for the VLSI Era Vol.1, 1986

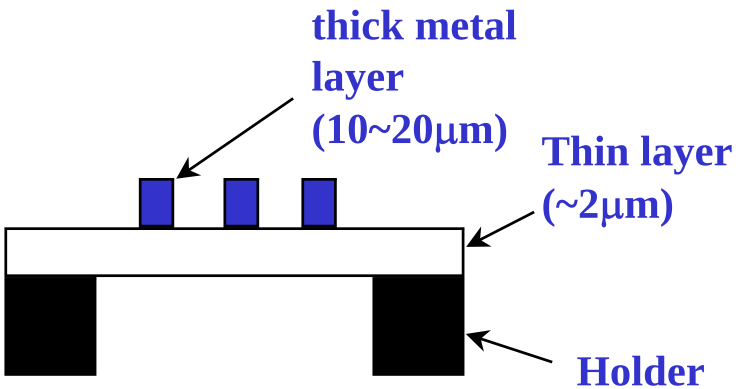
2.2.4 Advanced Lithography Techniques

- X-ray lithography

  + Short wavelength, high resolution

  + High throughput

  + Very difficult to make an X-ray mask



- Electron Beam (E-beam) lithography

  + Short wavelength, high resolution

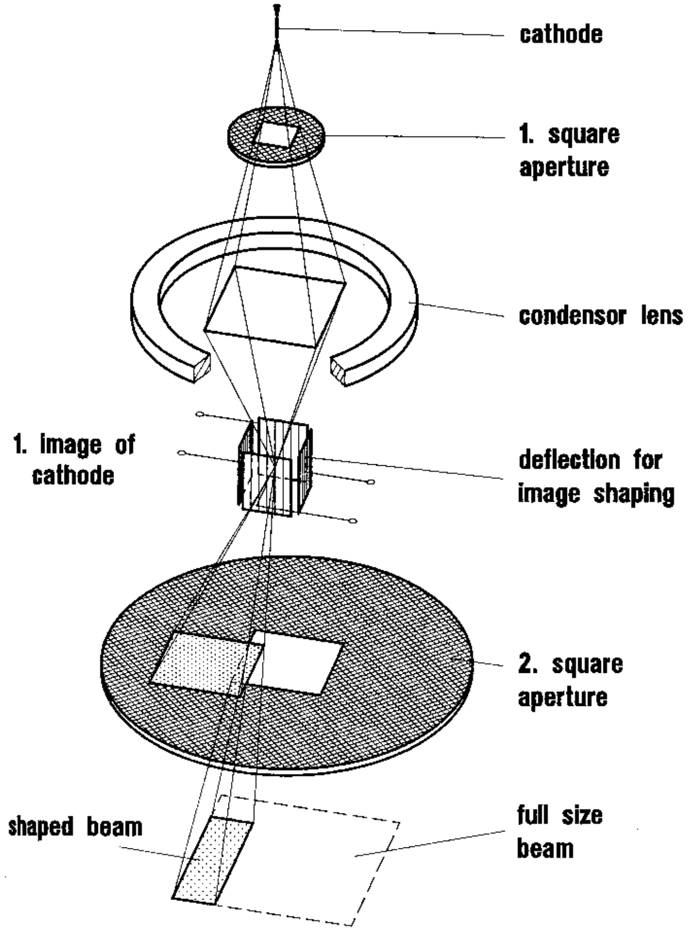
  + Direct writing the pattern on resist without mask is possible

  + Very low throughput

  + Expensive

Electron Beam Technique

- In this technique an electron beam is applied to write a pattern onto the resist of a mask
- The mask fabricated through this technique is also a glass (or quartz) plate with chromium (Cr) pattern on its surface, however the PR is replaced by the E-beam resist

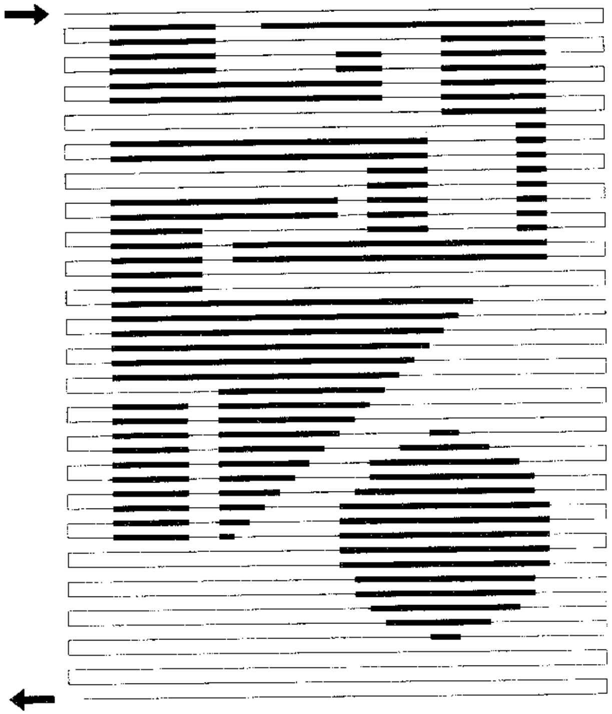


W. Menz, Microsystem Technology for Engineerings Intensive Course, 1994.

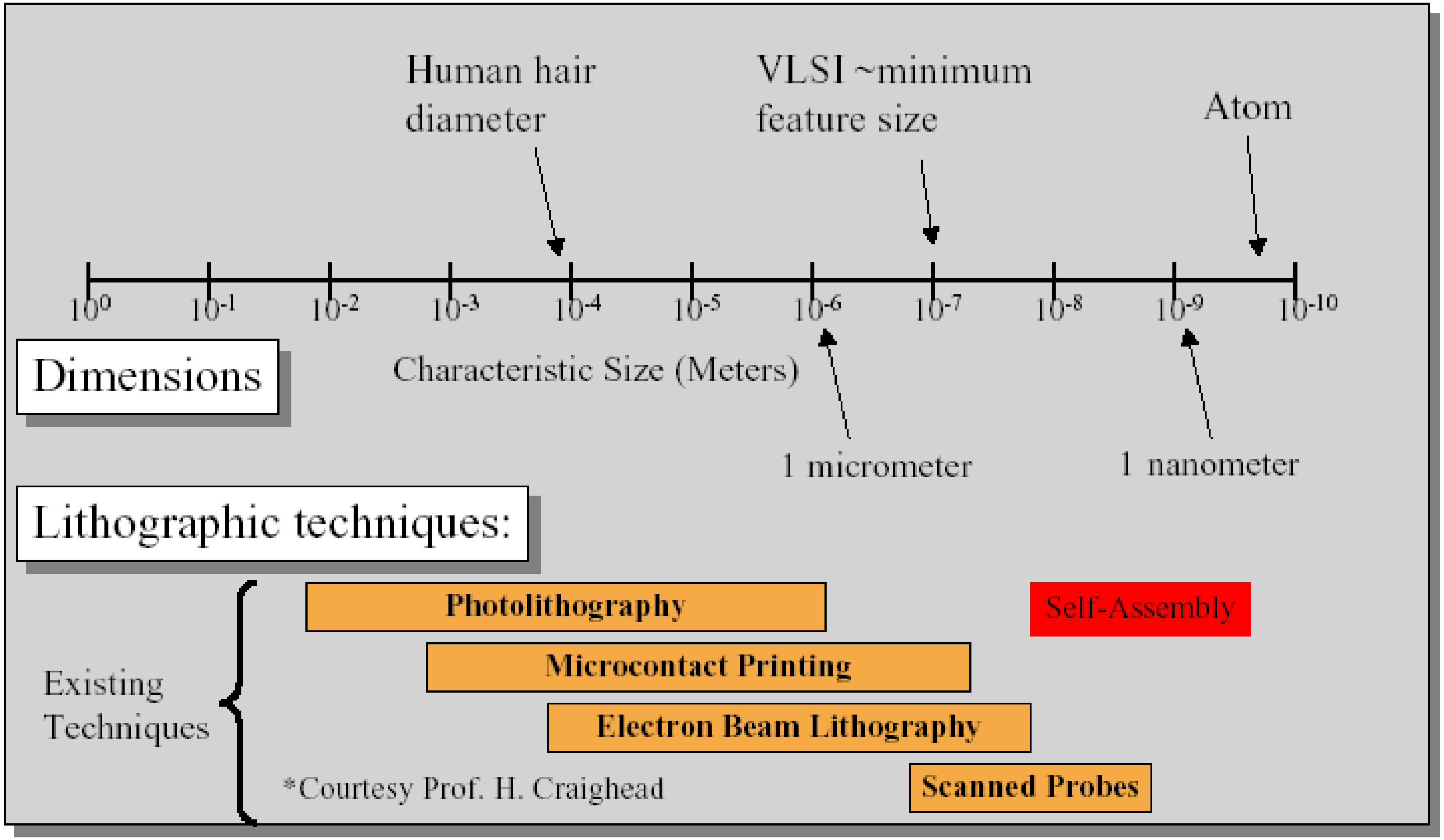
- The pattern is constructed by plenty of stripes which are defined by two aperatures

- No double exposed problem

- The throughput of this technique depends on the complexity of the desired pattern



W. Menz, Microsystem Technology for Engineerings Intensive Course, 1994.



Human hair diameter

VLSI ~minimum feature size

Atom

Dimensions

Characteristic Size (Meters)

1 micrometer

1 nanometer

Lithographic techniques:

Existing Techniques

Photolithography

Microcontact Printing

Electron Beam Lithography

Scanned Probes

Self-Assembly

*Courtesy Prof. H. Craighead

Conclusions

- The current lithography technique already satisfied the requirement for MEMS
- Compare with deposition, lithography is more straightforward, since there is less option
- The challenge of MEMS lithography : highly structured surface