Nanofabricação

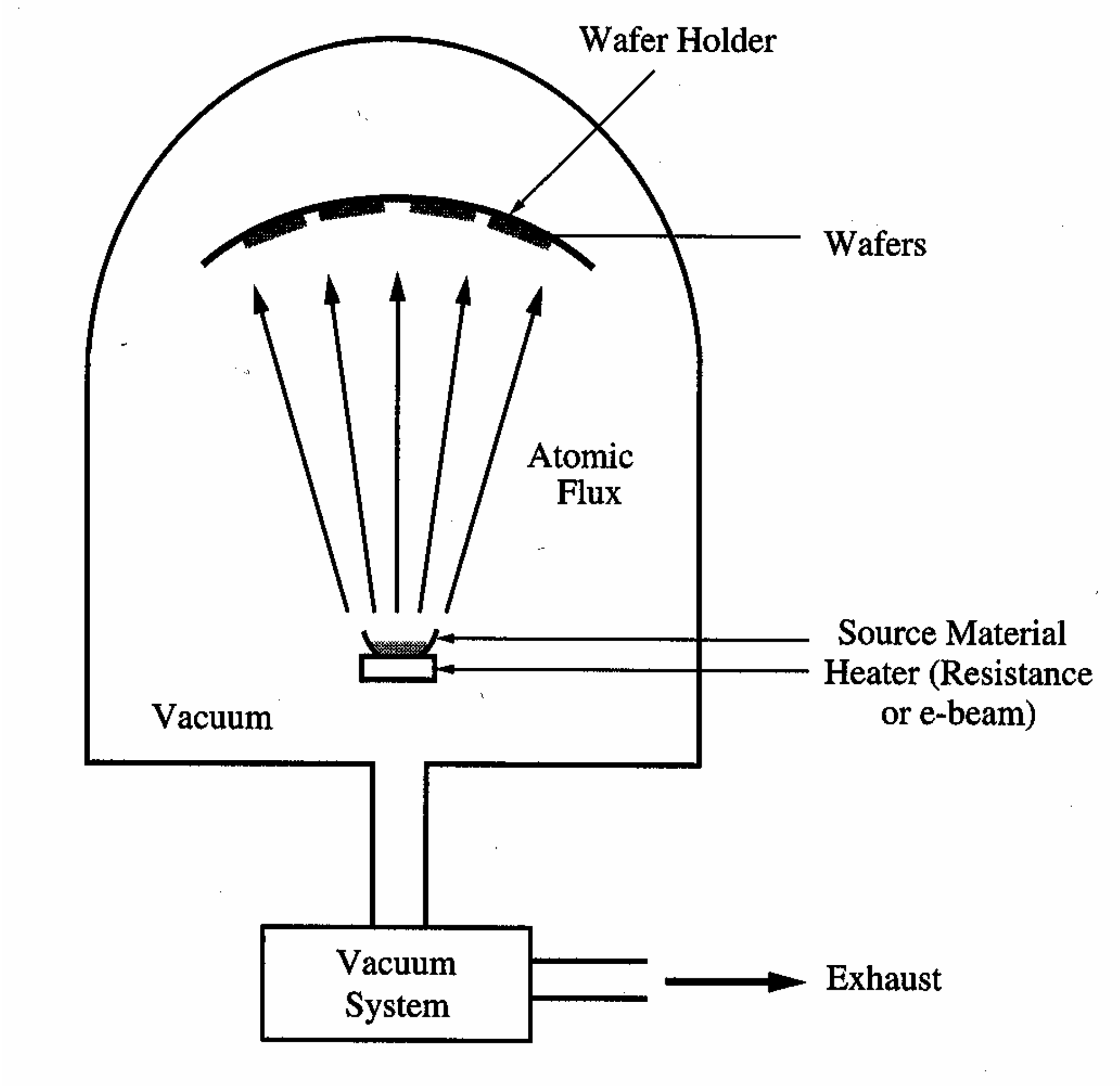
Aula 3 – Prof. Gomes

16 jul 2008

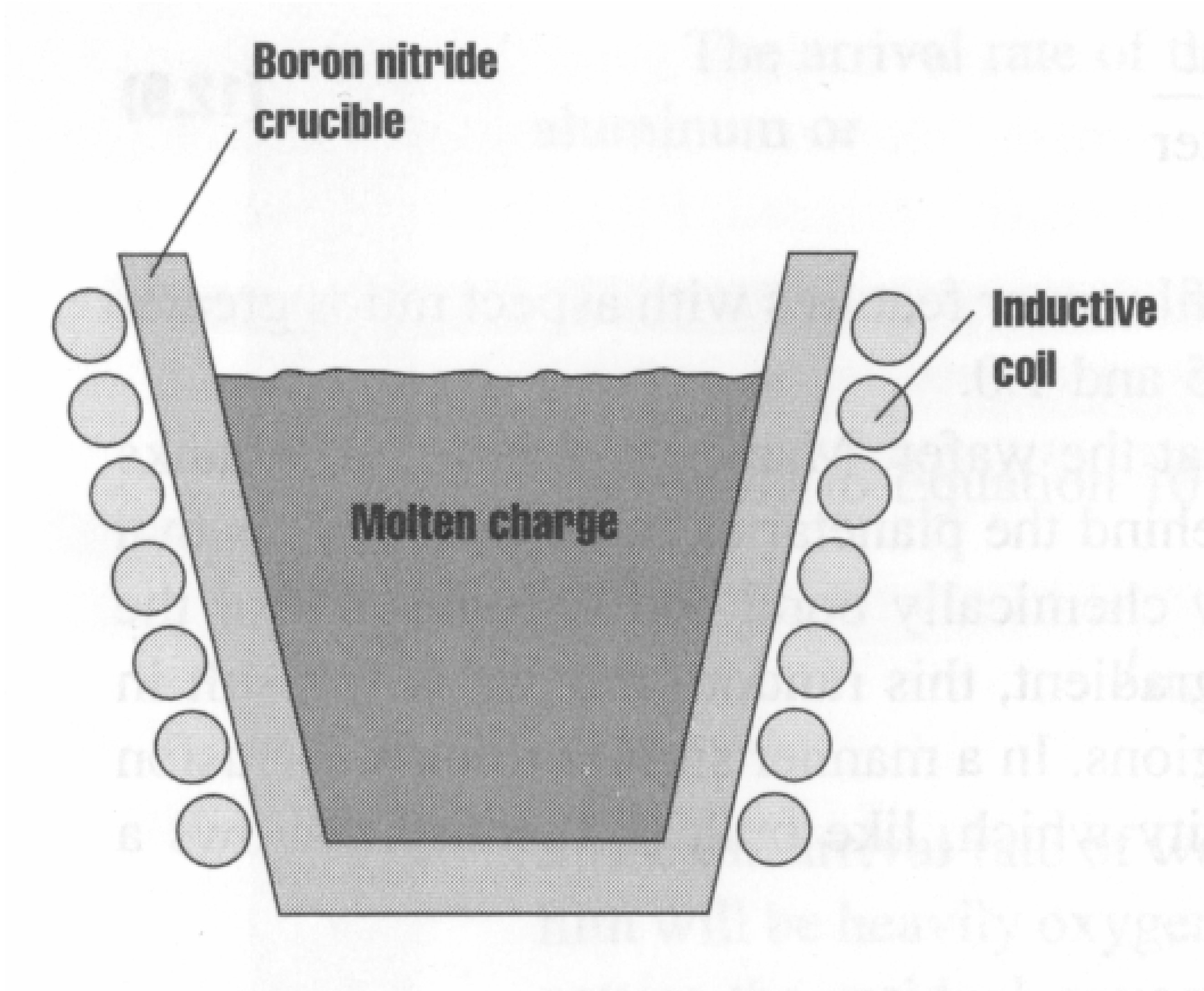
Thin Film Deposition

- **Physical Deposition**
  - Evaporation
  - Sputtering
  - Pulsed Laser Deposition
- **Chemical Deposition**
  - CVD
  - PECVD

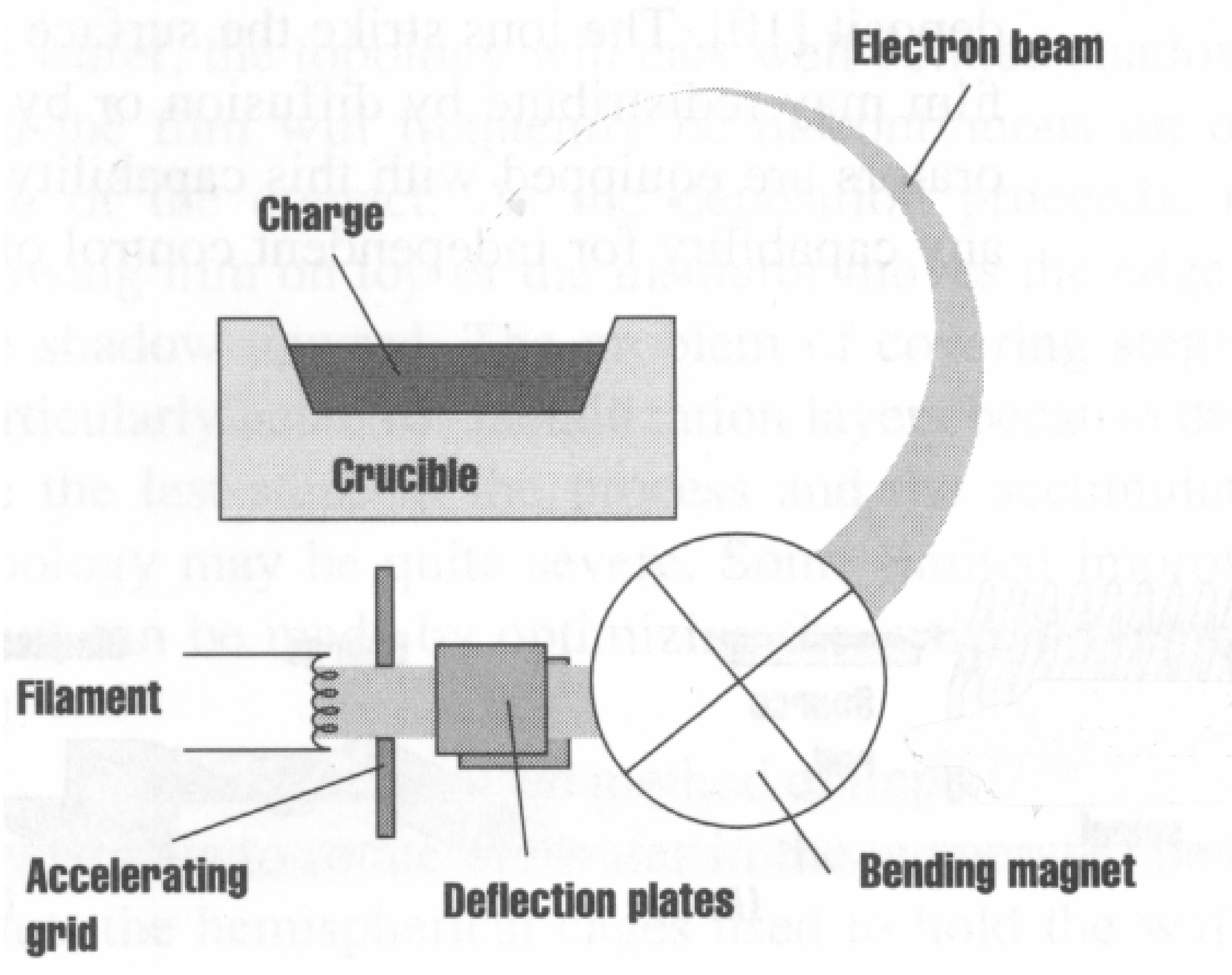
Evaporation Process



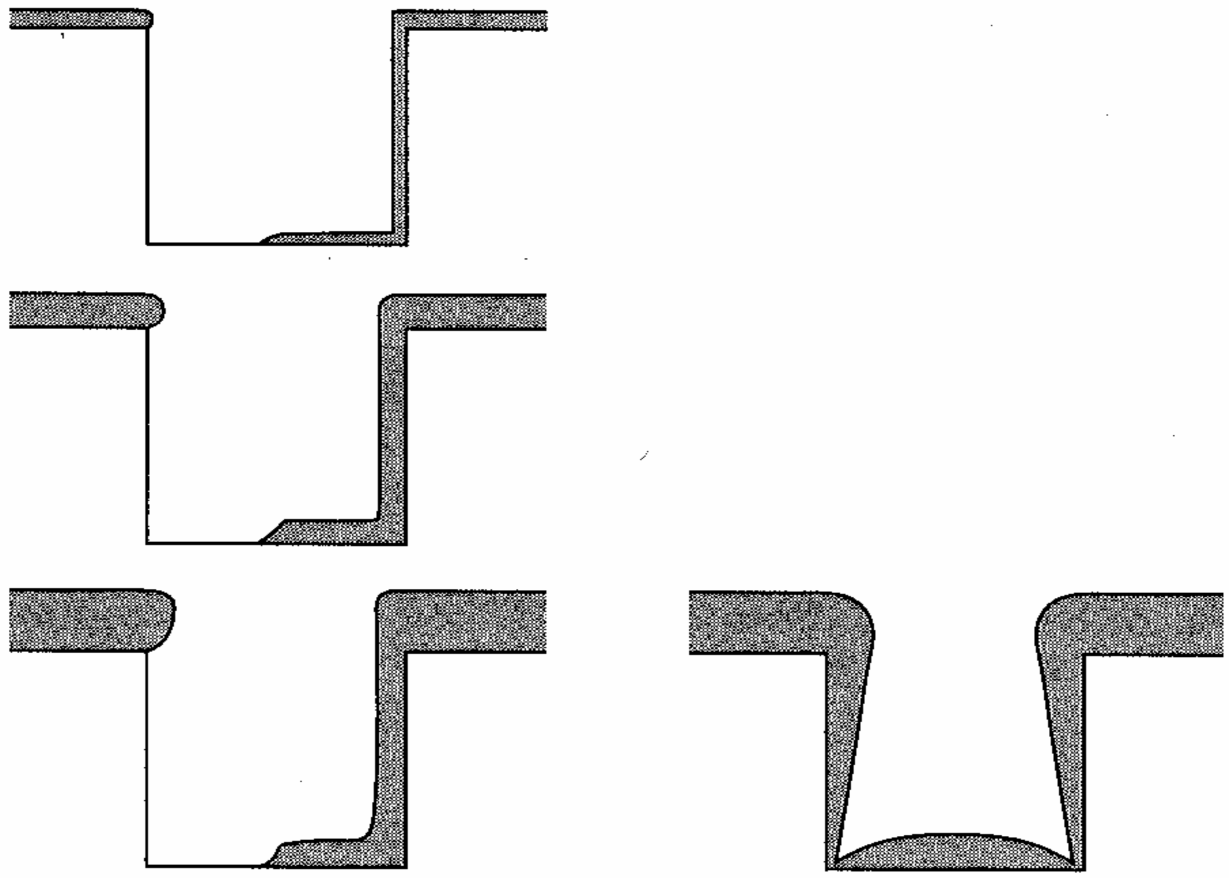
Thermal Evaporation



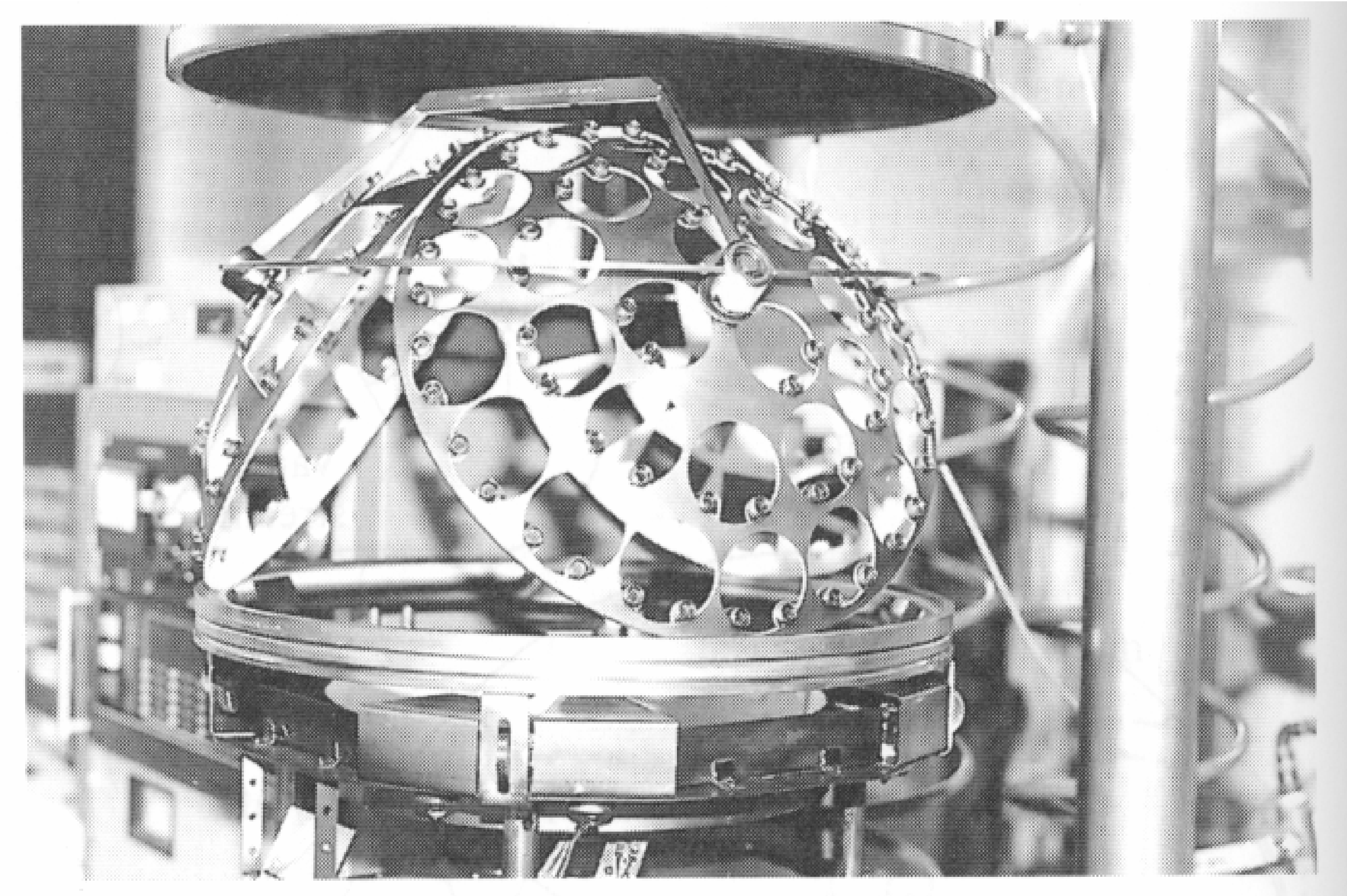
Electron Beam Evaporation



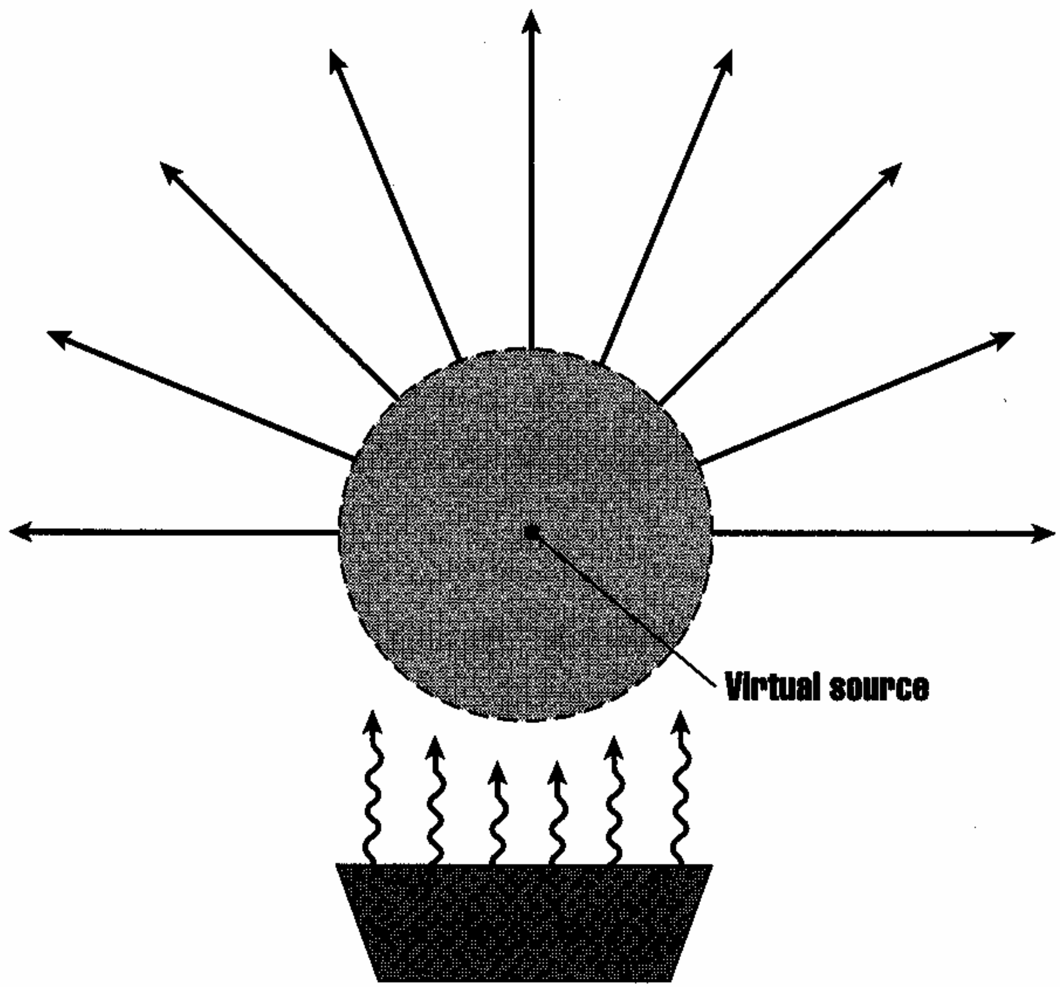
Shadow in Deposition



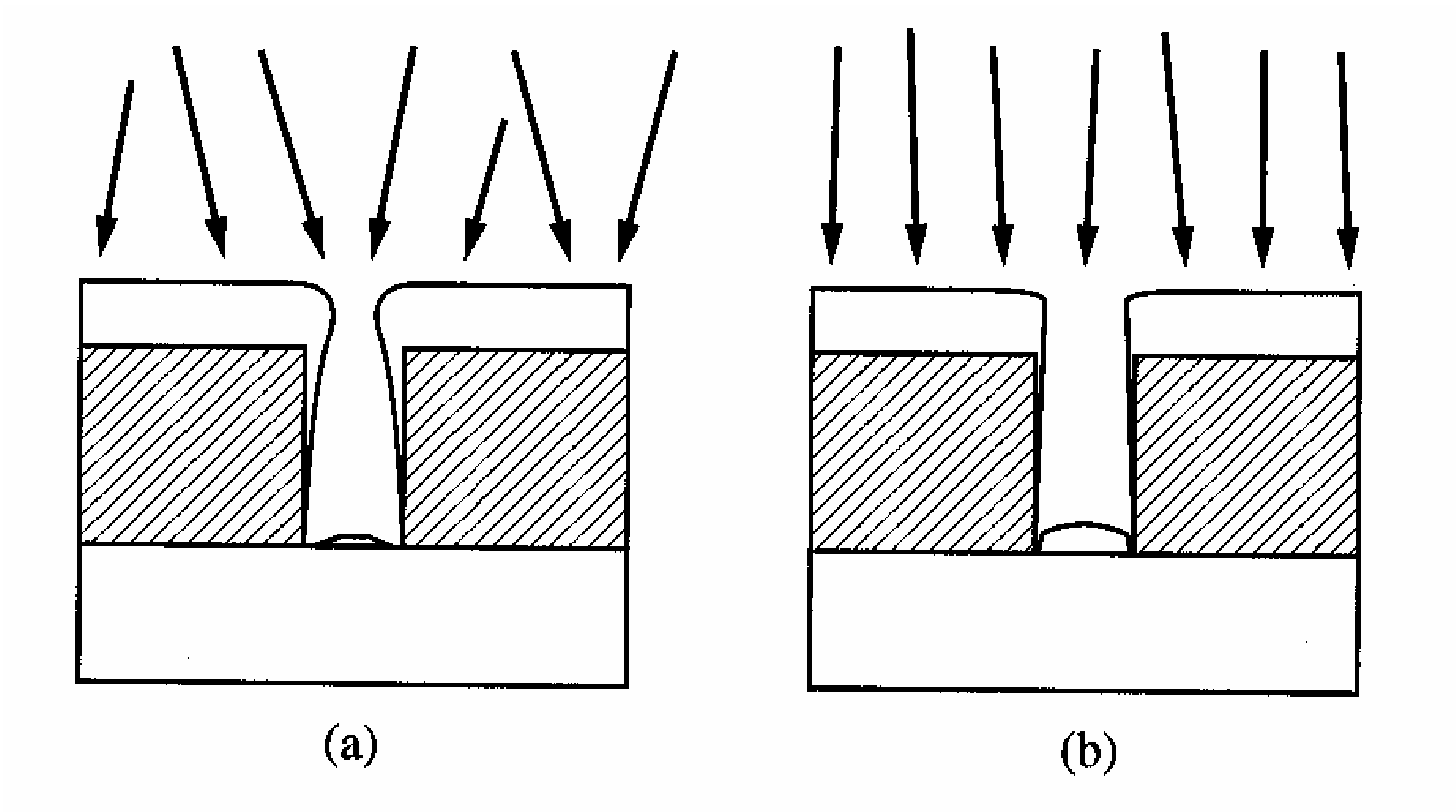
Rotation Planetary



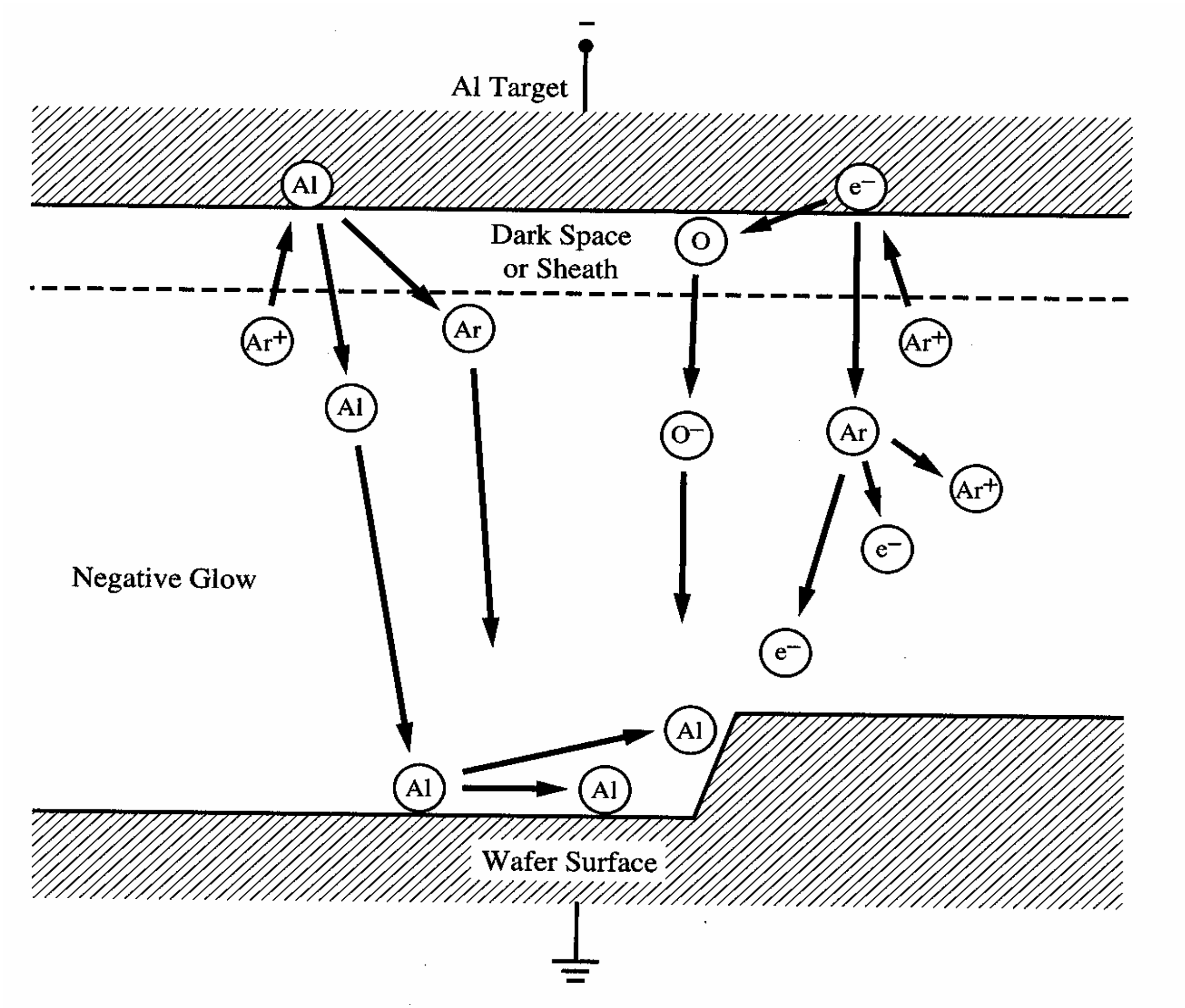
Virtual Source



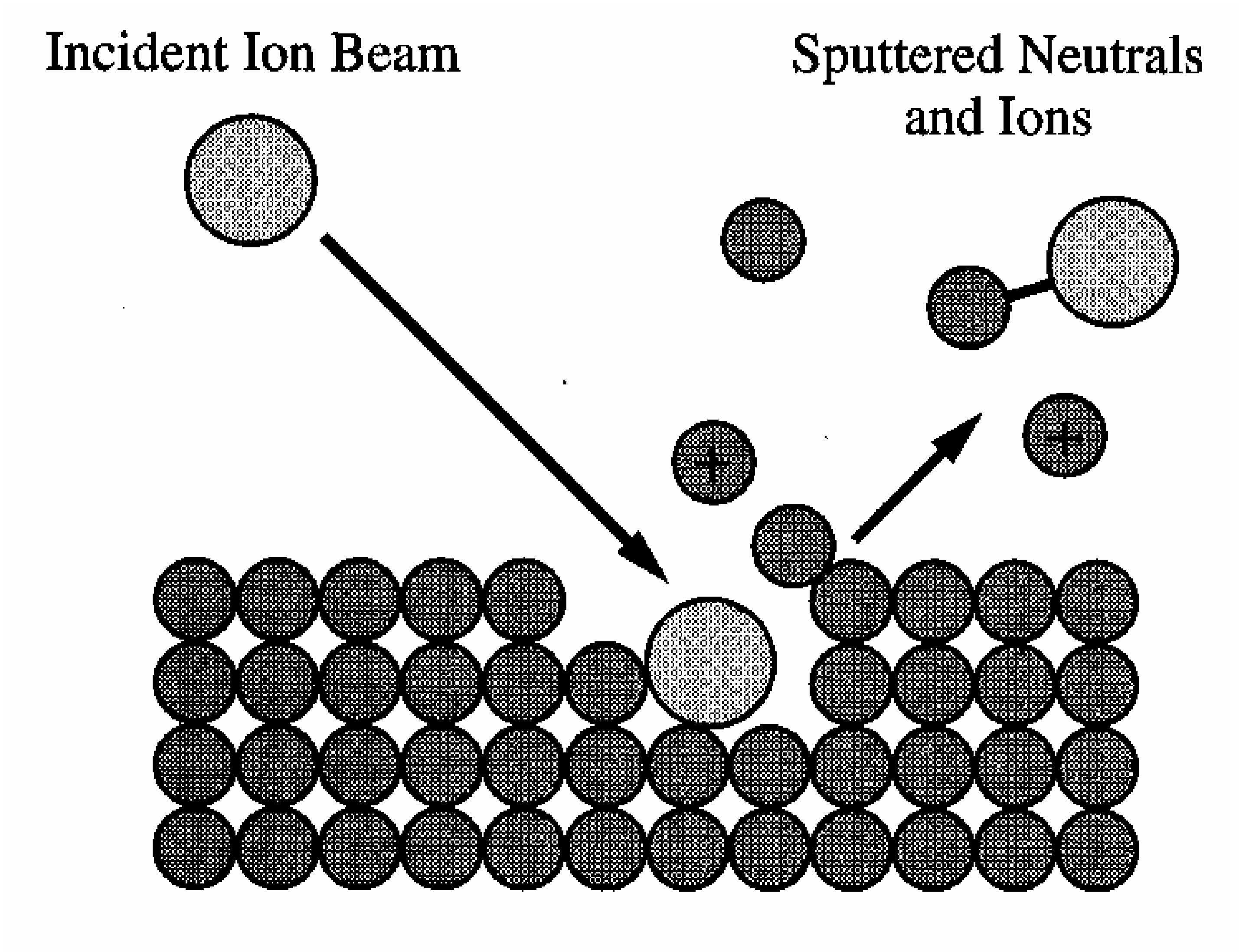
High Aspect Ratio Trench



Sputtering Process



Source Sputtering



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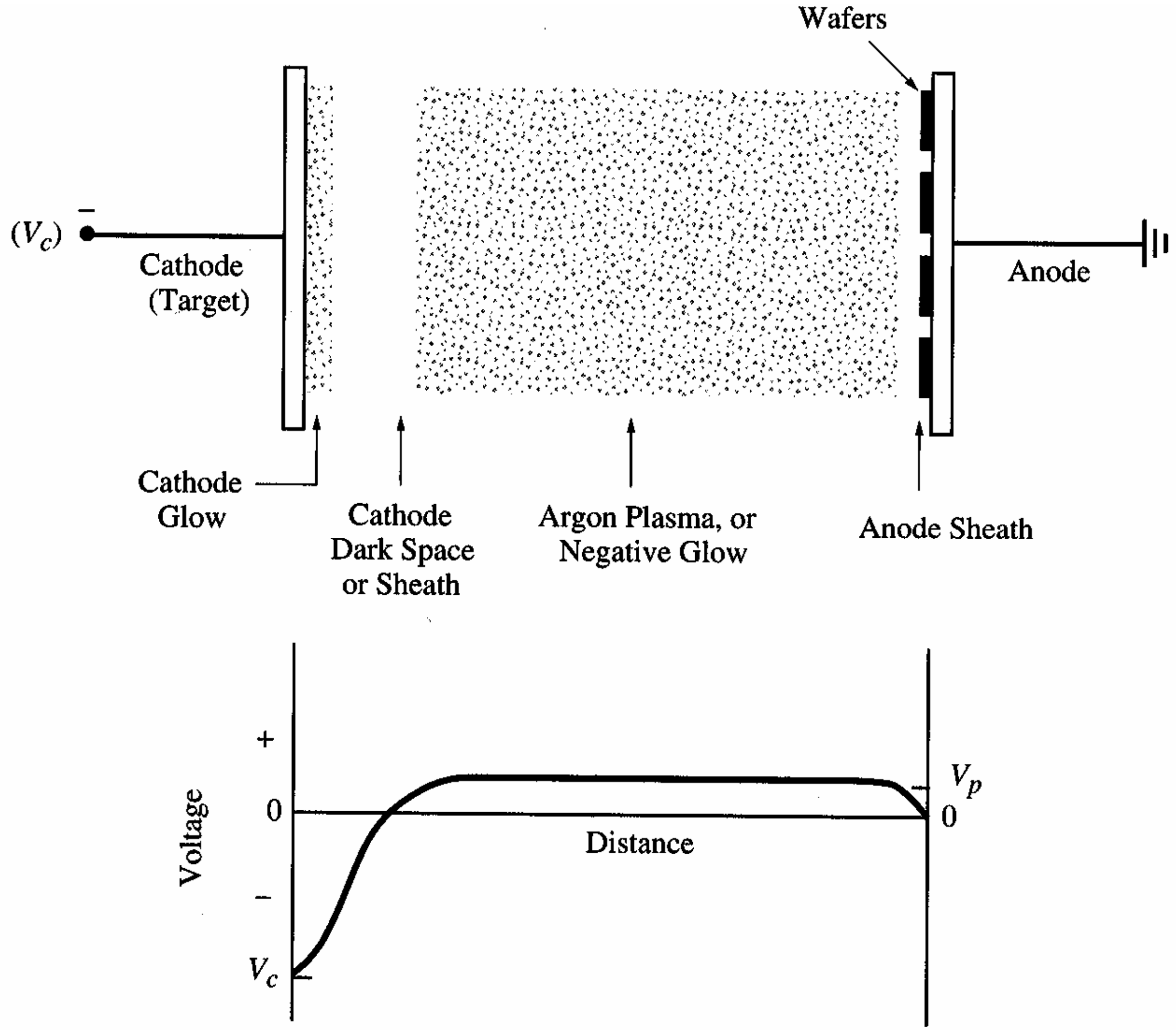
DC Sputtering



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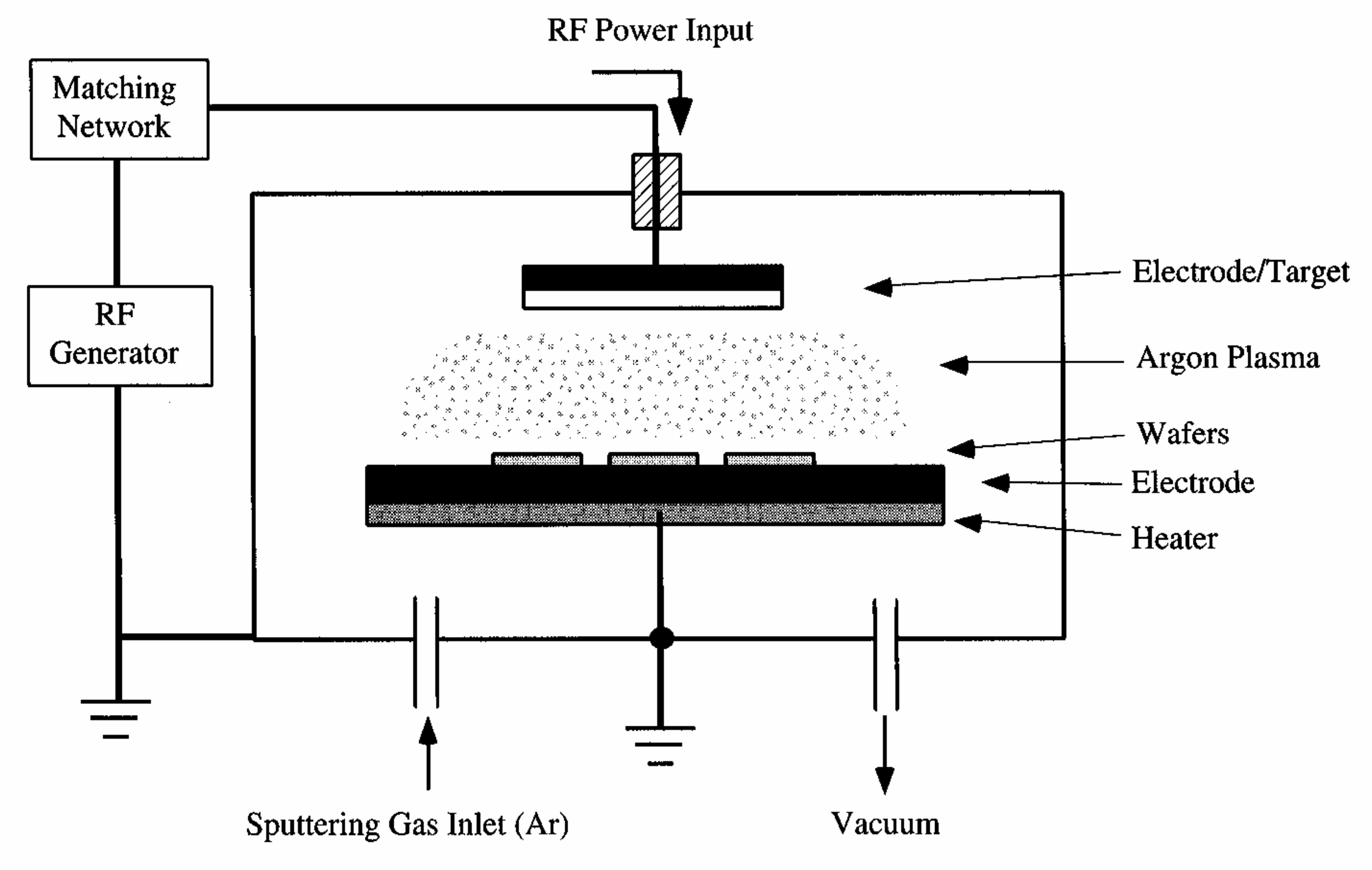
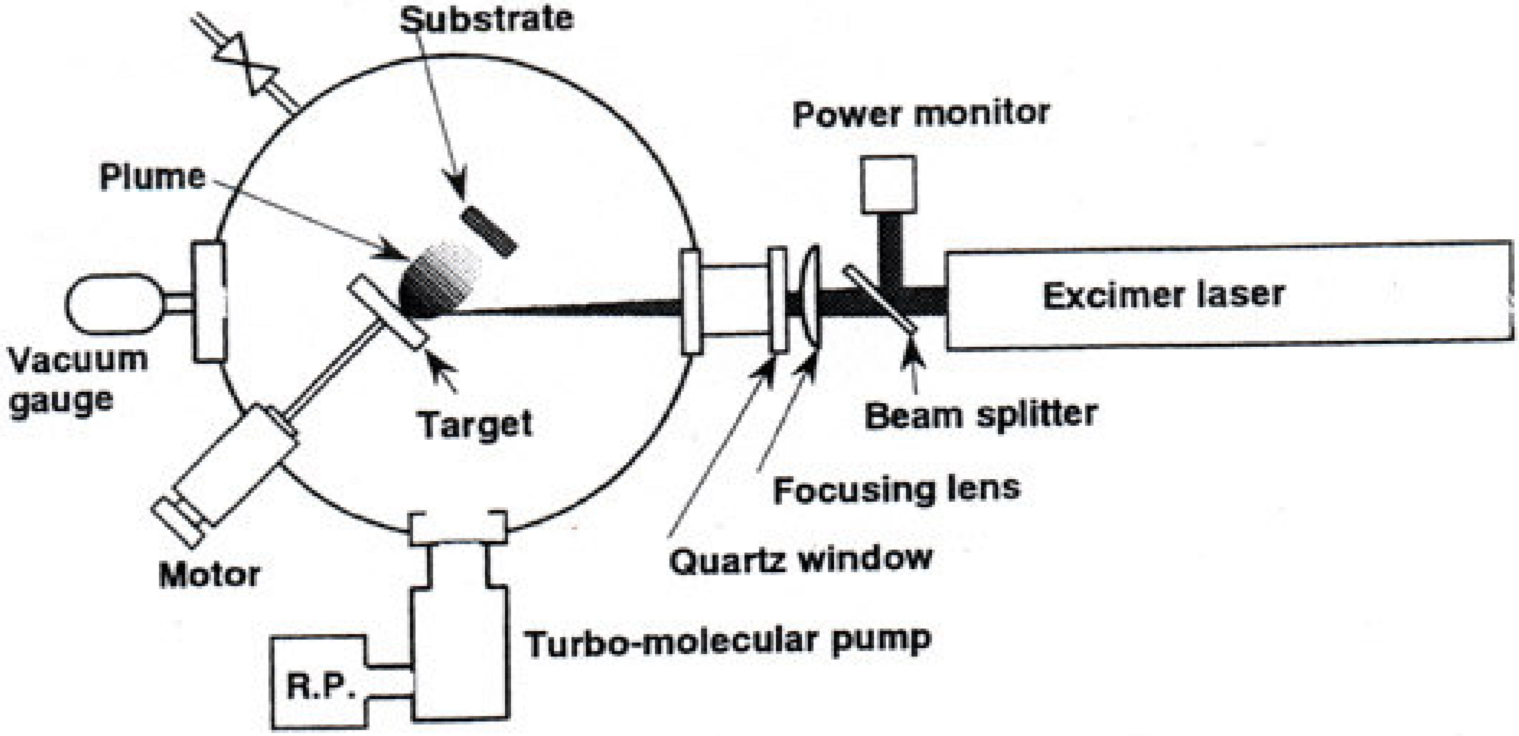
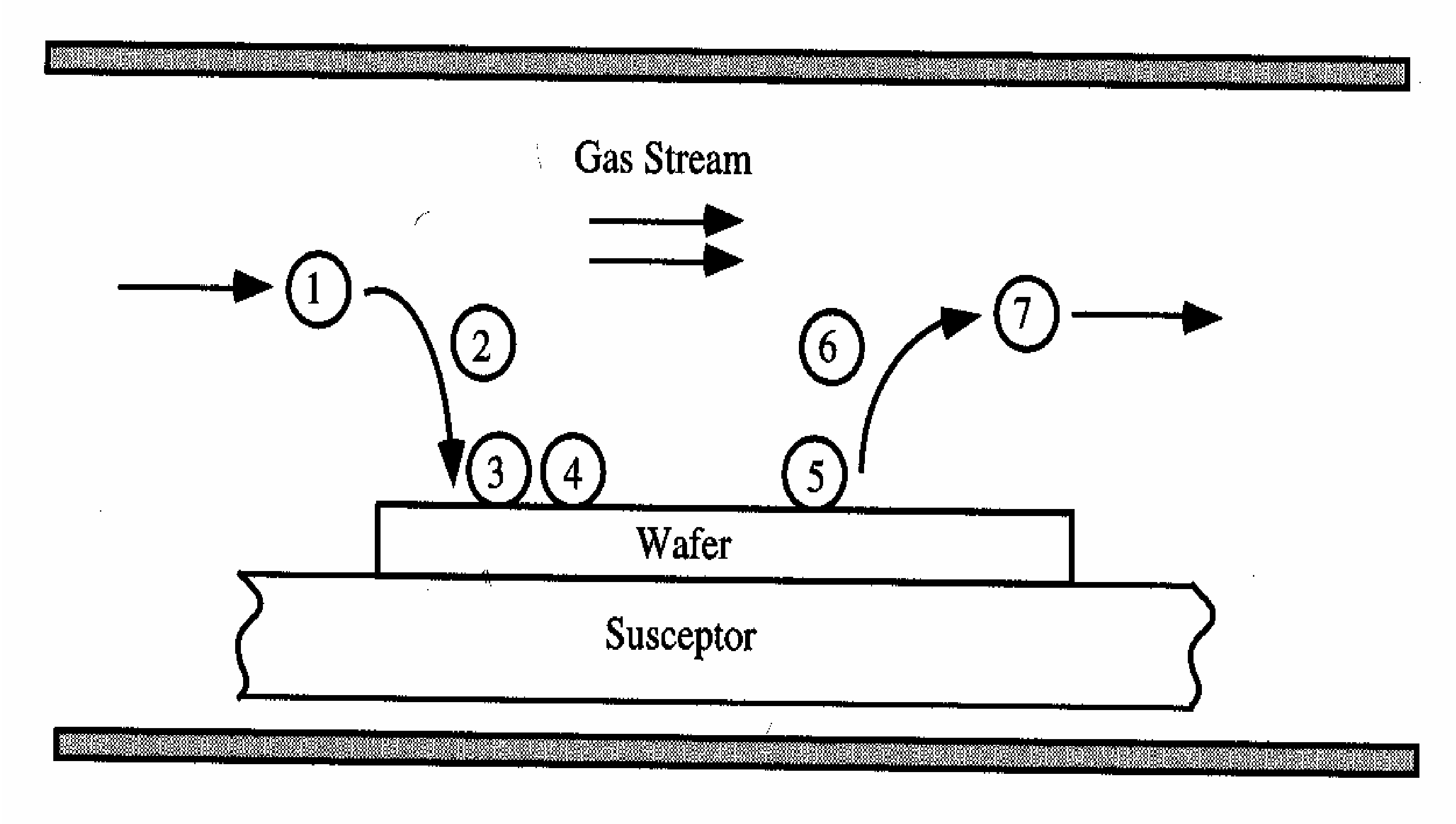
RF Sputtering



Pulsed Laser Sputtering



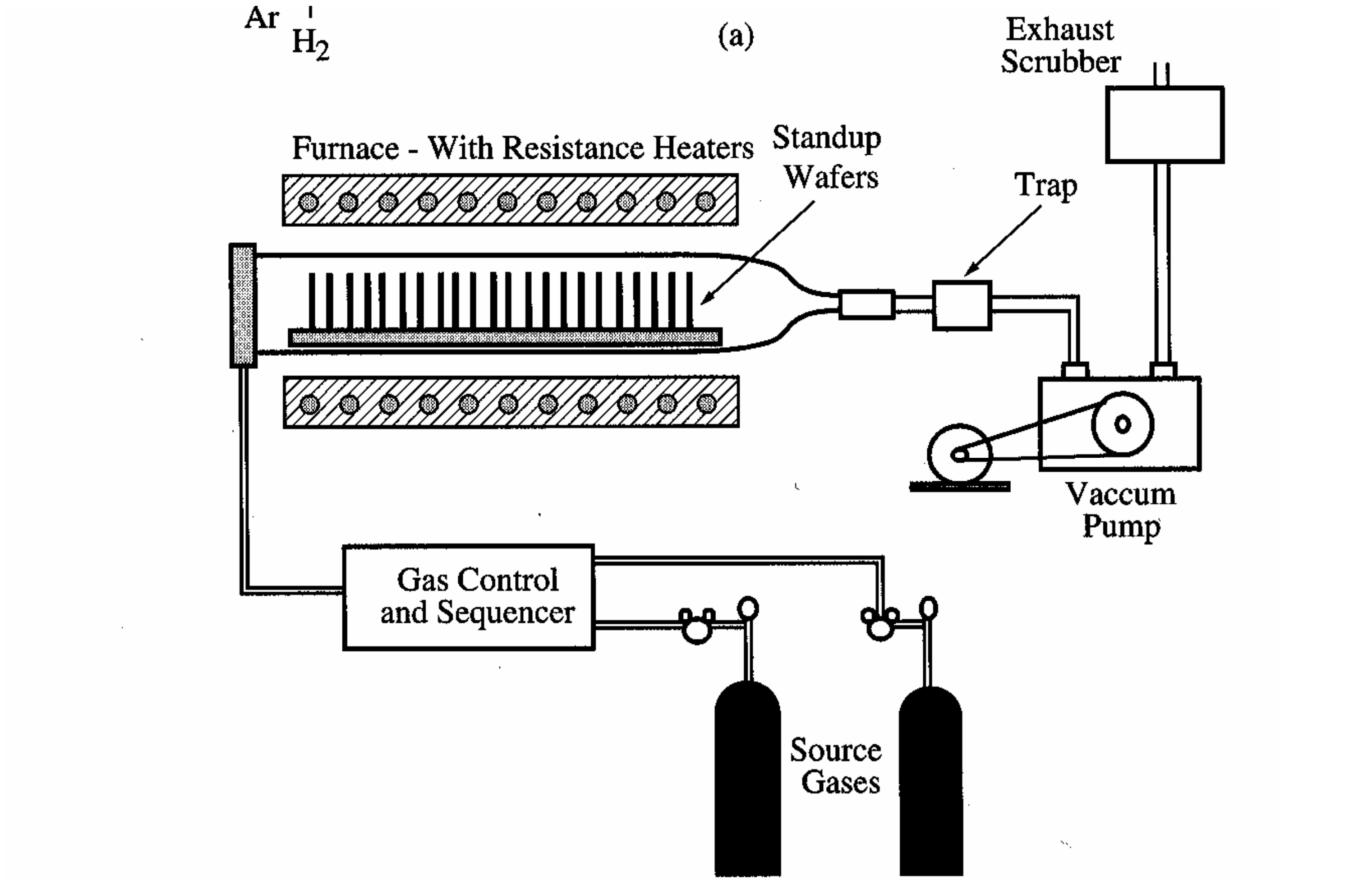
Chemical Vapor Deposition (CVD)



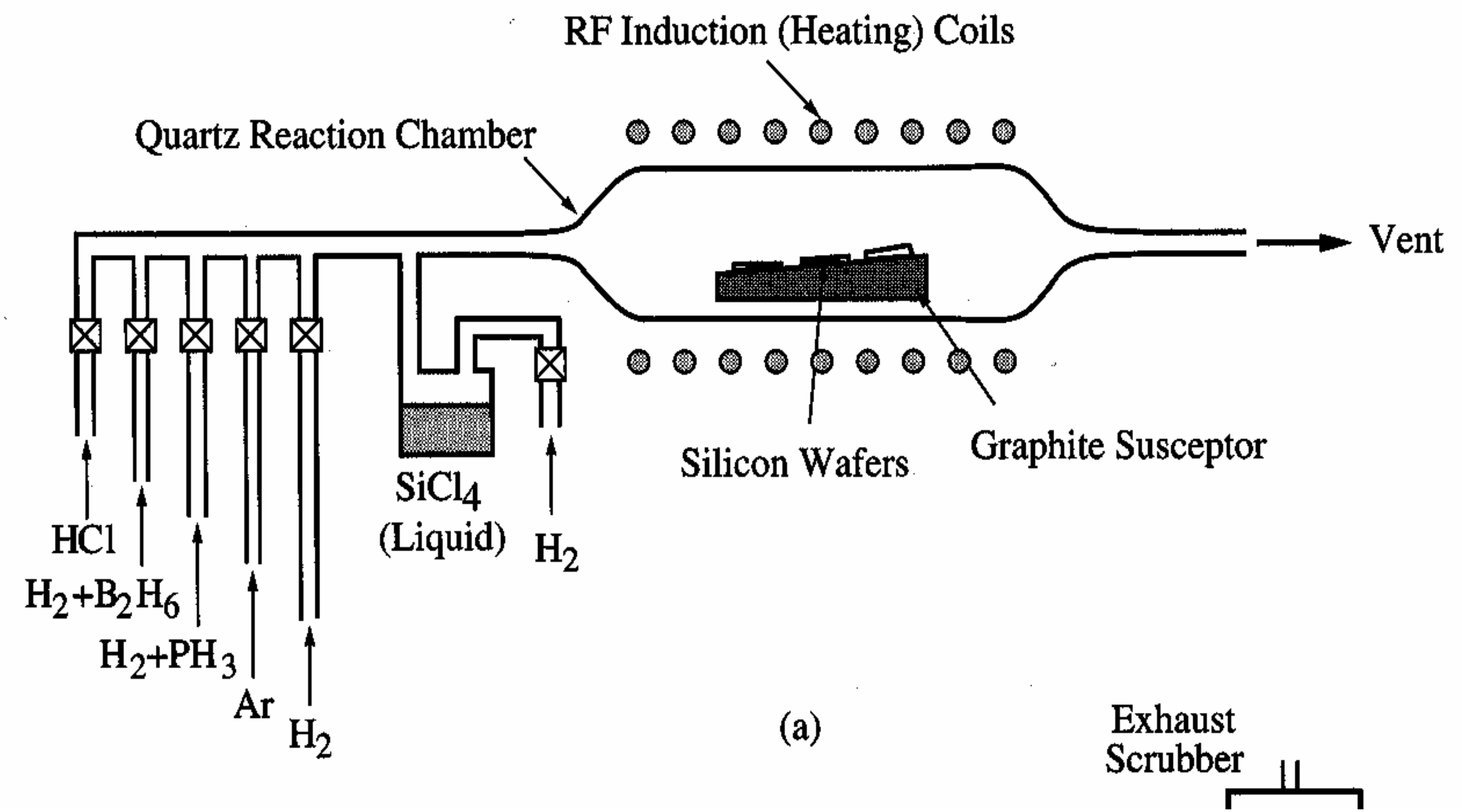
Steps of the CVD Process

1. Reactant transport by convection
2. Reactant transport by diffusion
3. Adsorption of reactant
4. Surface processes: chemical decomposition and reaction, migration and attachment.
5. Desorption of byproduct
6. Byproduct transport by diffusion
7. Byproduct transport by convection

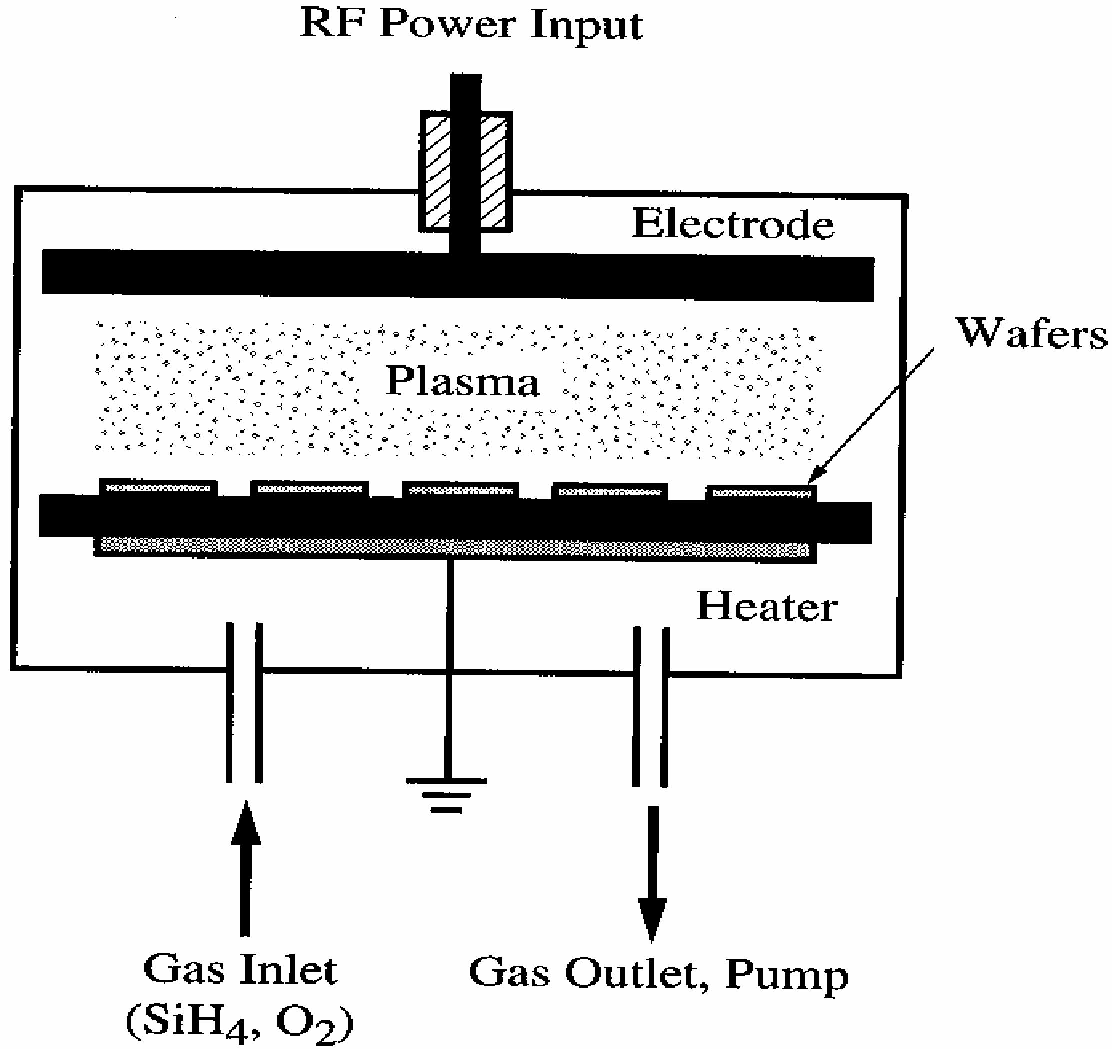
Low Pressure CVD System



Atmospheric Pressure CVD



Plasma Enhanced CVD



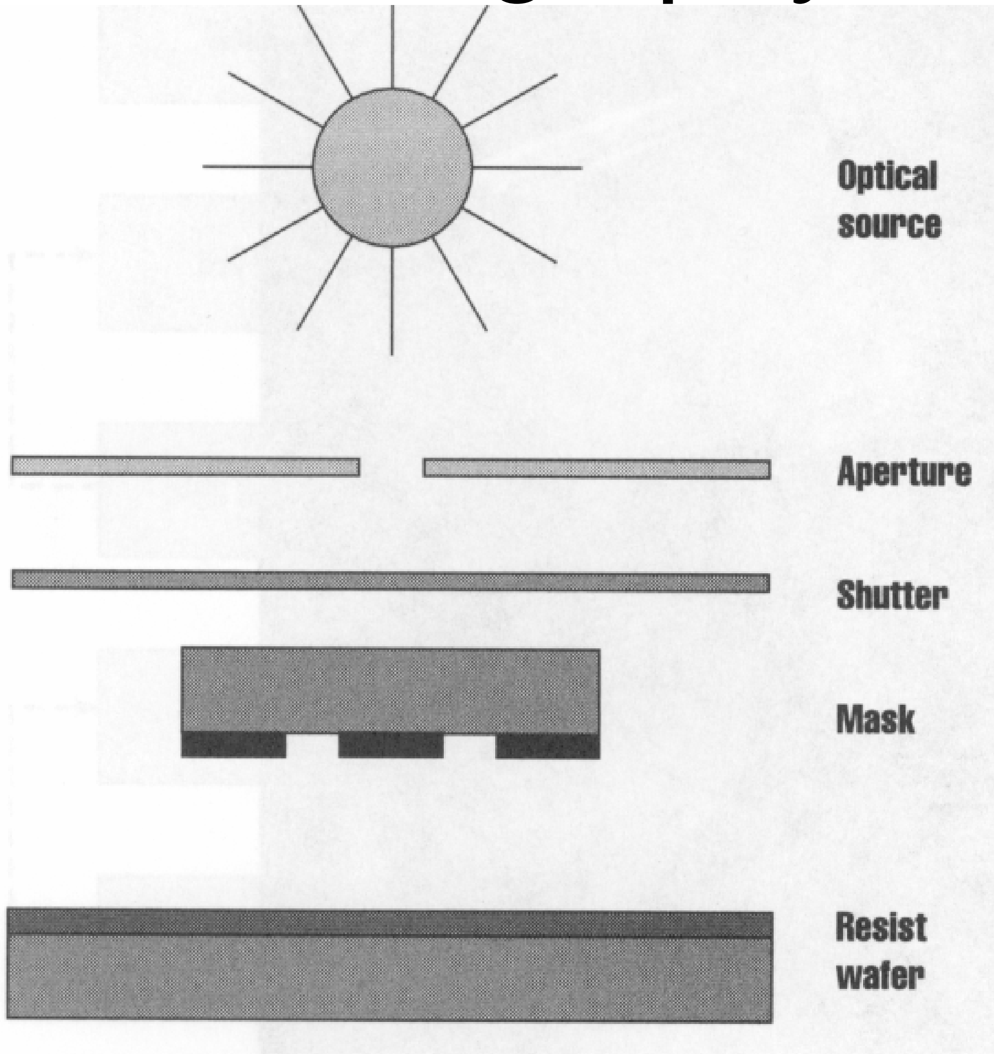
Lithography

- **Photolithography**
  - Contact
  - Proximity
  - Projection
- **Electron Beam Lithography**
- **X-Ray Lithography**
- **Ion Beam Lithography**

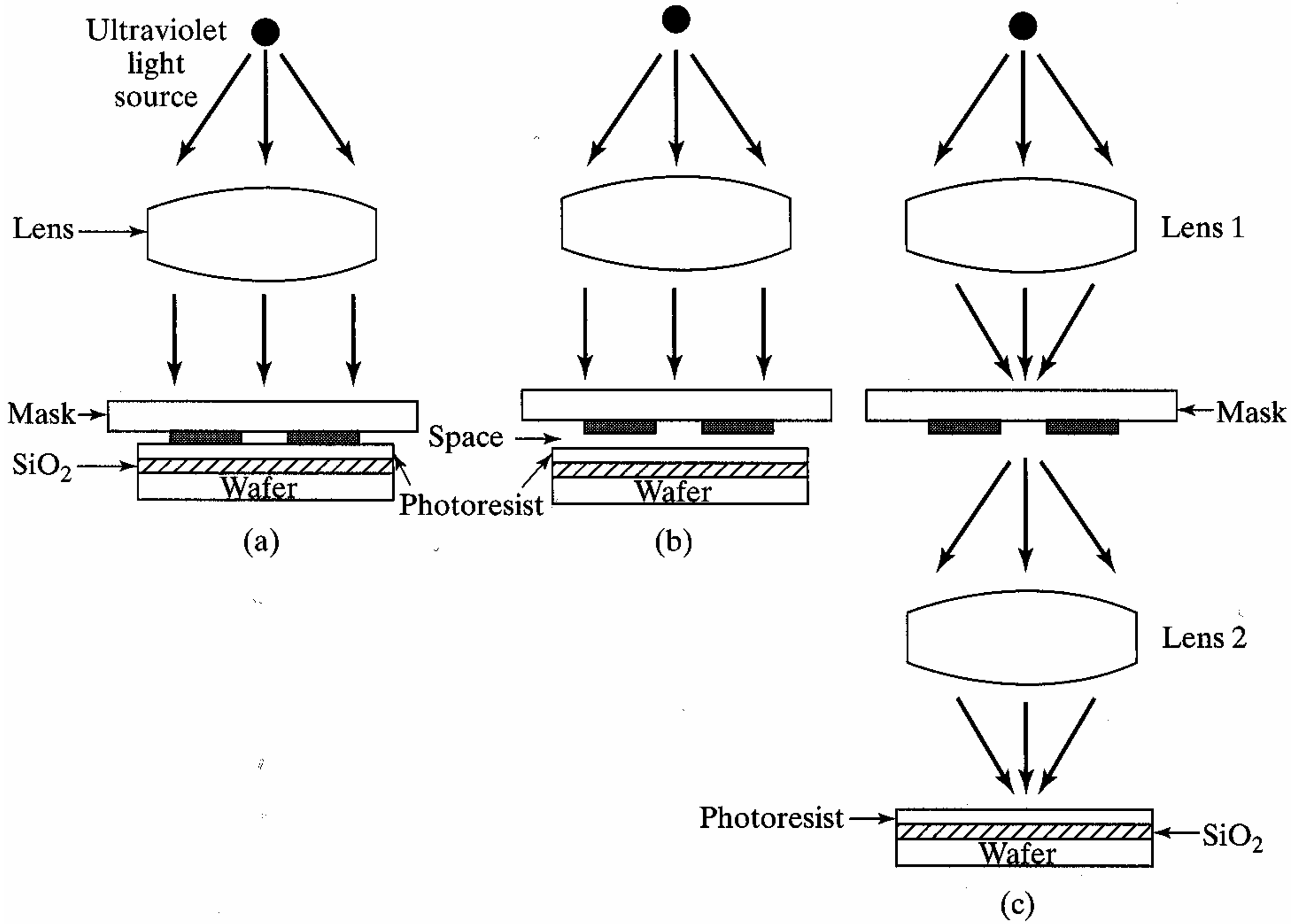
Lithography

- Spin coat radiation sensitive polymer - Resist
- Expose layer (through mask or direct write)
- Develop
- Etch away or deposit material

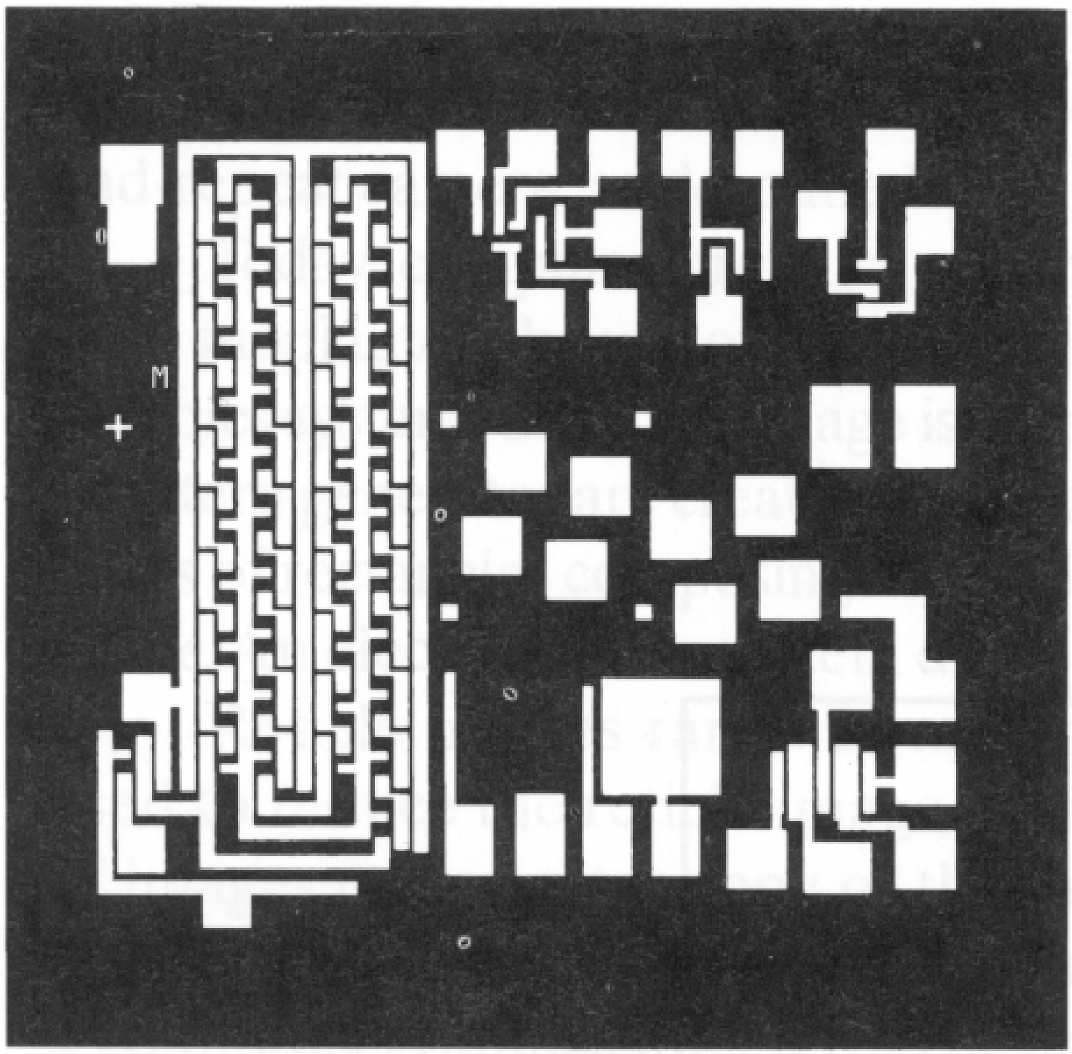
Photolithography



Types of Photolithography



Photomask



(b)

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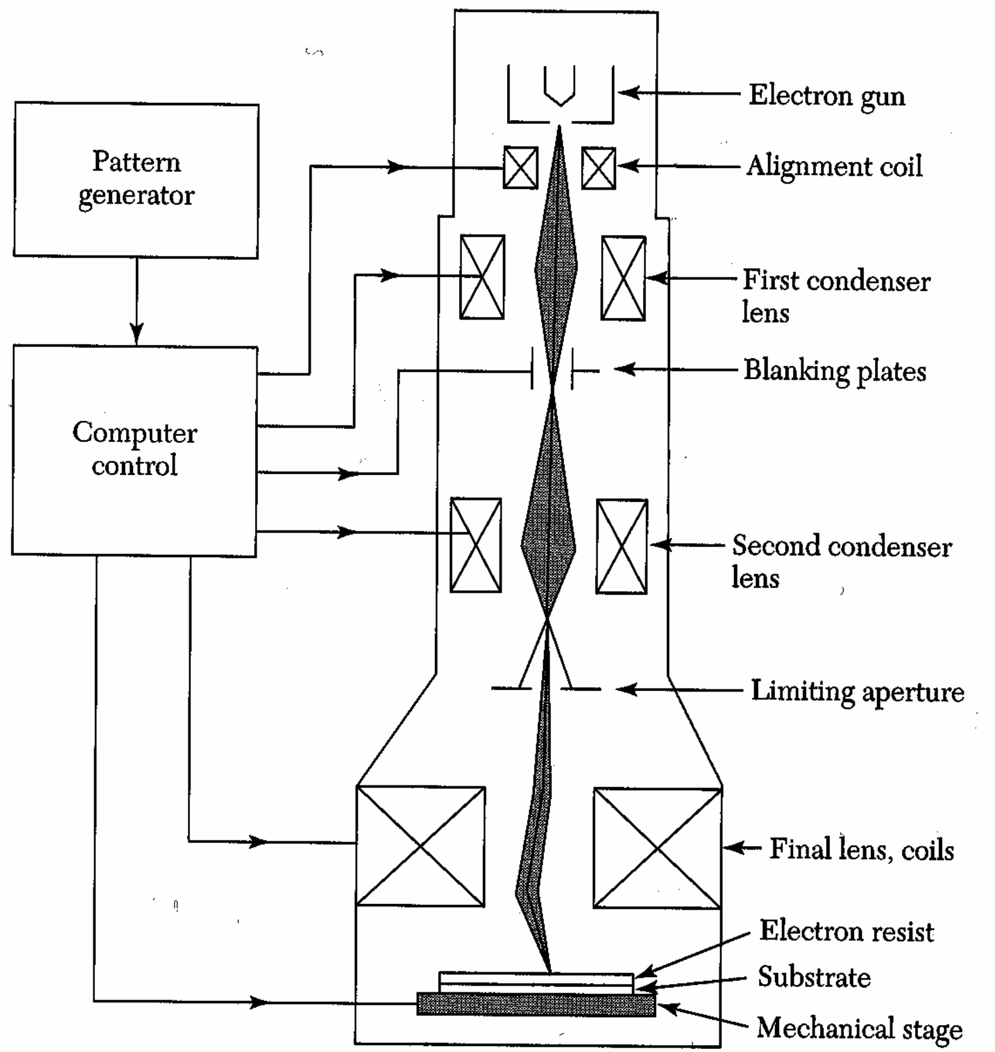
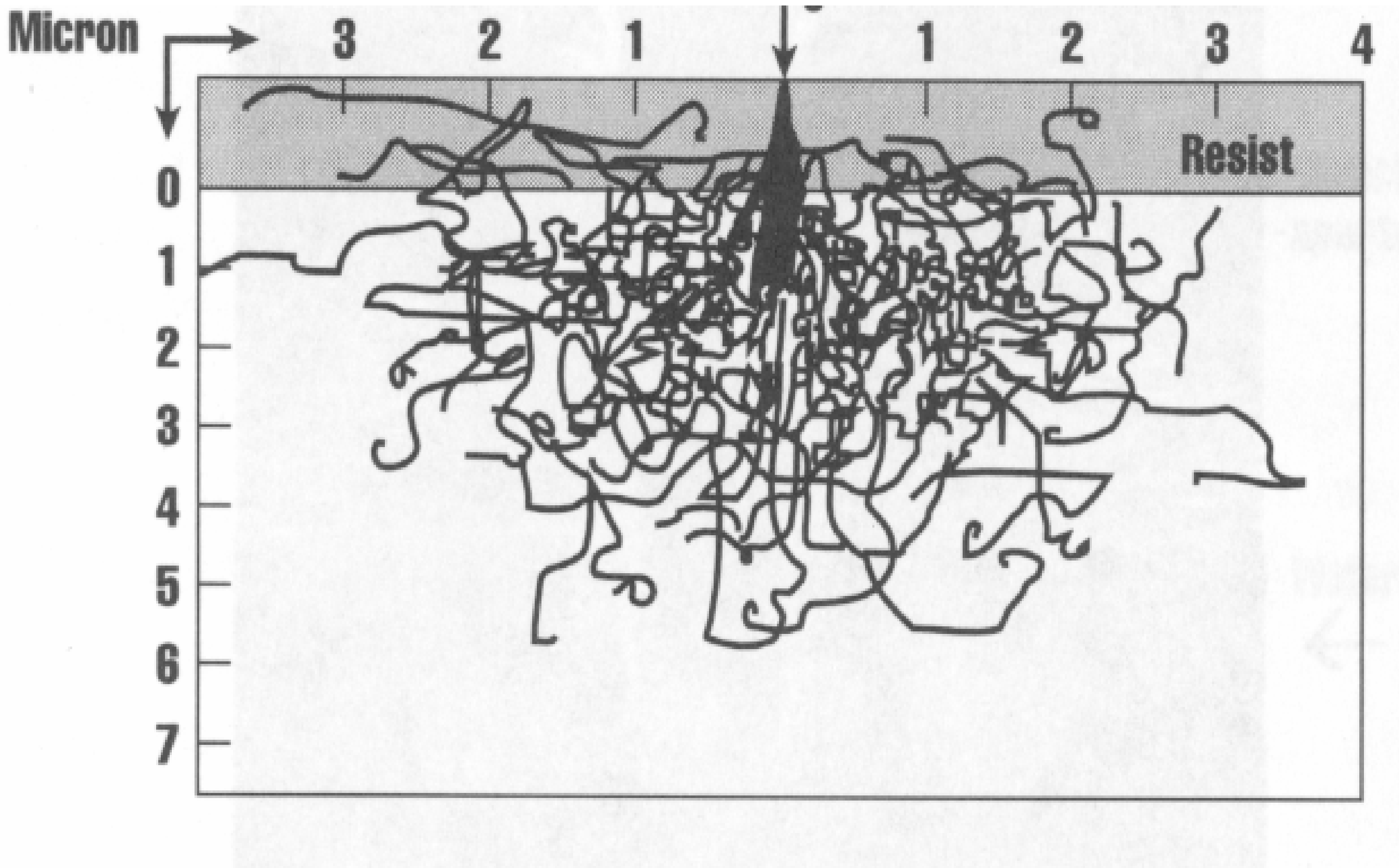
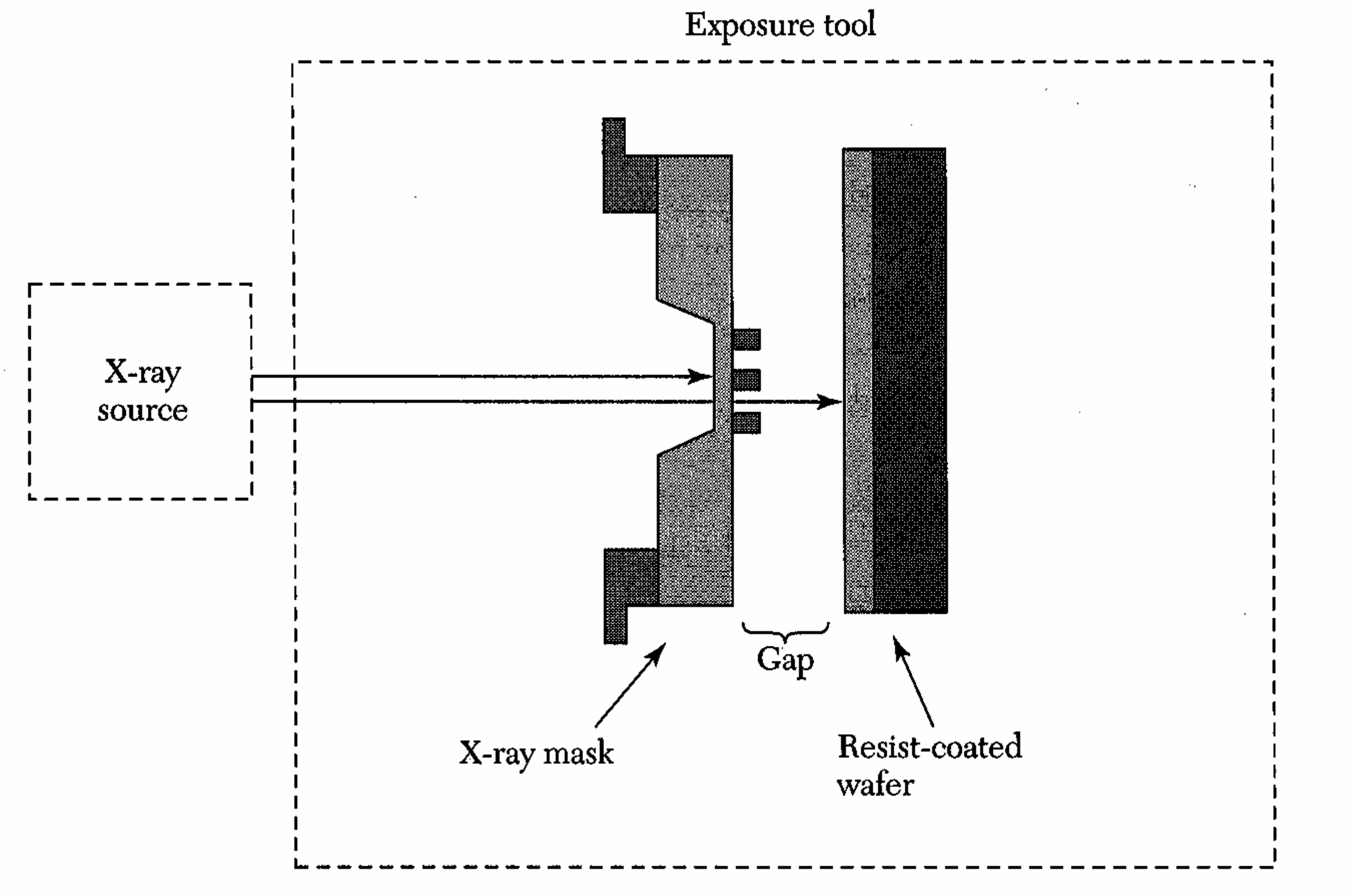
Electron Beam Lithography



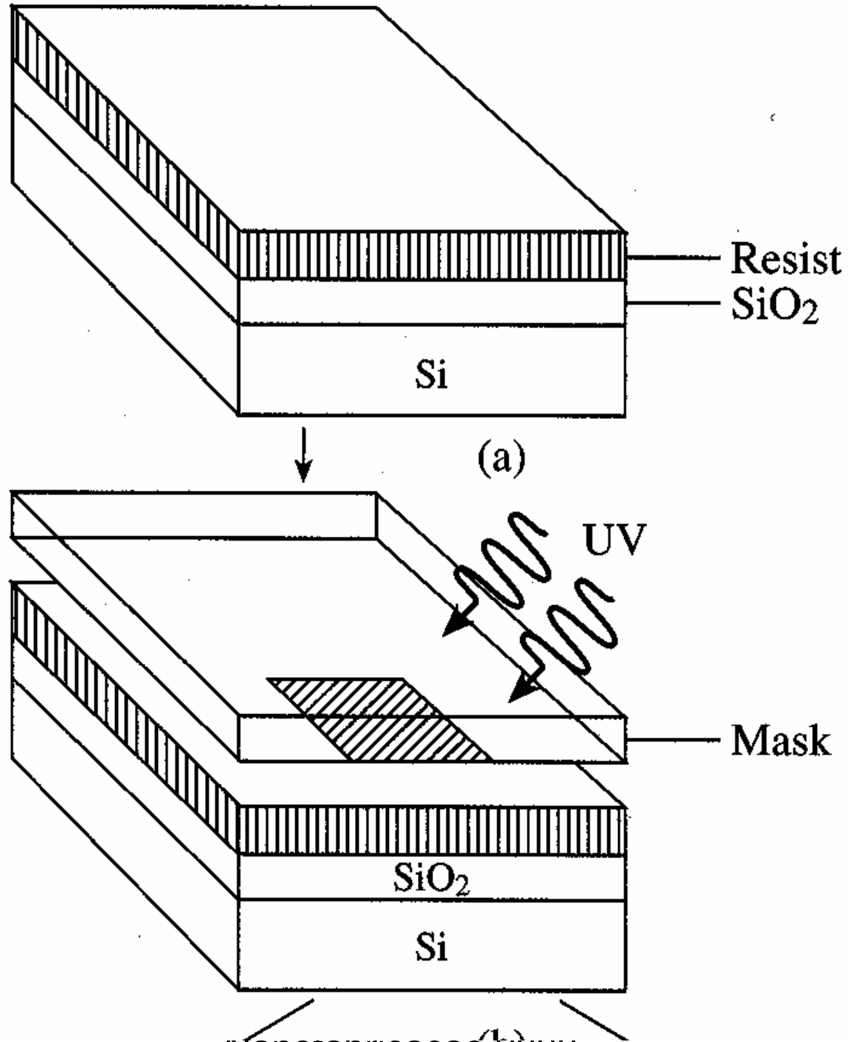
Substrate Damage



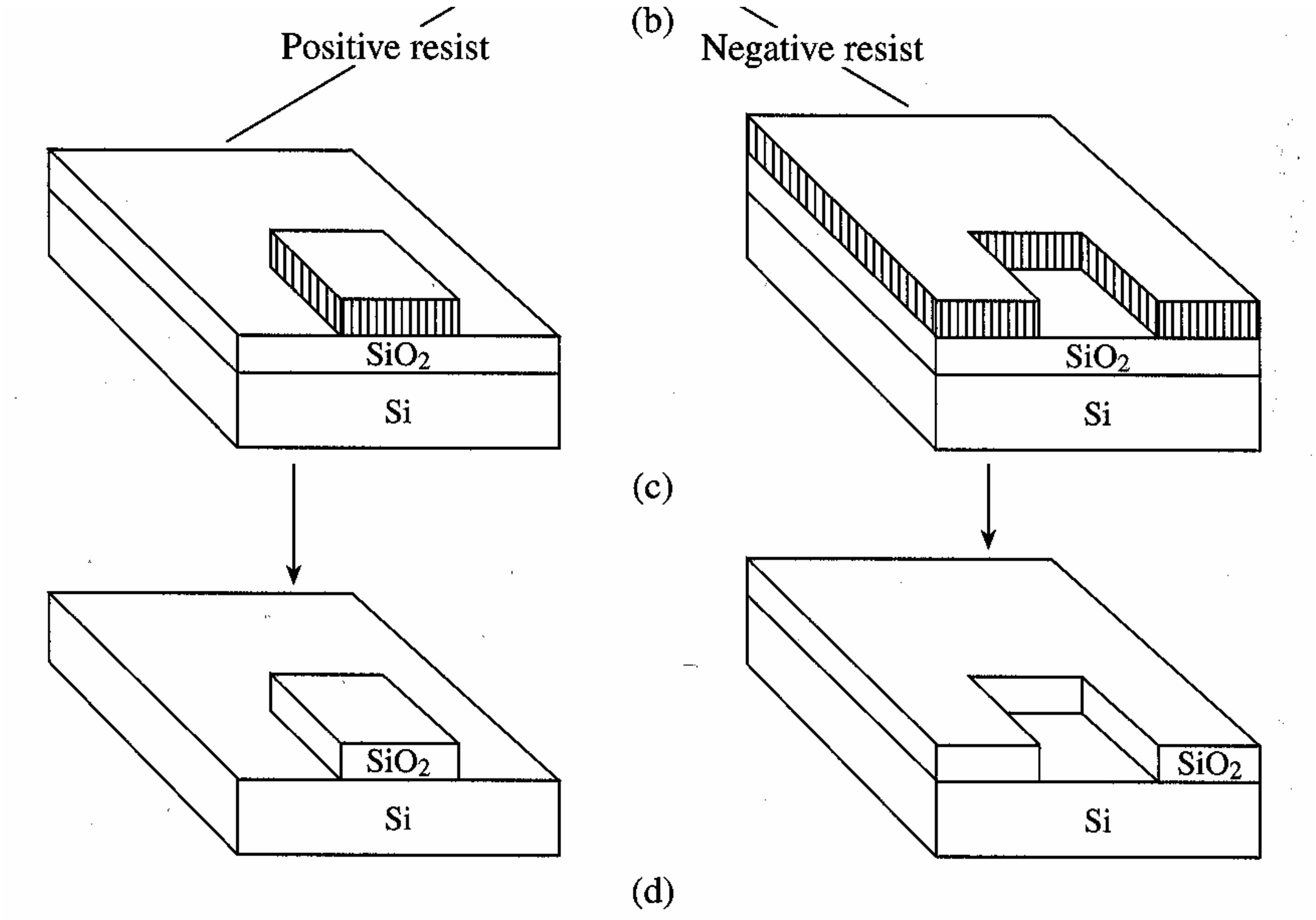
X-Ray Lithography



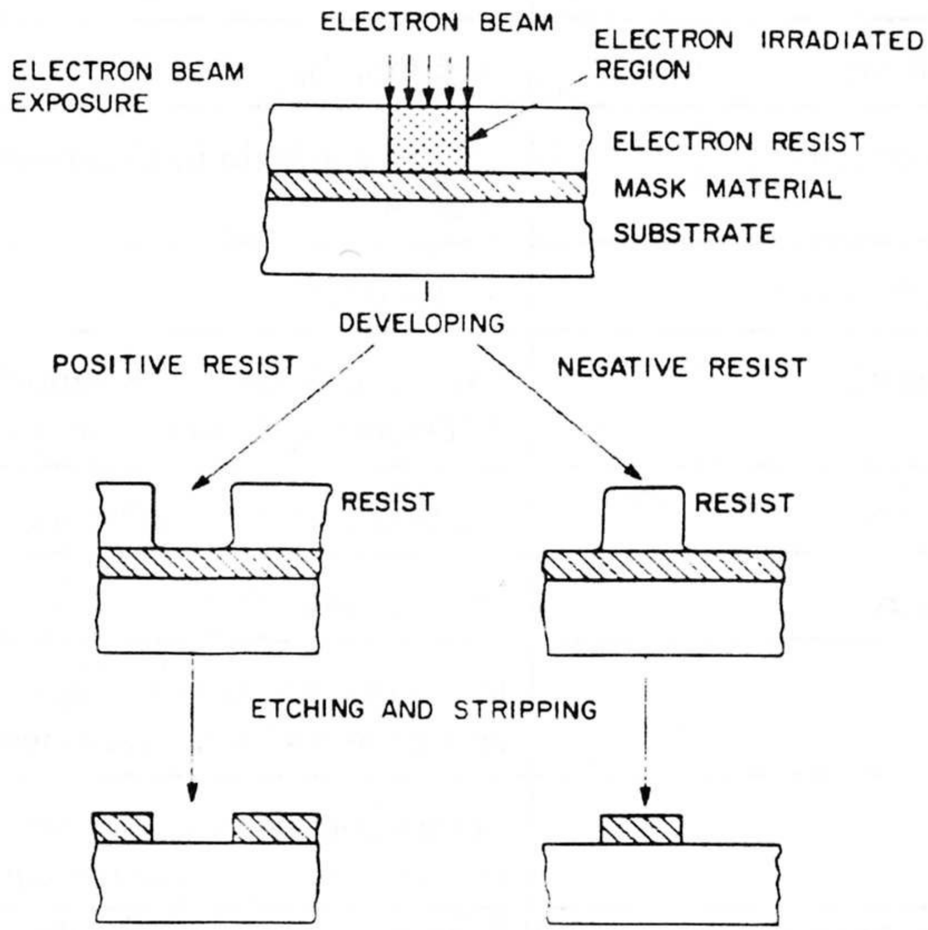
Example of Photolithography (I)



Example of Photolithography (II)



Positive and negative resist



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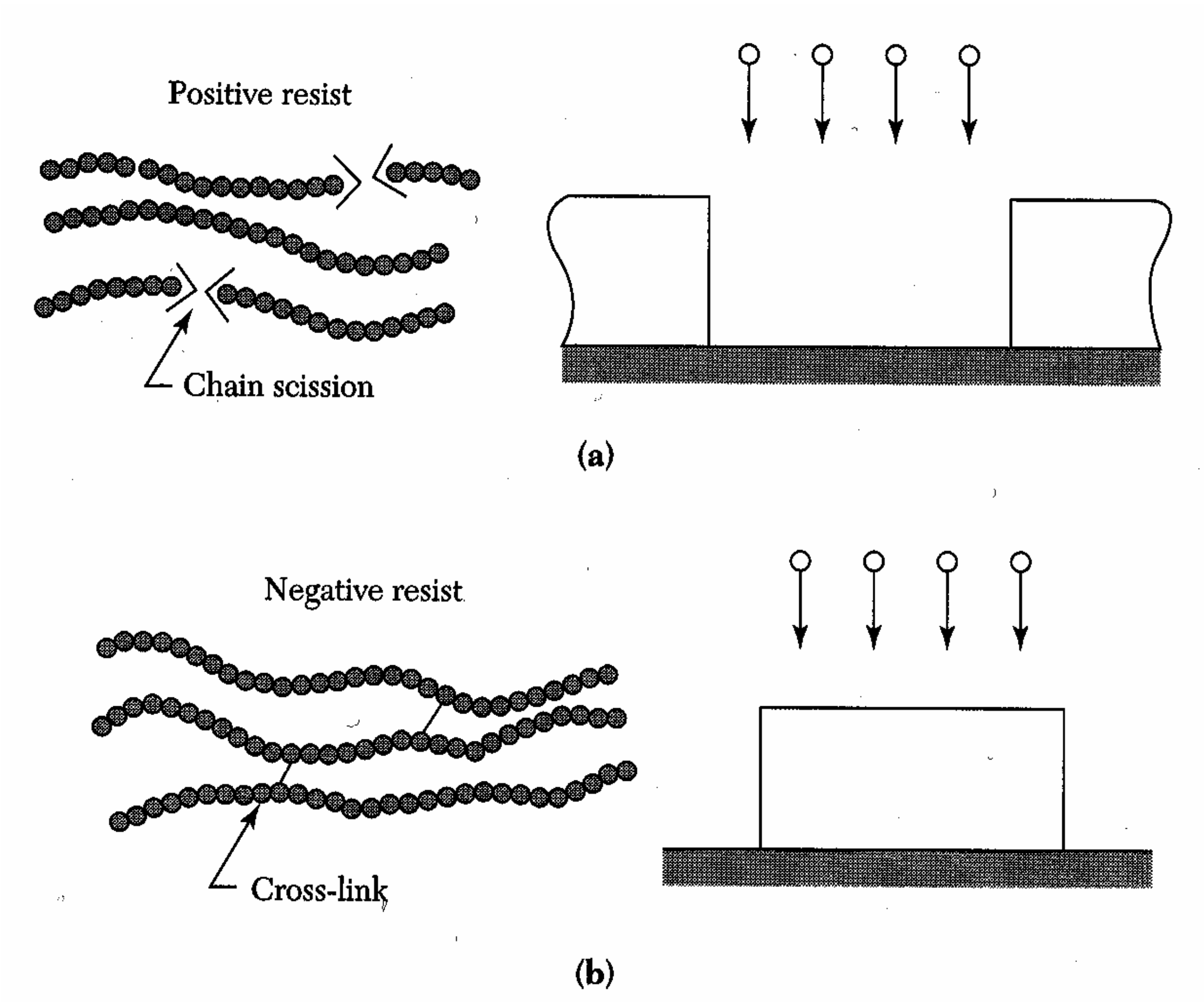
Photoresist (PR)



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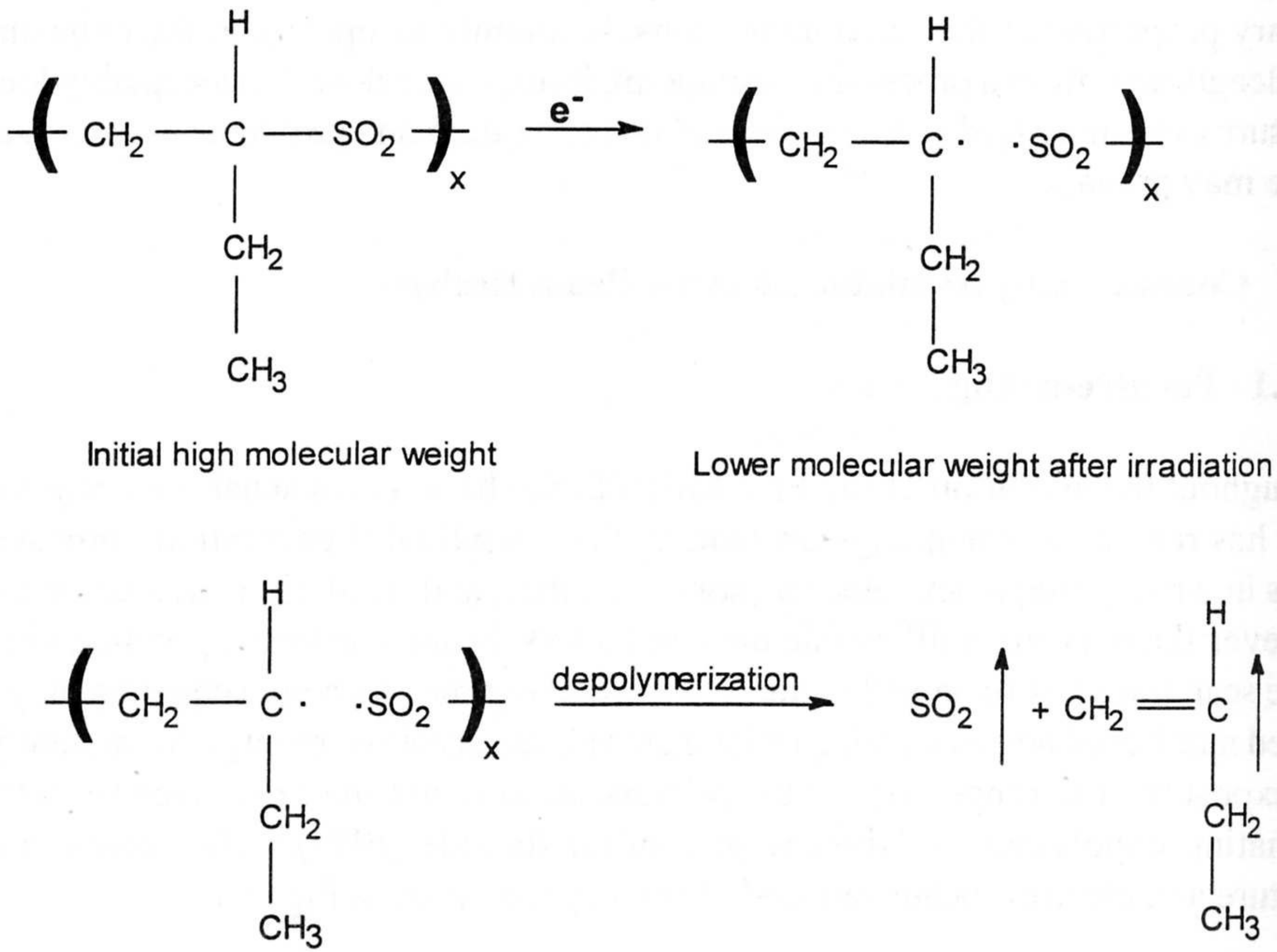
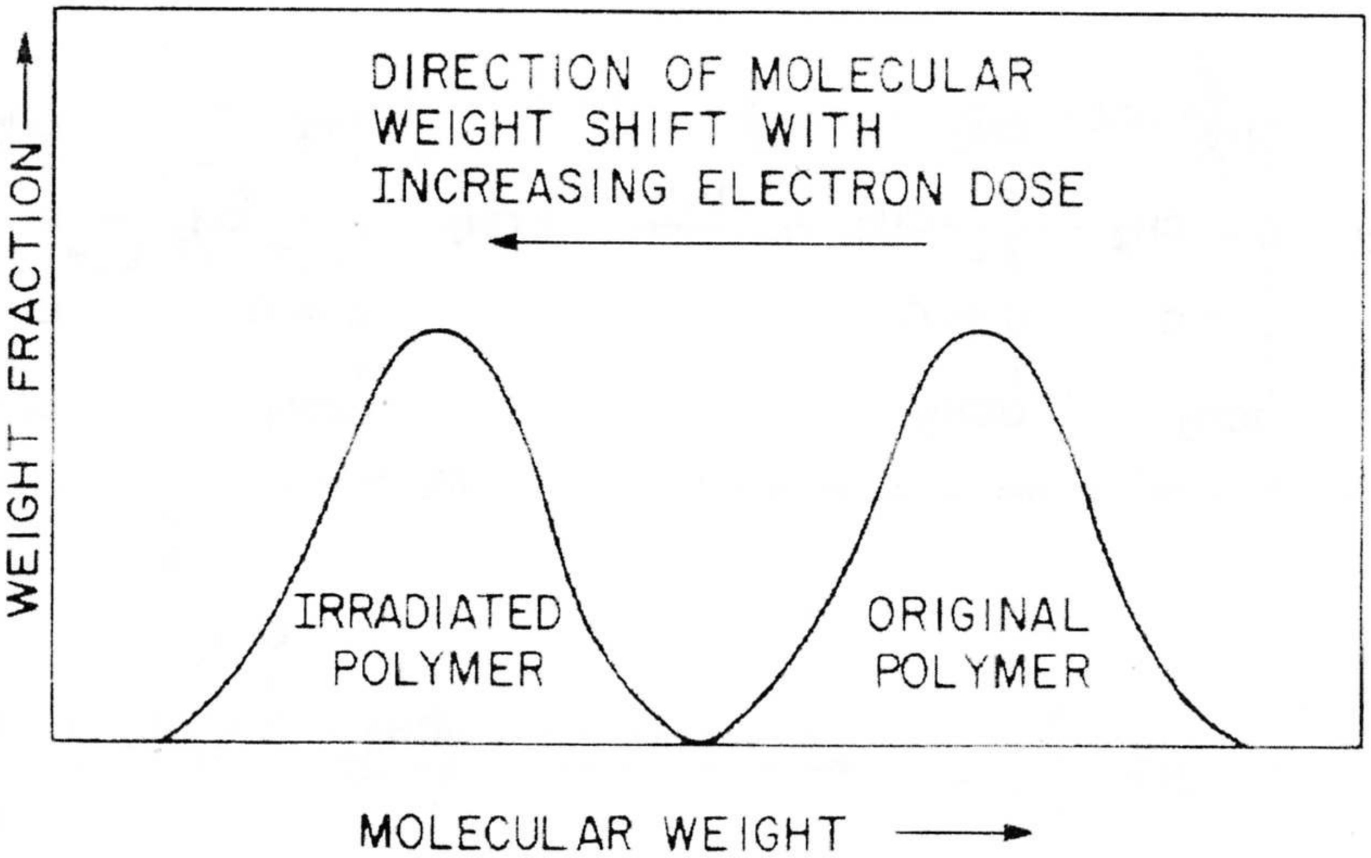
Positive Resist Chemistry



Molecular weight shift

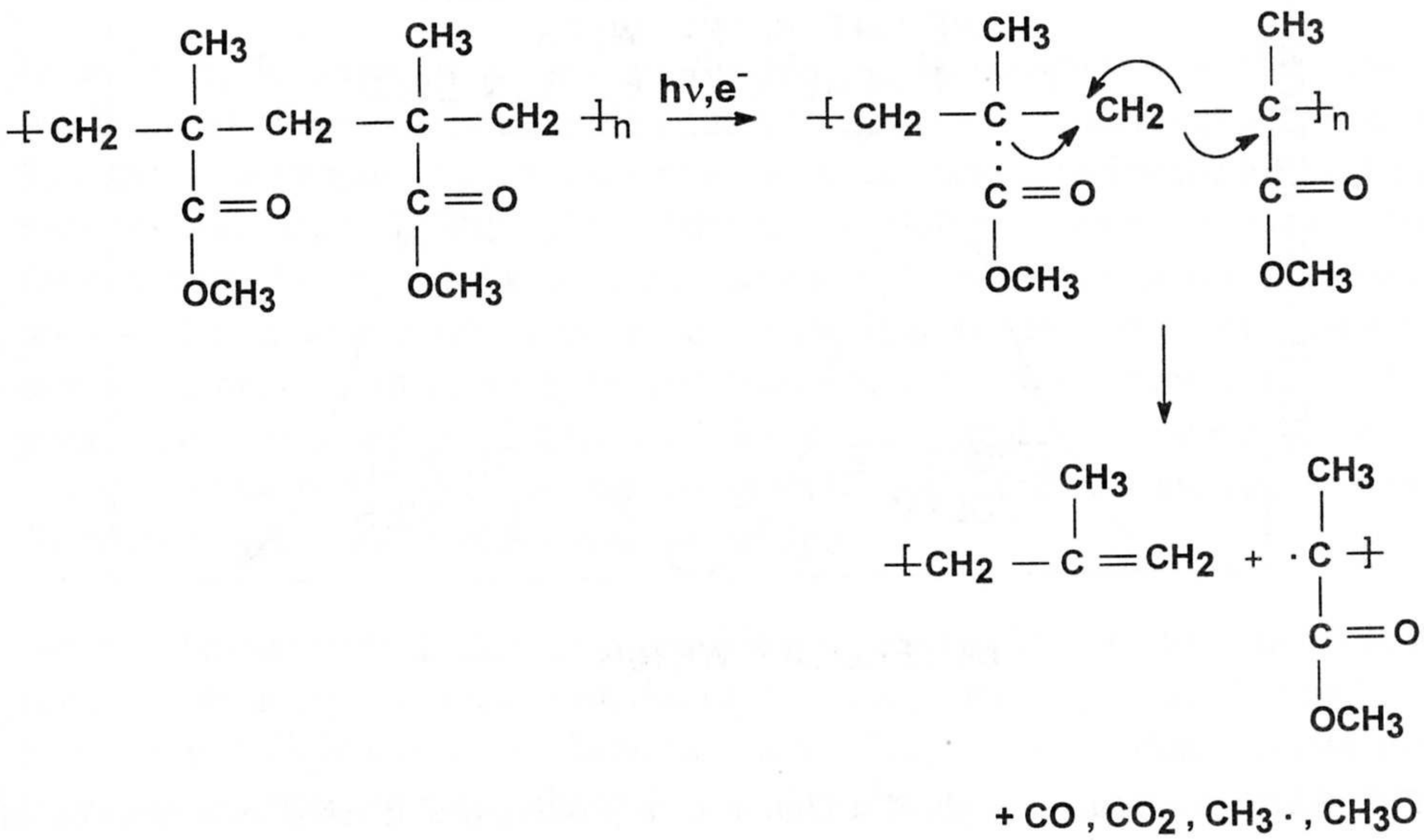


Typical Positive Resist process

EXAMPLE PROCESS: AZ5206 POSITIVE MASK PLATE

- Soak mask plate in acetone > 10 min to remove the original photoresist.
  Rinse in isopropanol, blow dry.
- Clean the plate with RIE in oxygen. *Do not* use a barrel etcher.
  RIE conditions: 30 sccm O2, 30 mTorr total pressure, 90 W (0.25 W/cm2), 5 mi
- Immediately spin AZ5206, 3 krpm.
- Bake at 80 C for 30 min.
- Expose with e-beam, 10 kV, 6 C/cm2, Make sure the plate is well grounded.
  (Other accelerating voltages may be used, but the dose will be different.)
- Develop for 60 s in KLK PPD 401 developer. Rinse in water.
- Descum - important Same as step 2 above, for only 5 seconds
  Or use a barrel etcher, 0.6 Torr oxygen, 150W, 1 min.
- If this is a Cr plate, etch with Transene Cr etchant, ~1.5 min.
  If this is a MoSi plate, then RIE etch:
  0.05 Torr total pressure, 0.05 W/cm2, 16 sccm SF6, 4.2 sccm CF4,1 min.
- Plasma clean to remove resist: same as step 2 above, for 3 min.

Negative Resist Cemistry

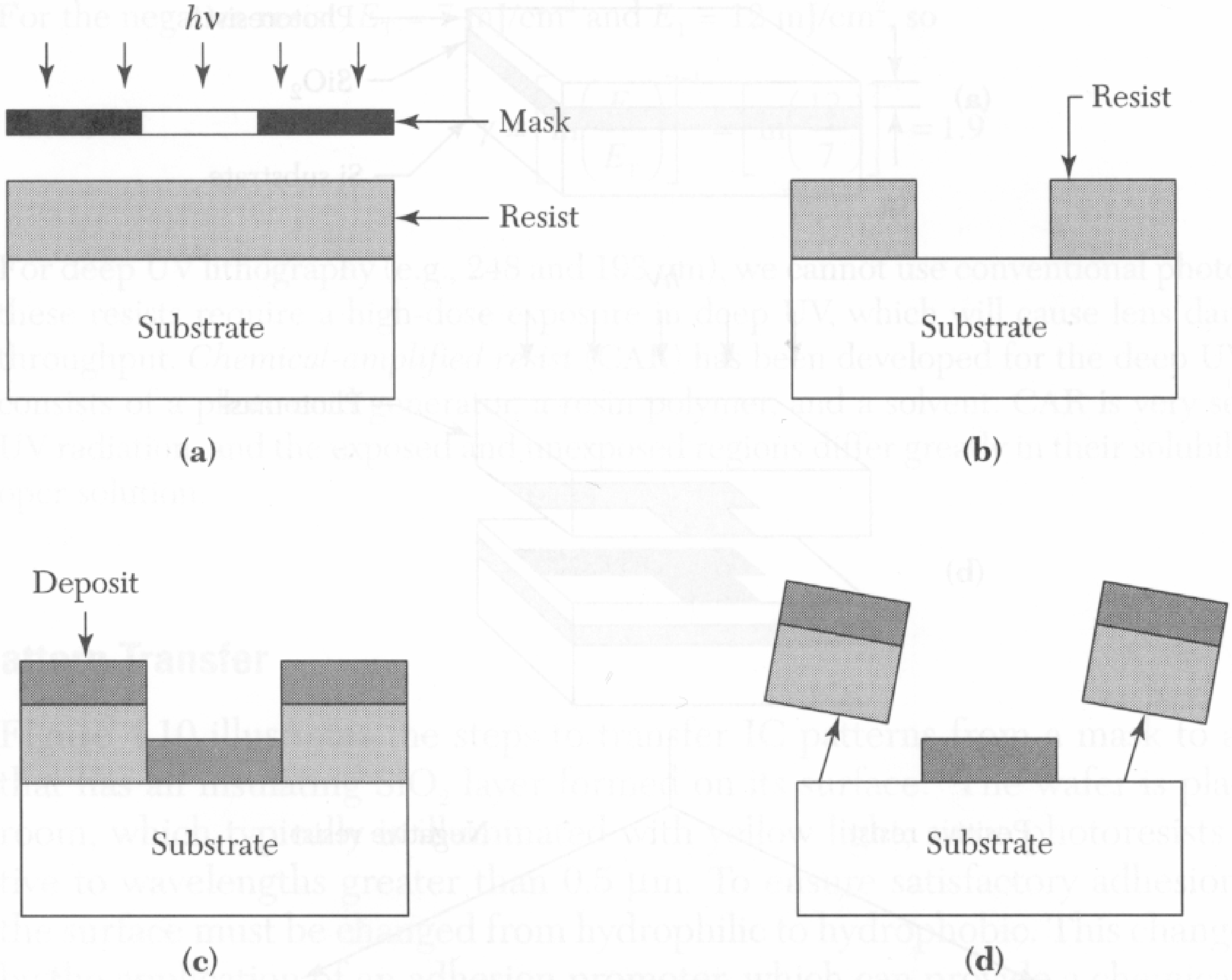


Typical Negative resist process

EXAMPLE PROCESS: SAL NEGATIVE MASK PLATE

- Soak mask plate in acetone > 10 min to remove photoresist.
- Clean the plate with RIE in oxygen. *Do not* use a barrel etcher.
  RIE conditions: 30 sccm O2, 30 mTorr total pressure, 90 W (0.25 W/cm2), 5 min.
- Immediately spin SAL-601, 4 krpm, 1 min.
- Bake in 90 C oven for 10 min. This resist is not sensitive to room light.
- Expose at 50 kV, 11 C/cm2. Be sure the plate is grounded.
- Post-bake for 1 min on a large hotplate, 115 C.
- Cool for > 6 min.
- Develop for 6 min in Shipley MF312:water (1:1) Be sure to check for underdevelopment.
- Descum 30 s with oxygen RIE: same as step 2, 10 s.
- Etch with Transene or Cyantek Cr etchant, ~1.5 min.
- Plasma clean to remove resist: Same as step 2, 5 min.

Lift-off Process



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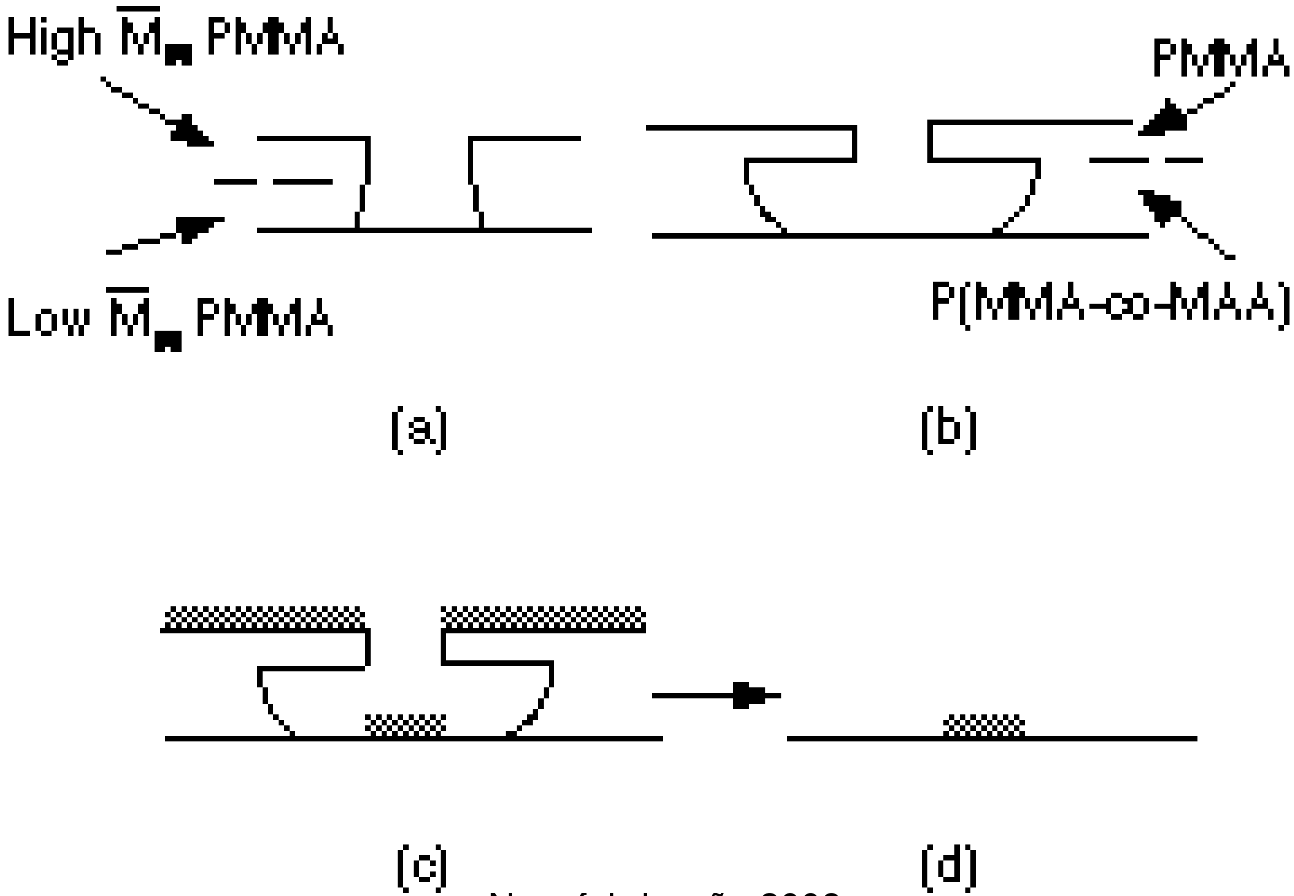
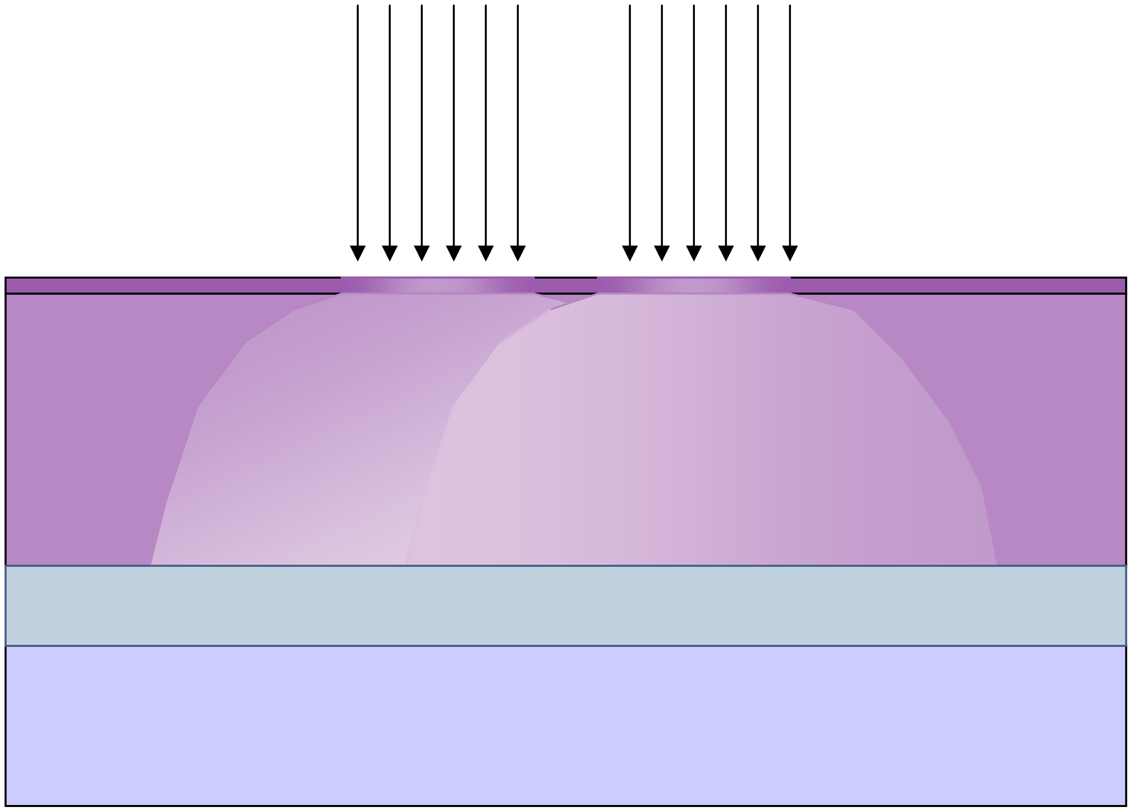
Liftoff requires undercut



Lithography and shadow evaporation

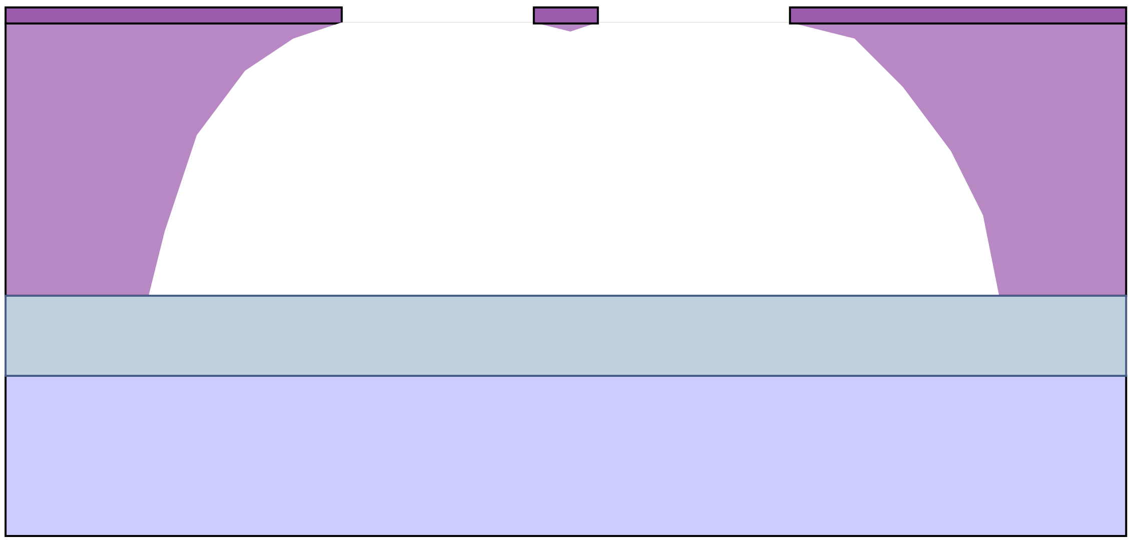
Lithography and shadow evaporation

Irradiate with electron beam



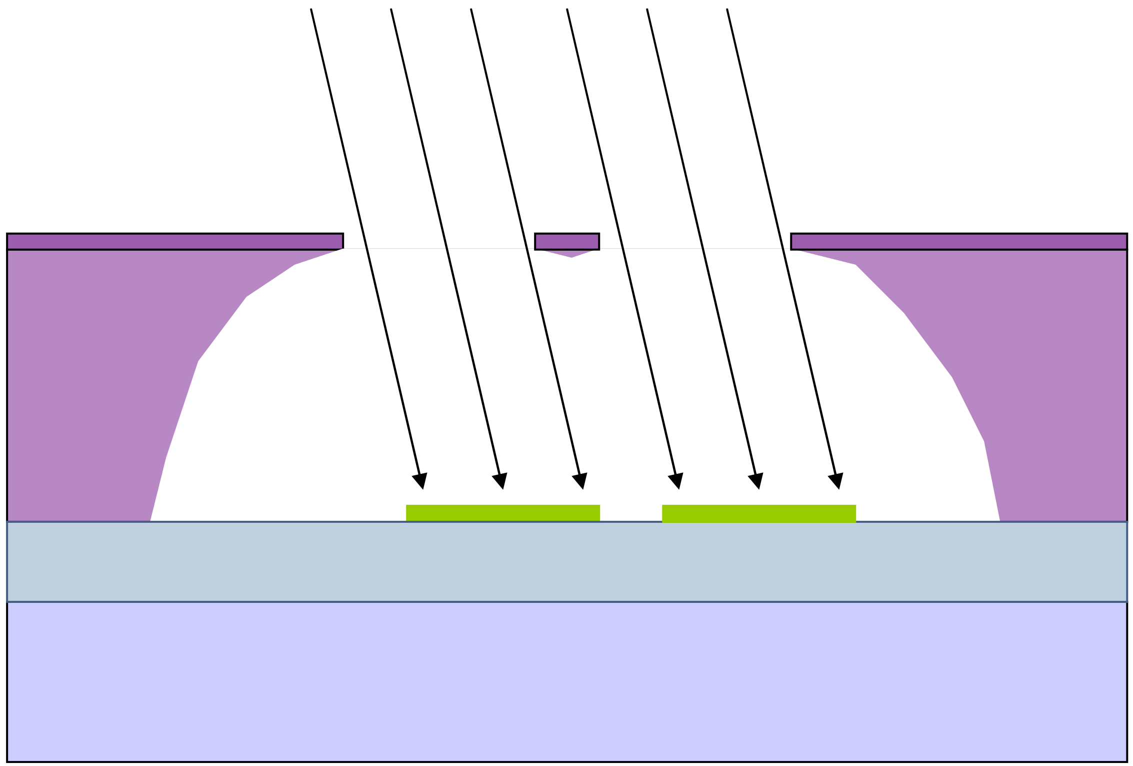
Lithography and shadow evaporation

Develop the two layers selectively
Top layer:
Bottom Layer:



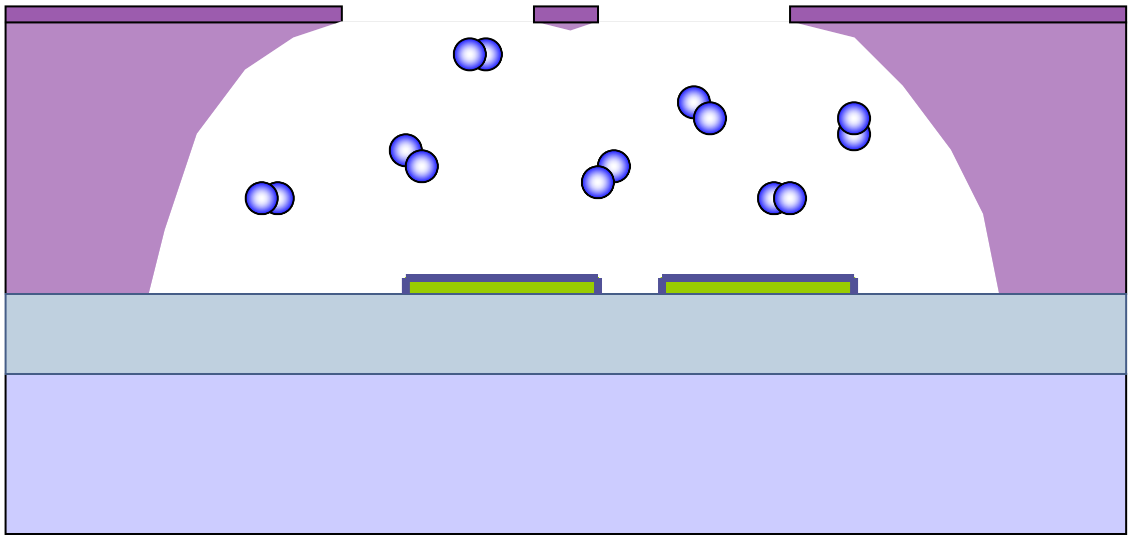
Lithography and shadow evaporation

Evaporate Al at an angle



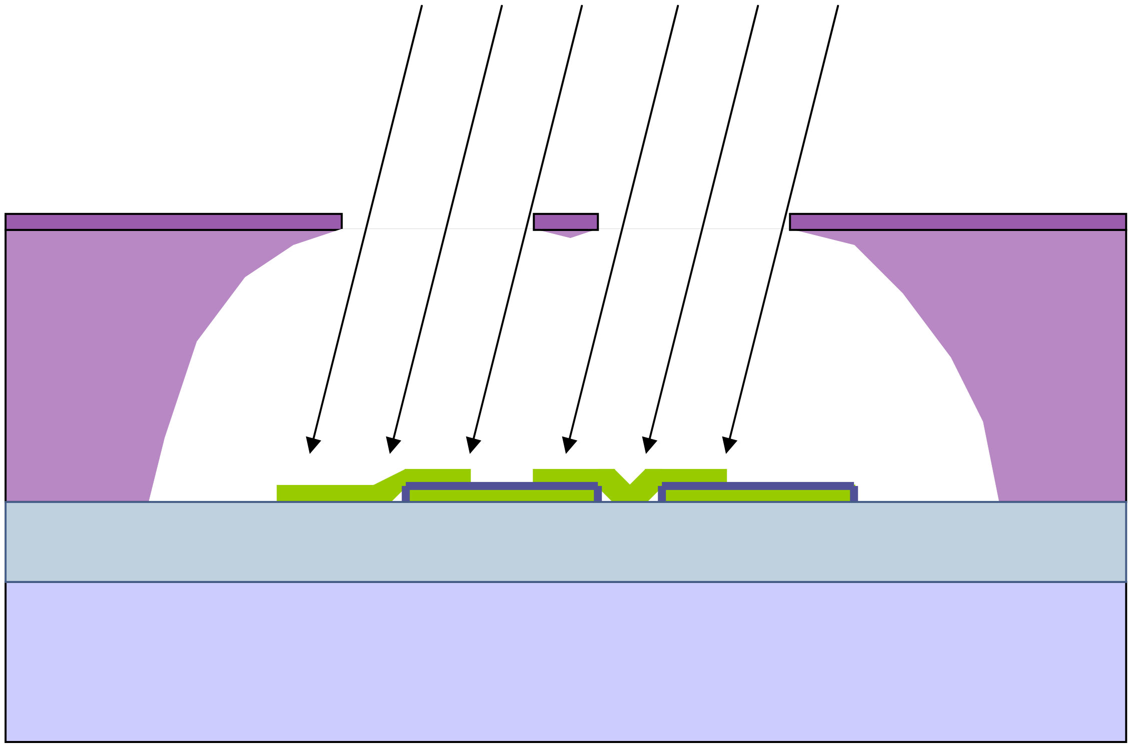
Lithography and shadow evaporation

Oxidize the first layer



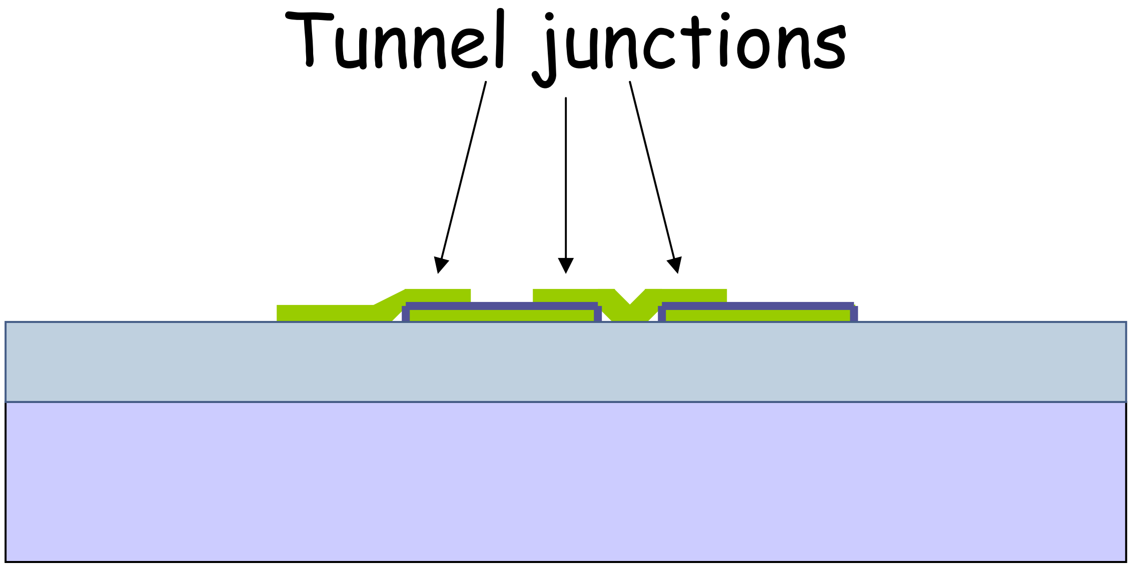
Lithography and shadow evaporation

Evaporate Al at opposite angle

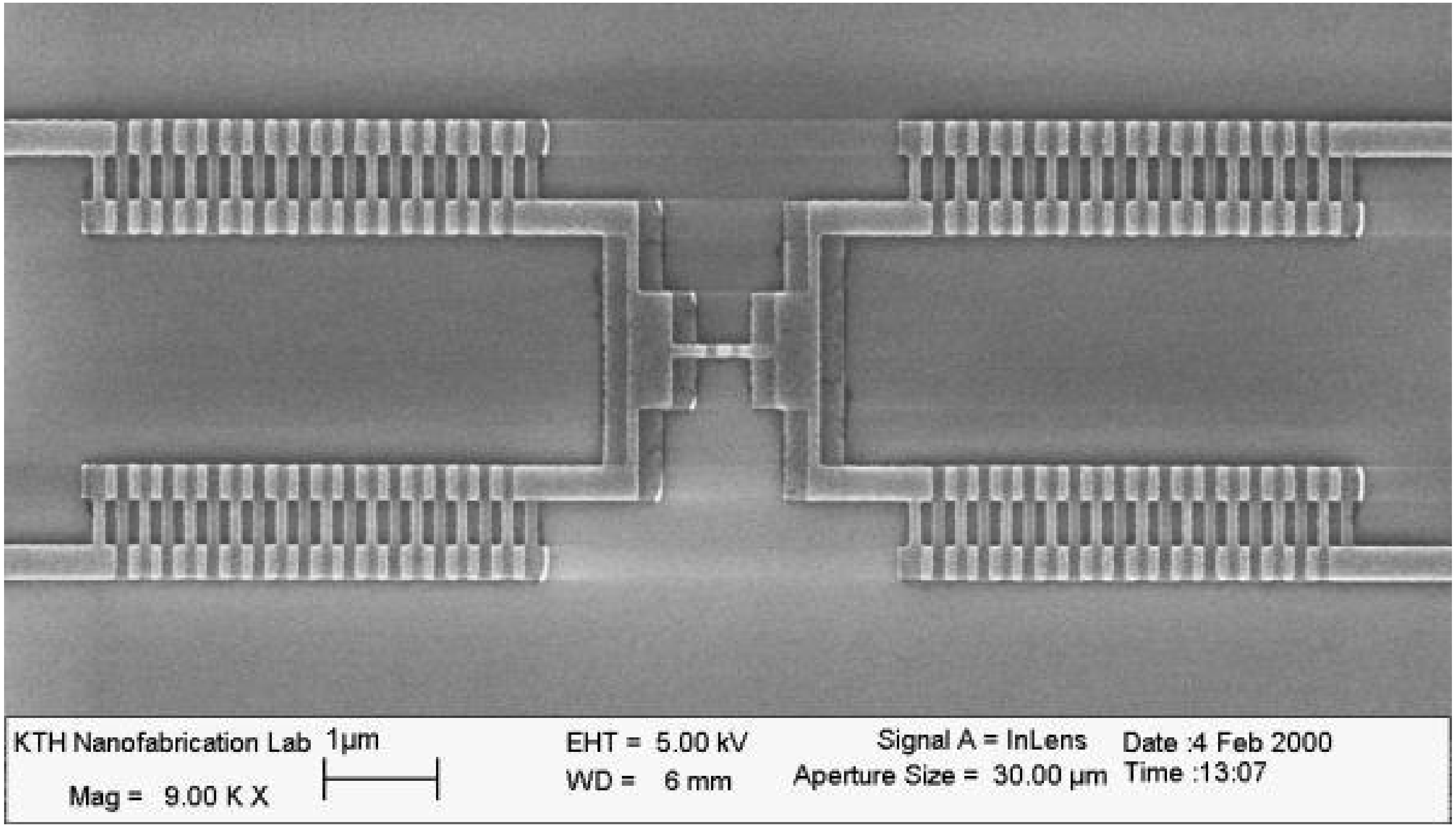


Lithography and shadow evaporation

Lift off the resist and excess metal



Voilà

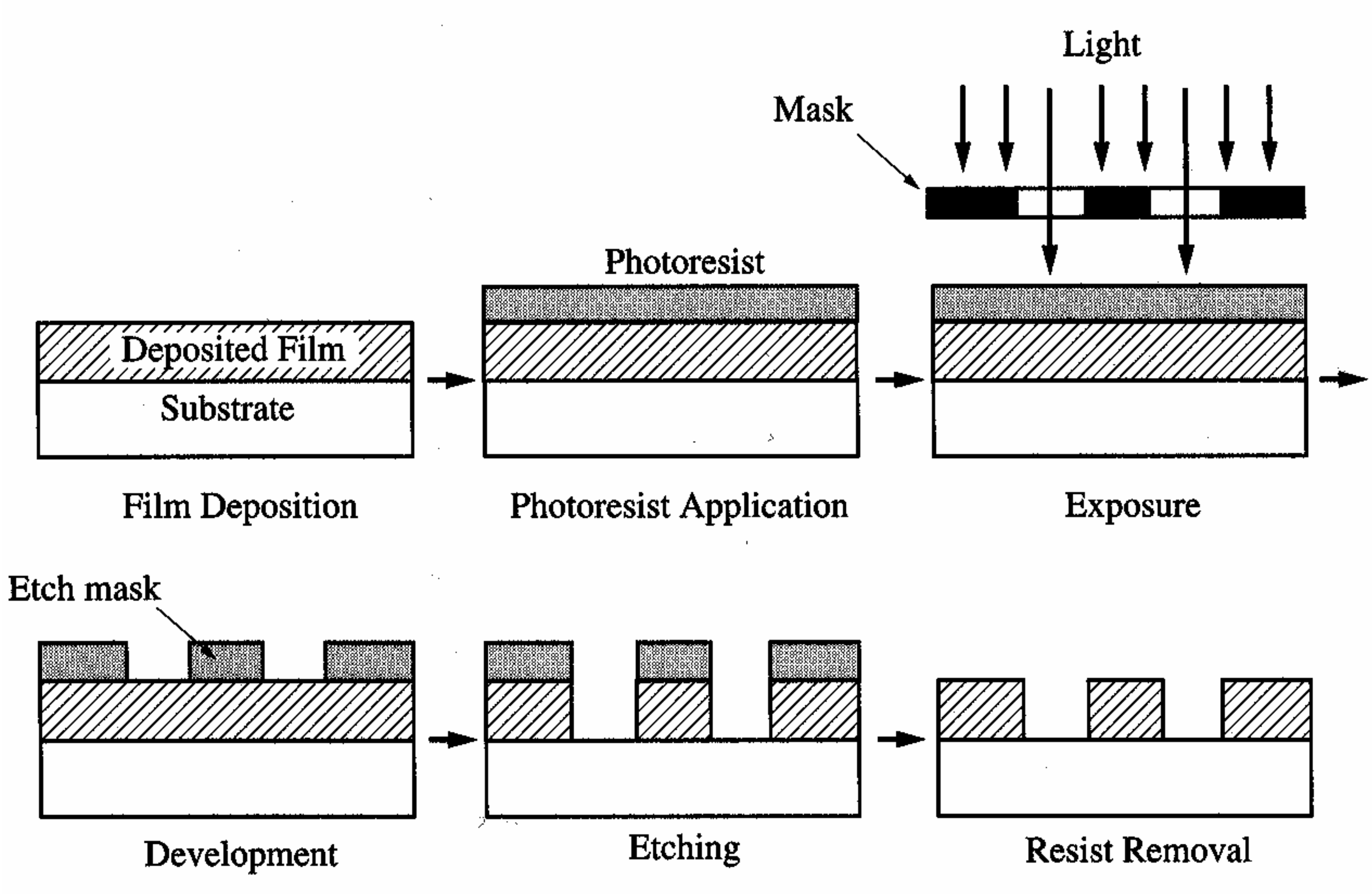


Circuit of SQUIDs and Josephson Tunnel Junctions

Etching

- **Chemical Etching**
  – Wet Etching
  – Plasma Etching
- **Physical Etching**
  – Sputter Etching
  – Ion Milling
- **Chemical/Physical Etching**
  – Chemically Assisted Ion Beam Etching (CAIBE)
  – Reactive Ion Etching (RIE)

Etching Procedures



Wet Etching

- **Etching Silicon Dioxide**

$SiO_2 + 6HF \rightarrow SiF_6 + 2H_2O + H_2\uparrow$

- **Etching Silicon**

$Si + HNO_3 + 6HF \rightarrow H_2SiF_6 + HNO_2 + H_2O + H_2\uparrow$

$Si + 2h^+ \rightarrow Si^{2+}$

$Si^{2+} + 2\,(OH)^- \rightarrow Si(OH)_2$

$Si(OH)_2 \rightarrow SiO_2 + H_2$

$SiO_2 + 6HF \rightarrow H_2SiF_6 + H_2O$

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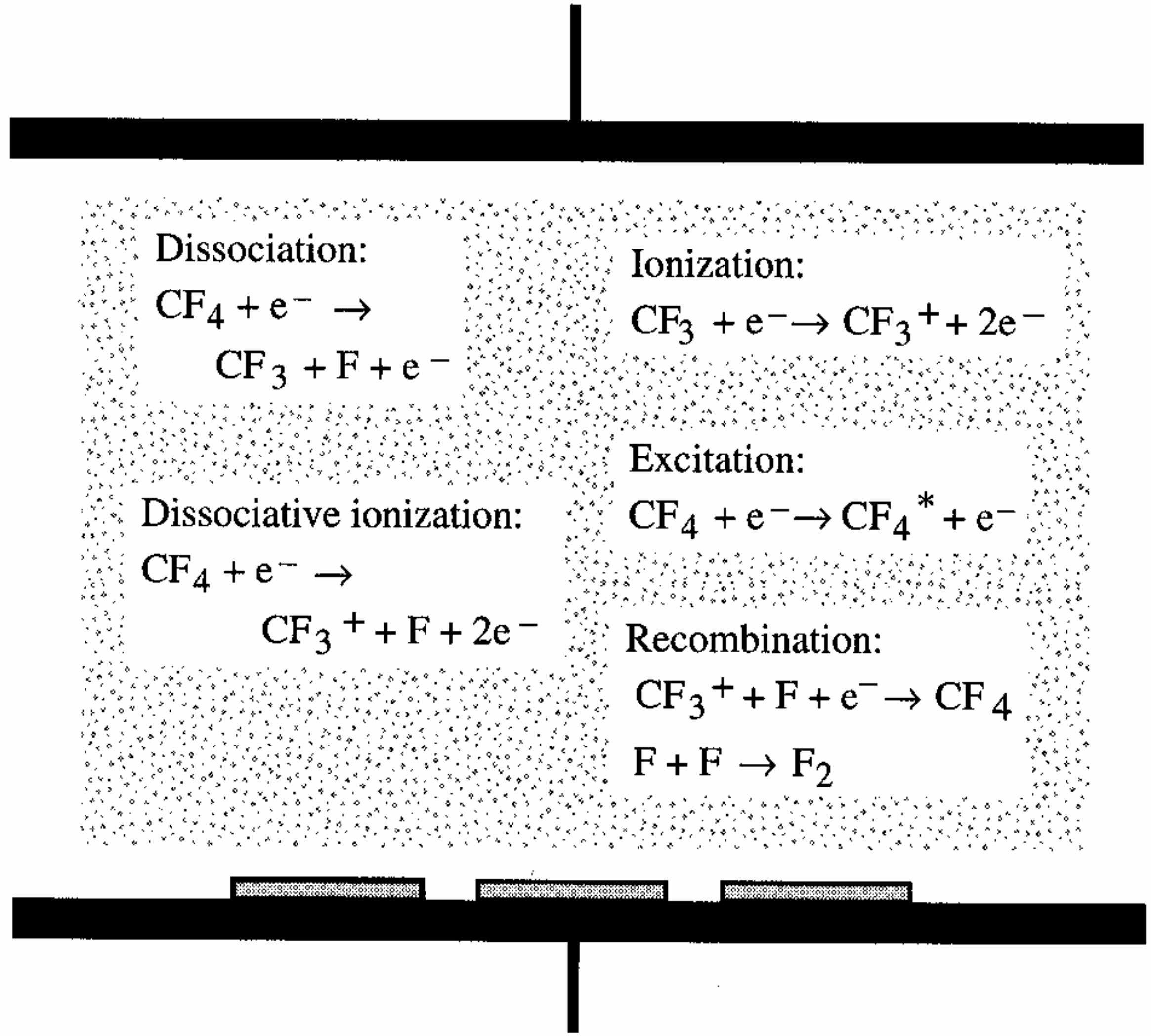
Plasma Etching



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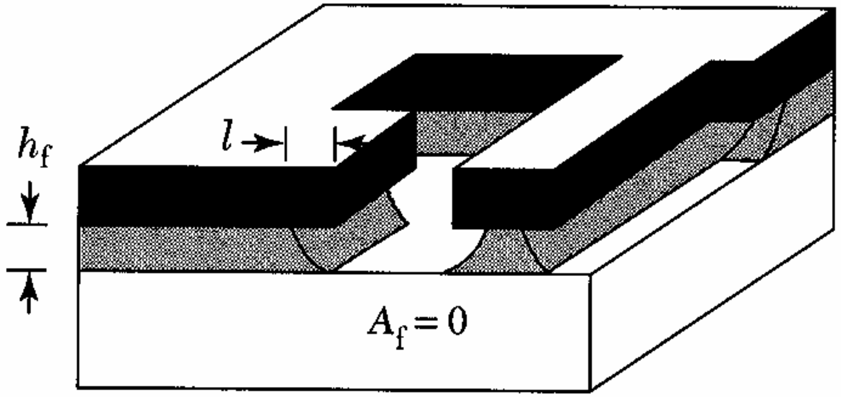
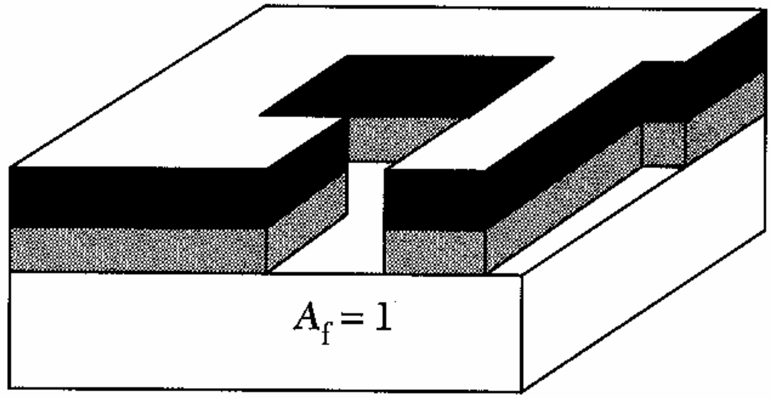
Problem with Chemical Etching



(b)



(c)

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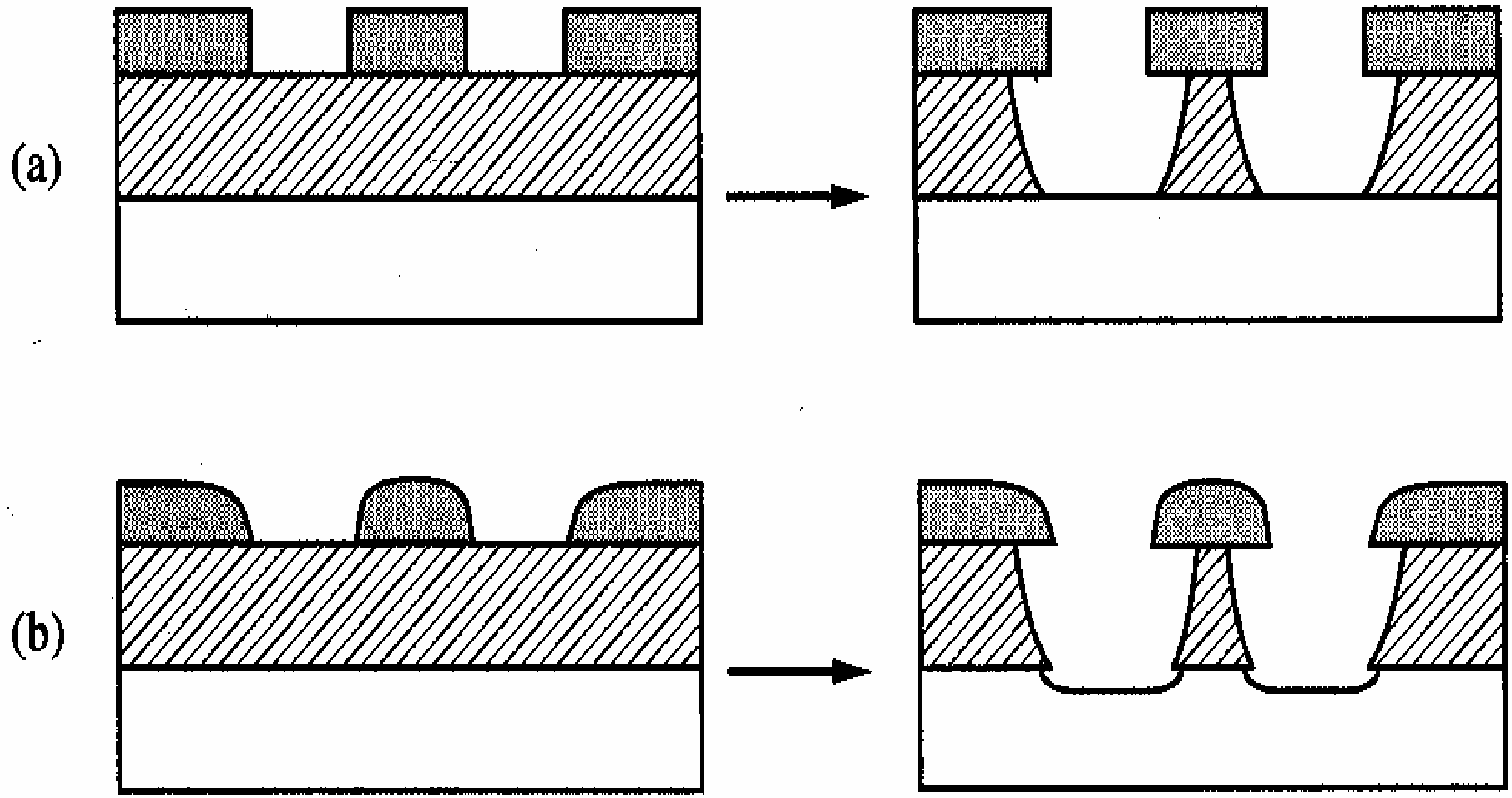
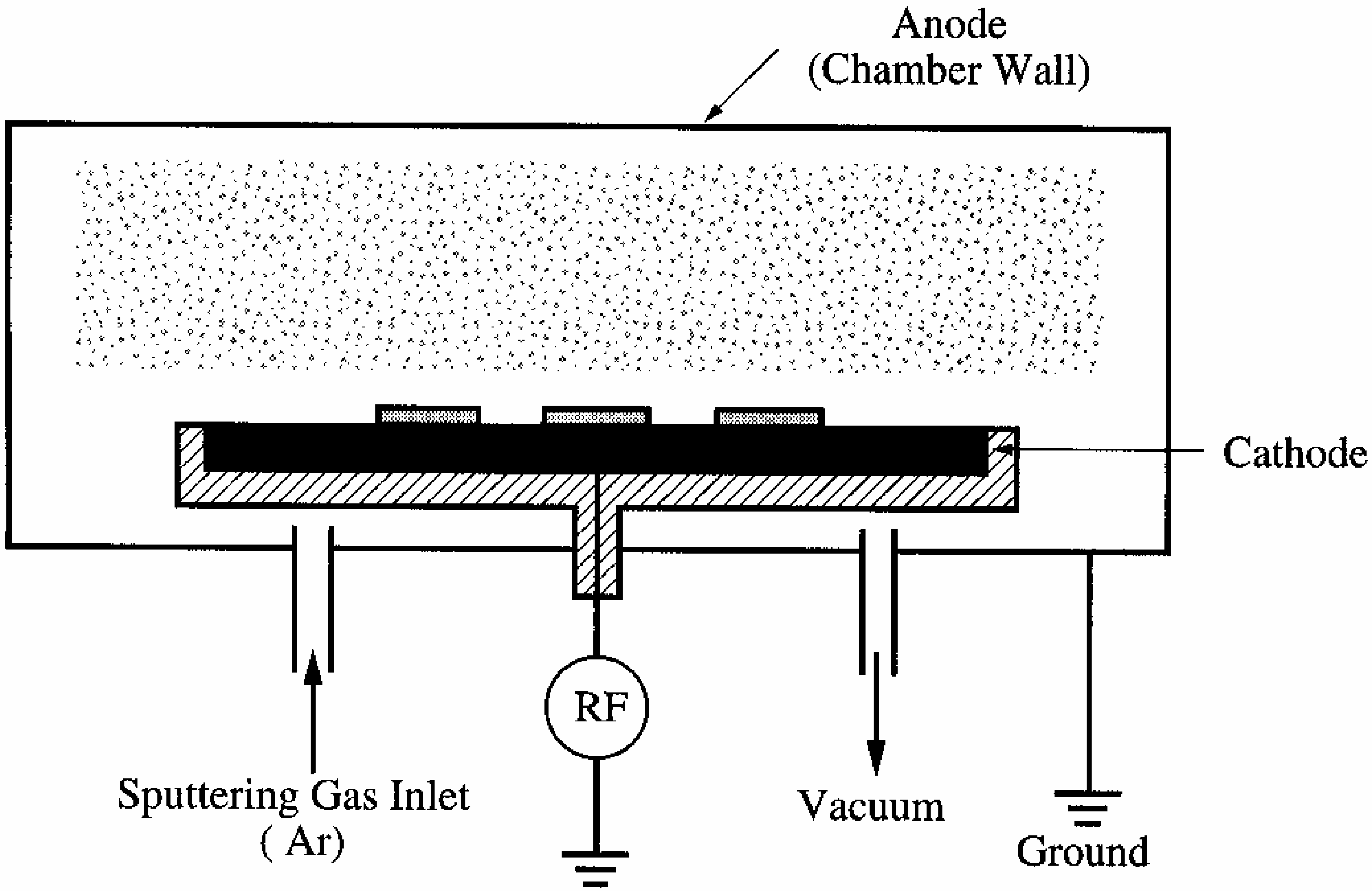
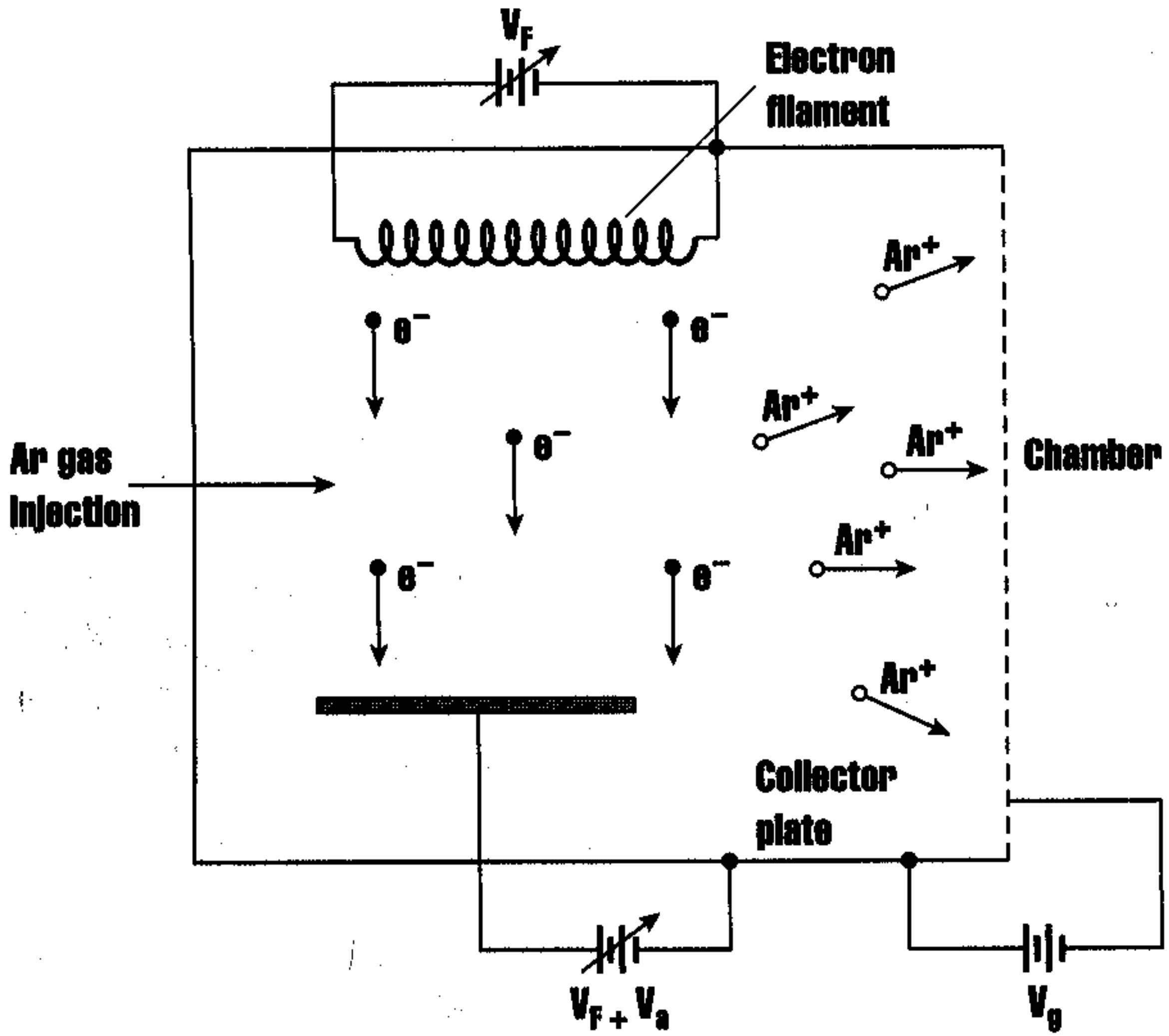
Isotropic and Selectivity



Sputter Etching



Ion Milling



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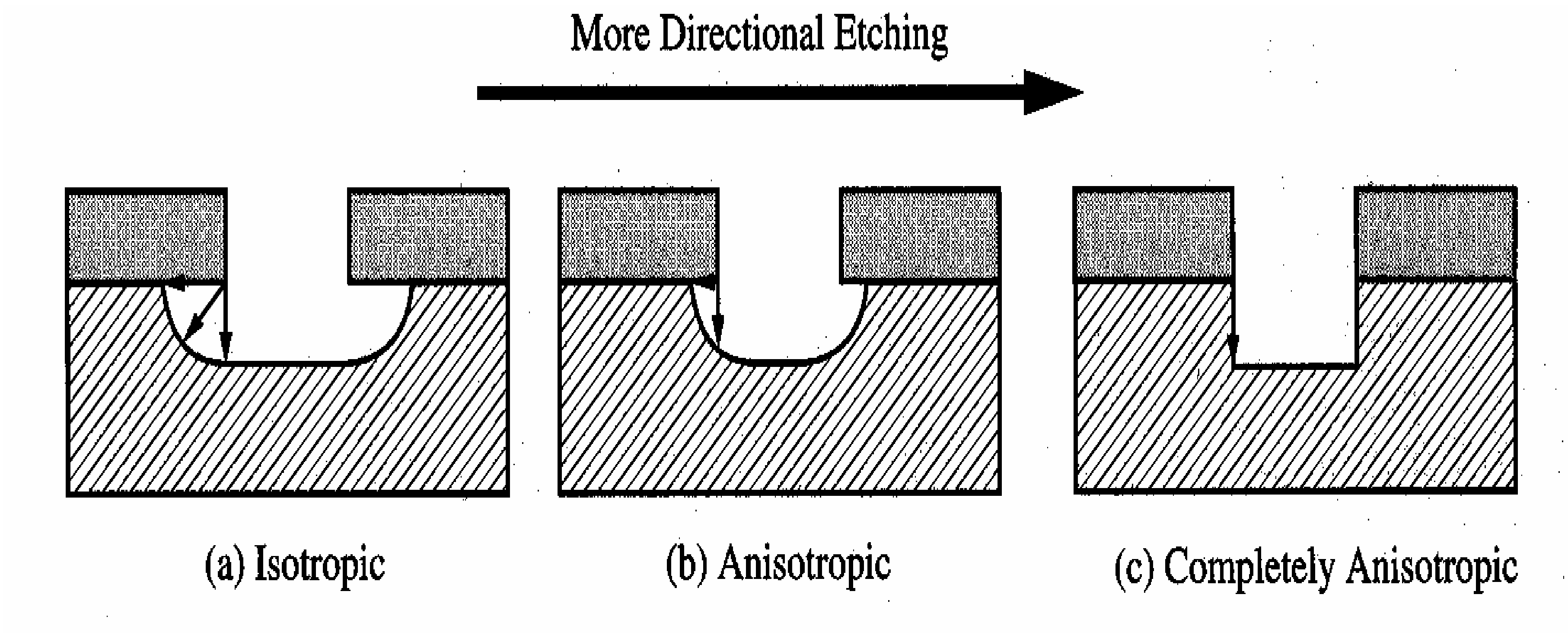
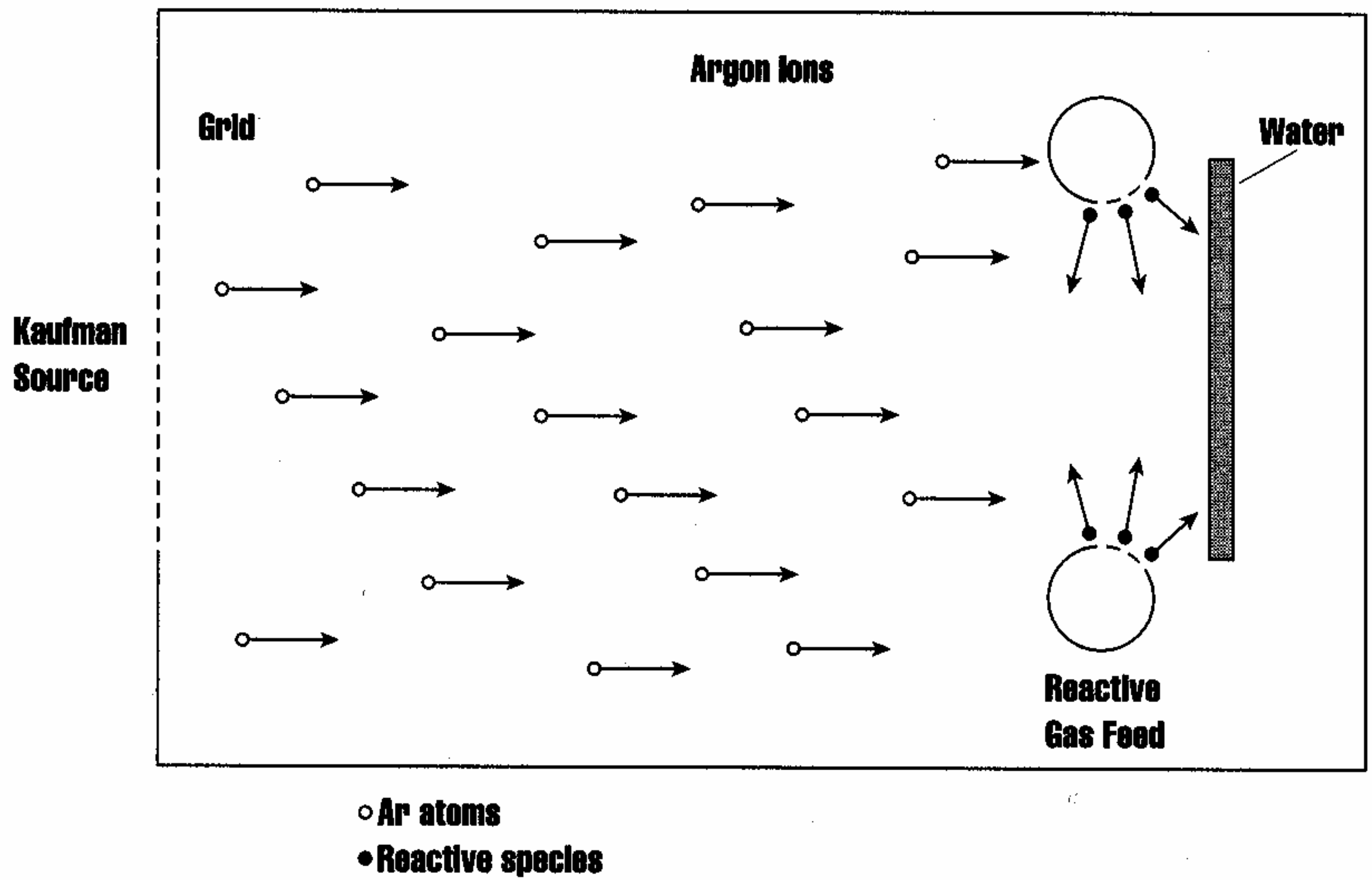
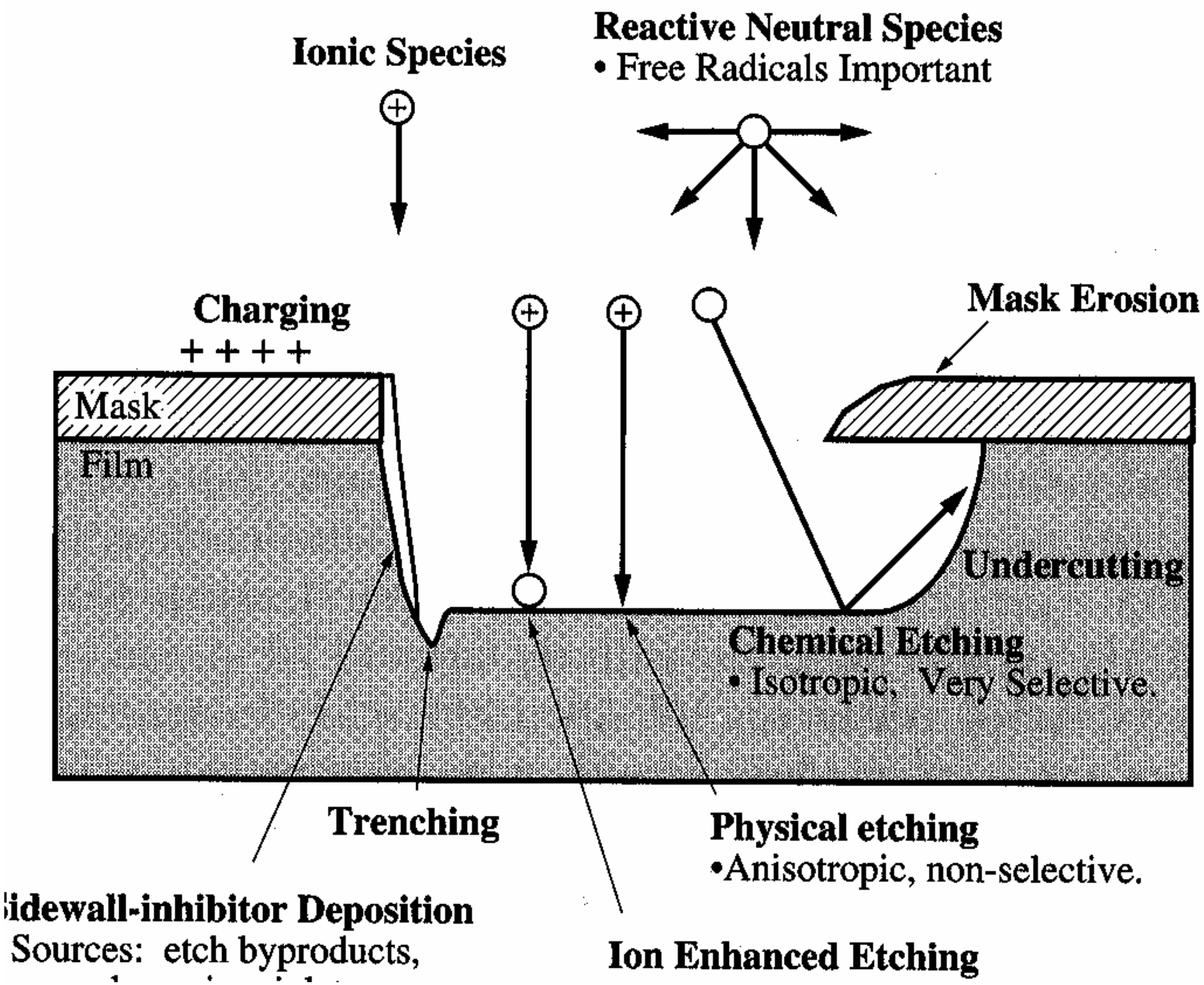
Comparison on Etching Profiles



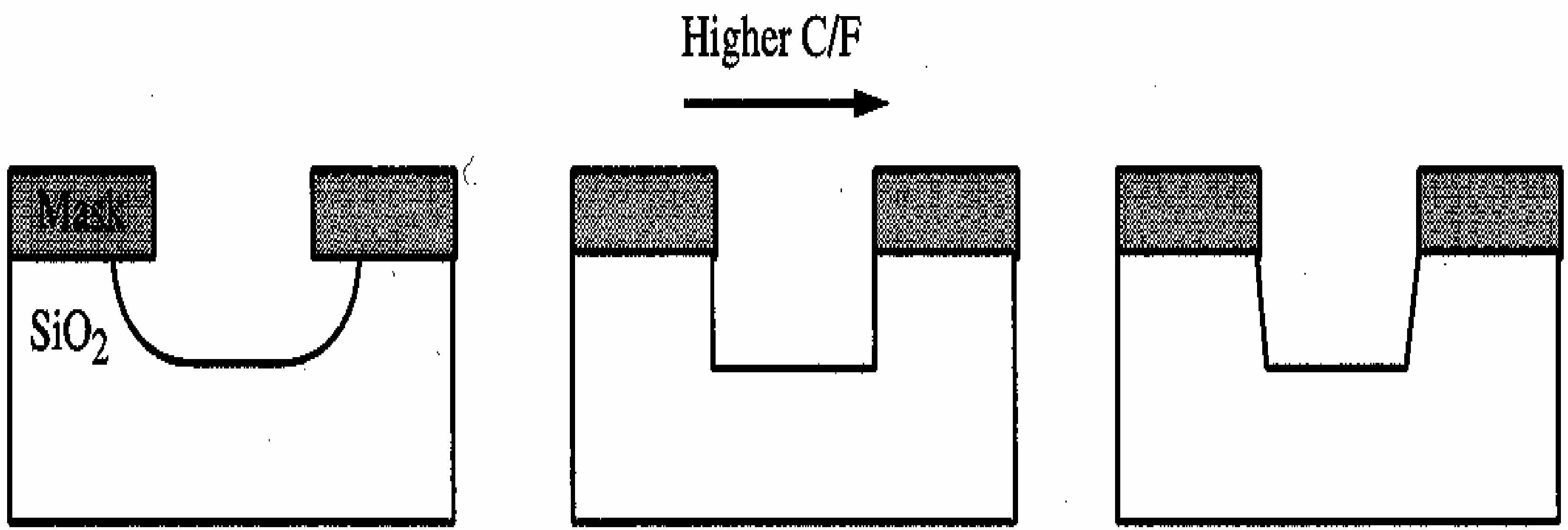
Chemically Assisted Ion Beam Etching (CAIBE)



Reactive Ion Etching



Side Wall Passivation

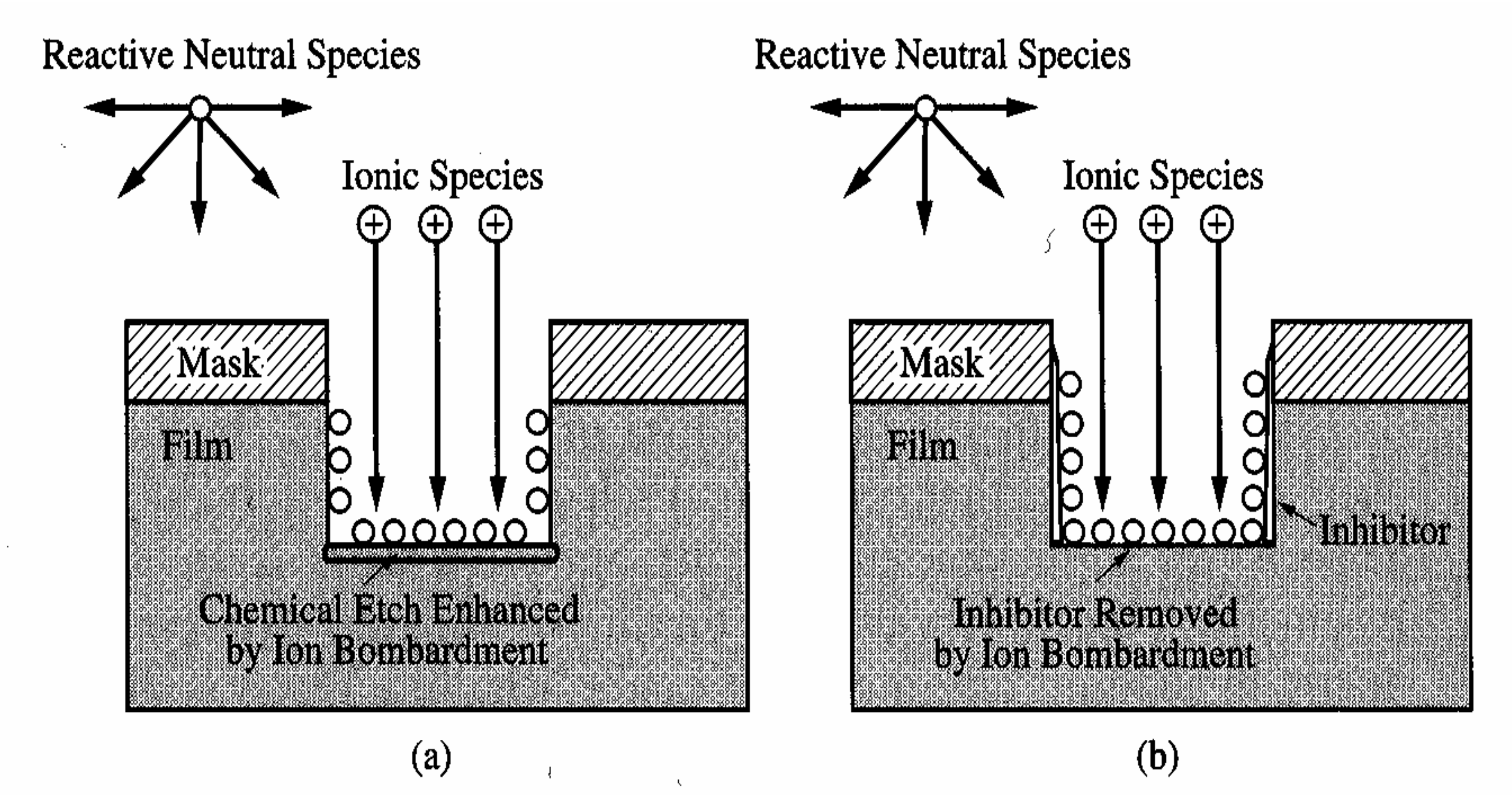


(a) Little or No Inhibitor Deposition (e.g. $CF_4 + O_2$)

(b) Inhibitor Deposition (e.g. $CF_4 + H_2$, or $CHF_3 + O_2$)

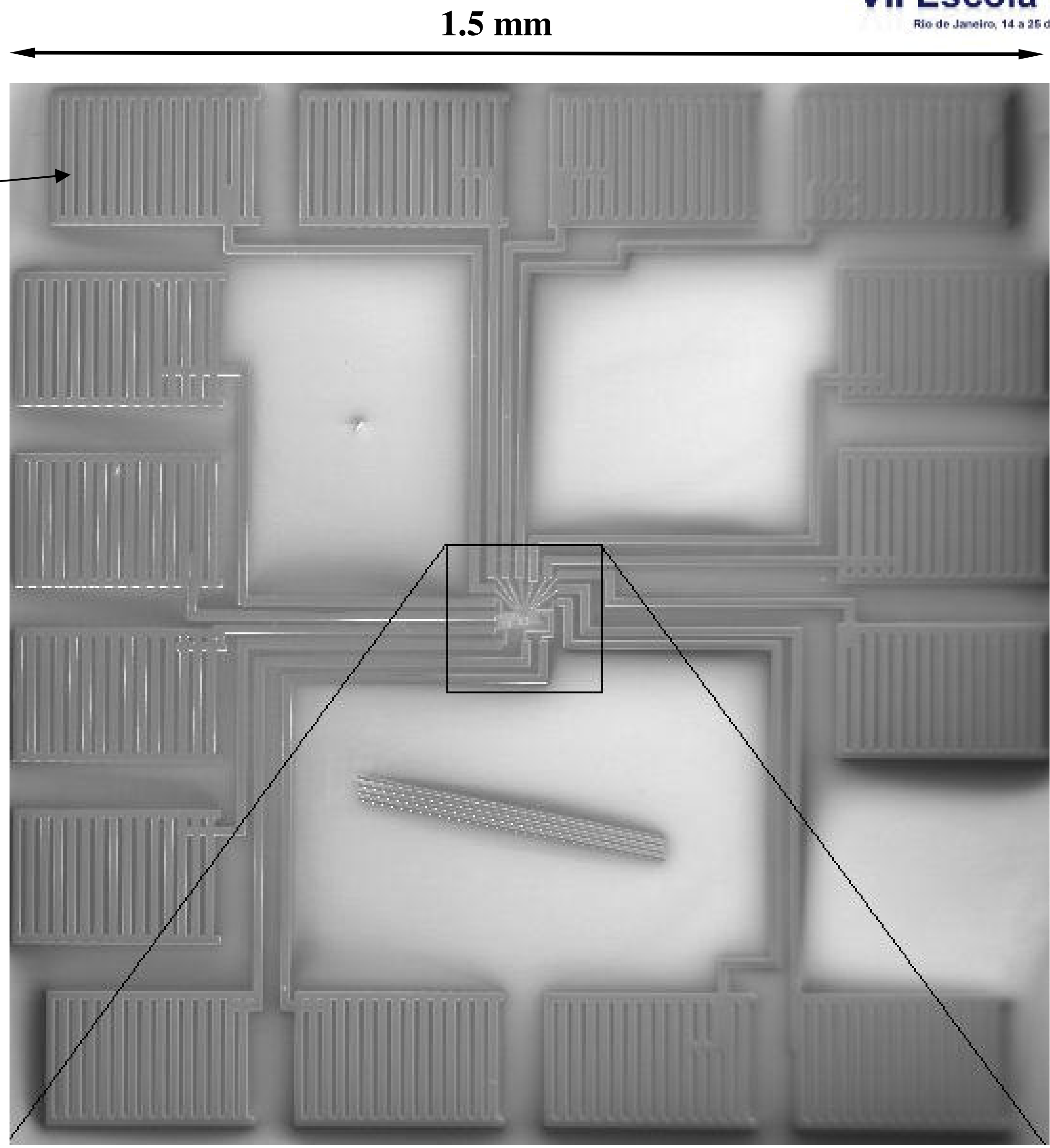
(c) Excess Inhibitor Deposition (e.g. CHF_3)

Optimized RIE



Some things you can do with EBL

Bonding
Pads



Contact "cage" to nano-circuit -- for rapid testing

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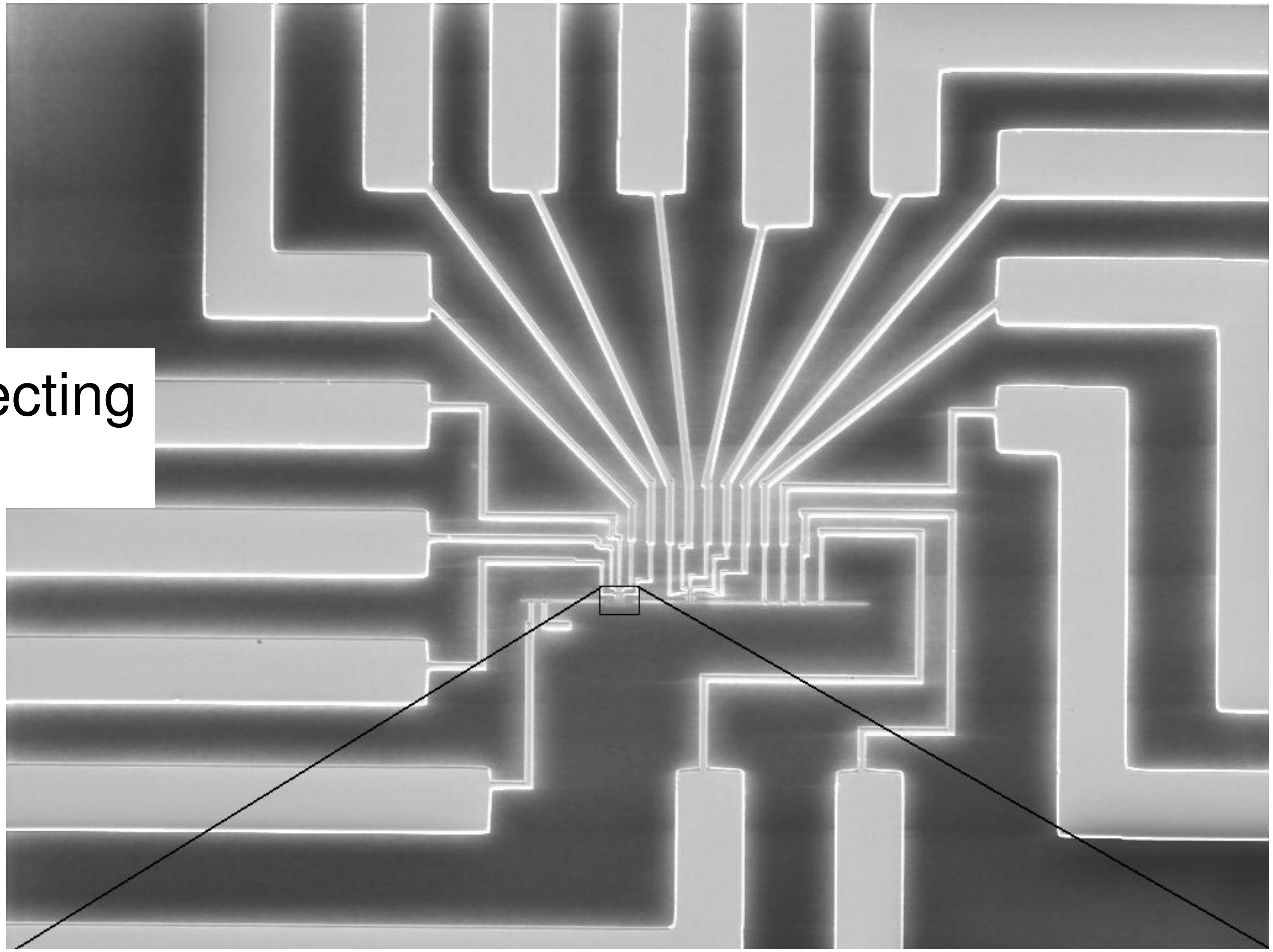
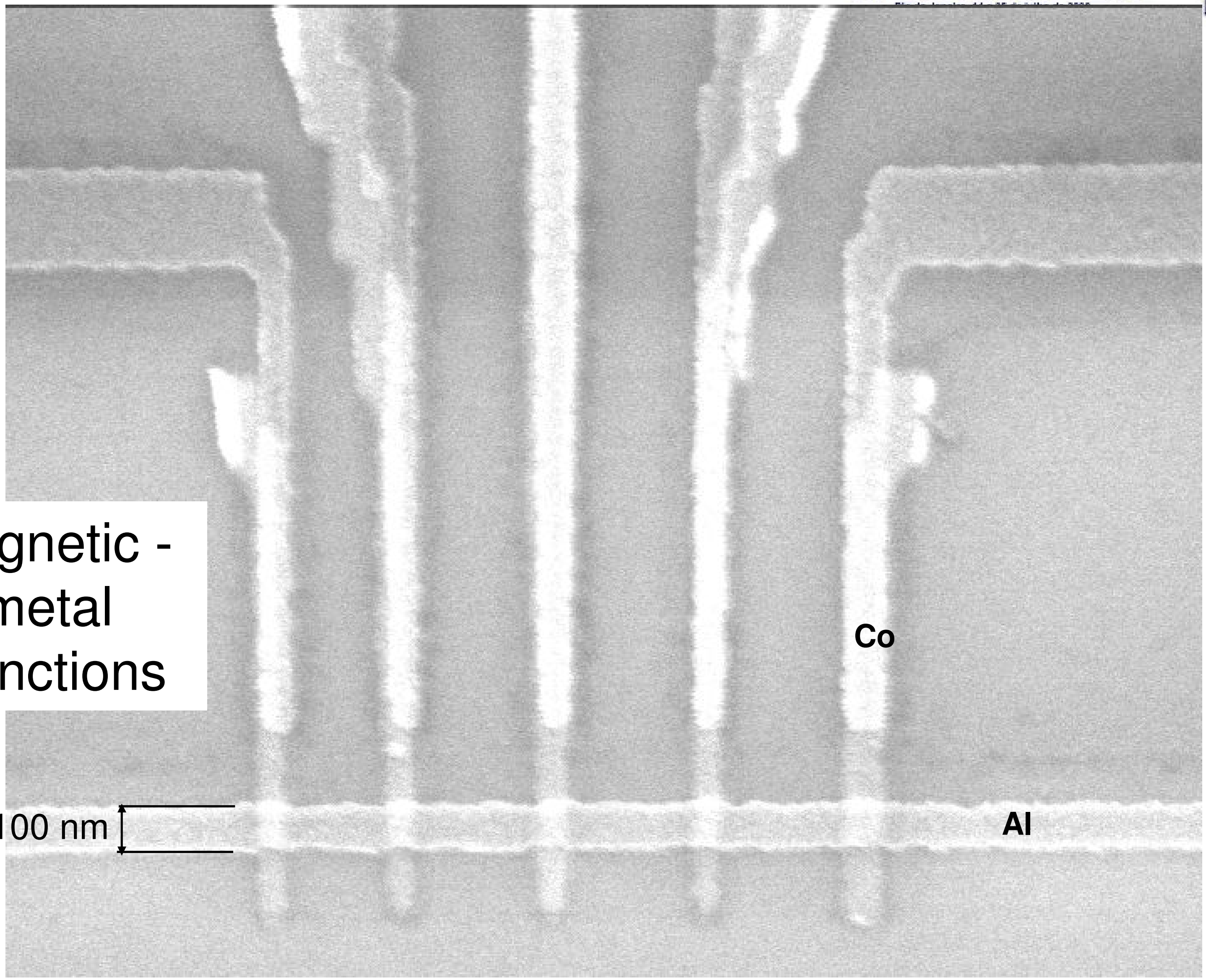


Connecting Strips

Ferromagnetic - Normal metal tunnel junctions



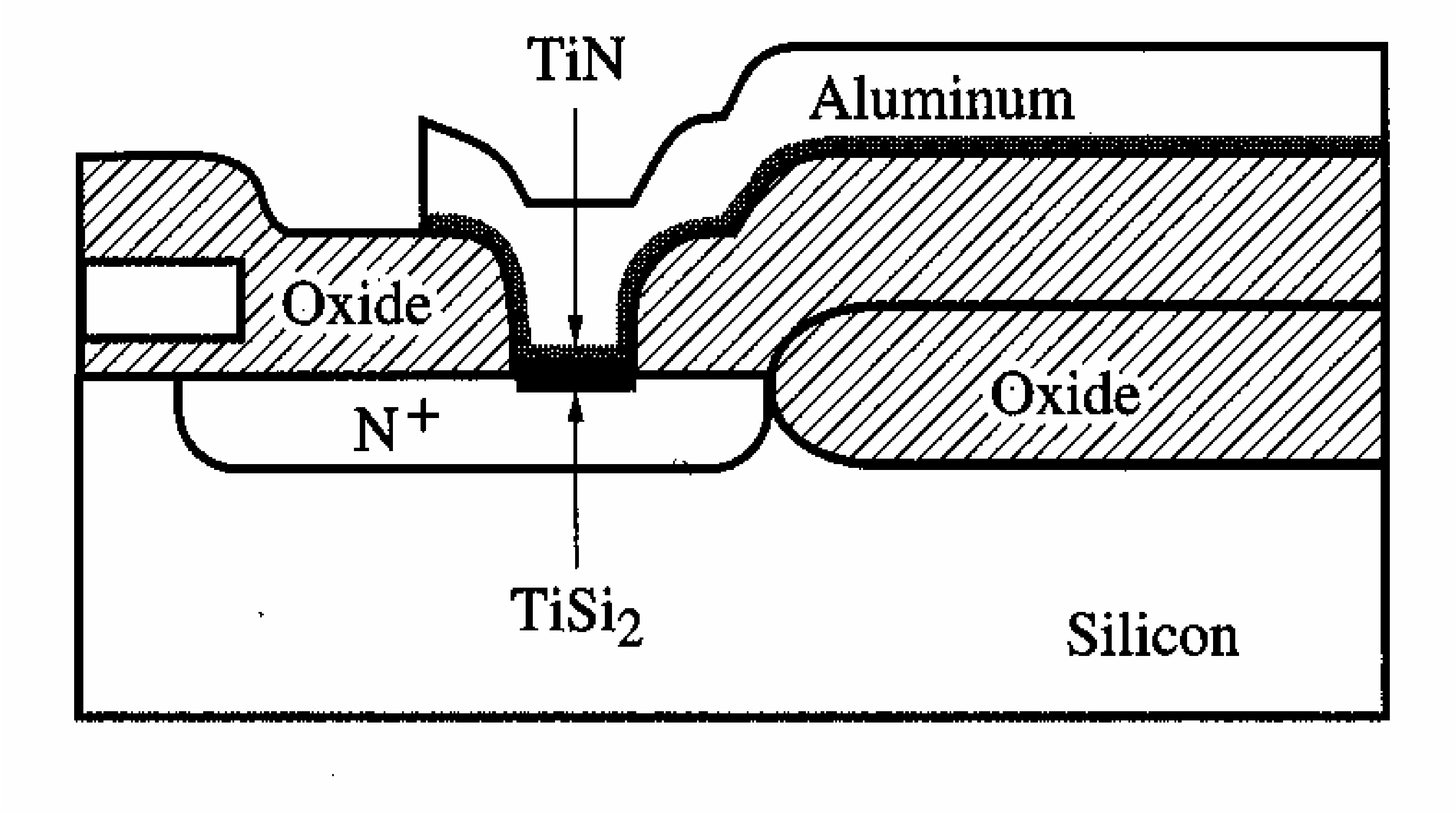
Circuit to measure spin injection from ferromagnet (Co) to normal metal (Al)

All these structure were made with *one* layer of e-beam lithography and *one* vacuum deposition cycle!

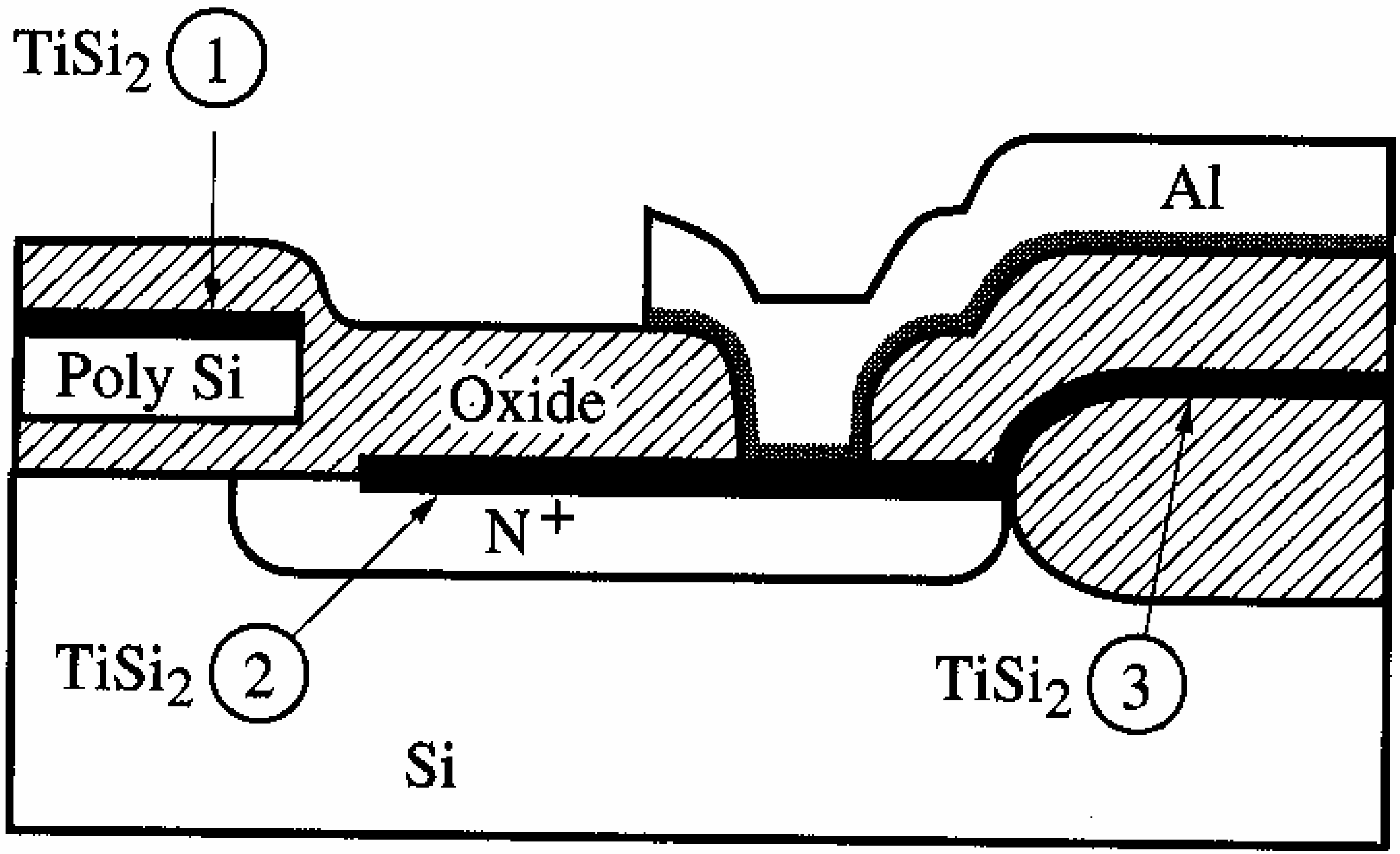
Interconnection

- Metal-Semiconductor Contact
- Metal Electromigration
- Multiple Layer Interconnection

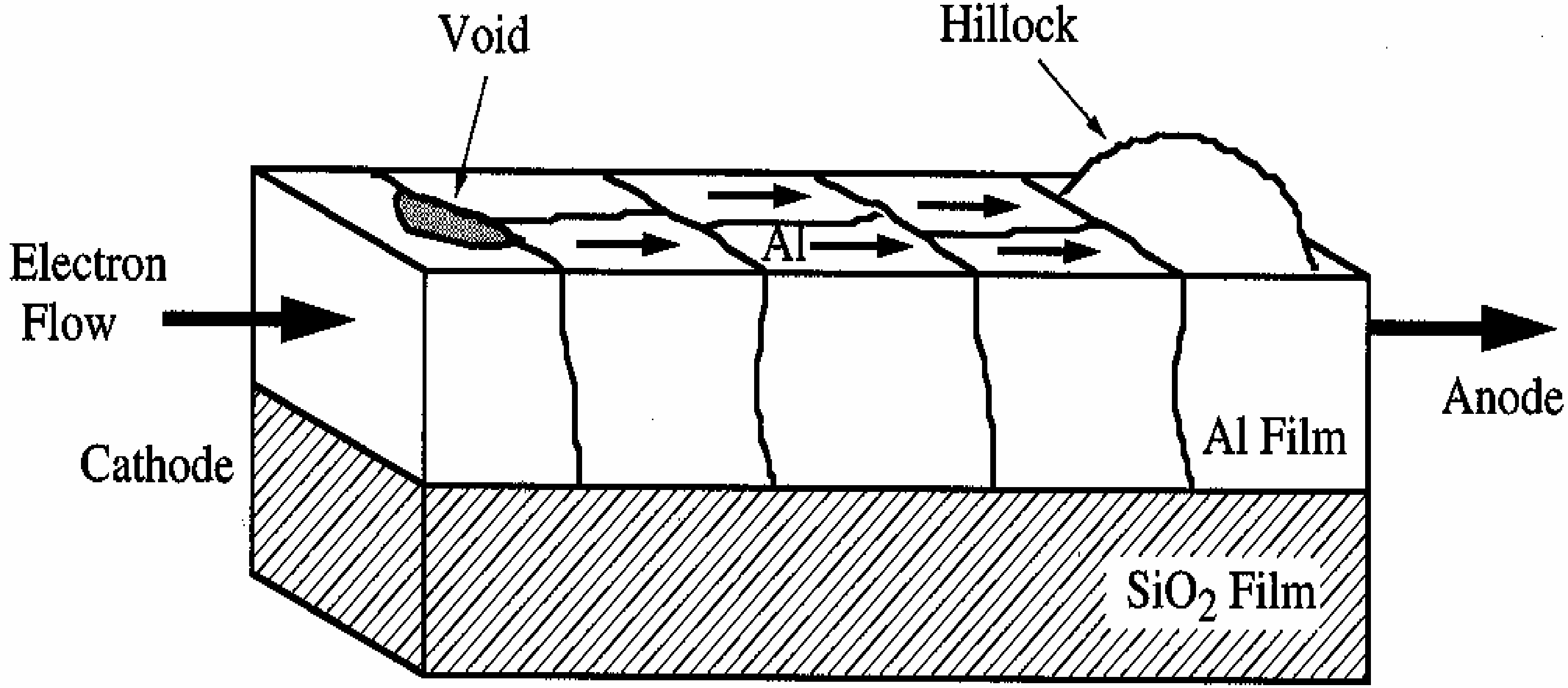
Silicide Barrier Material



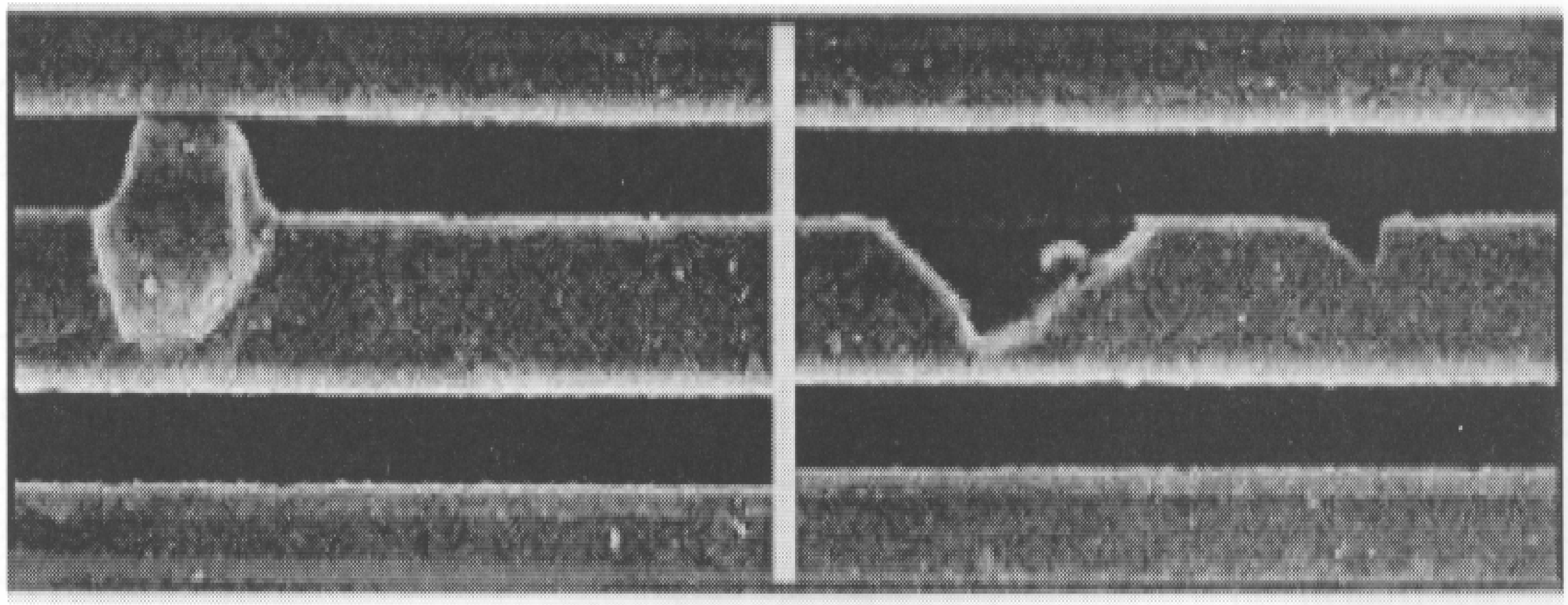
Resistance Reduction



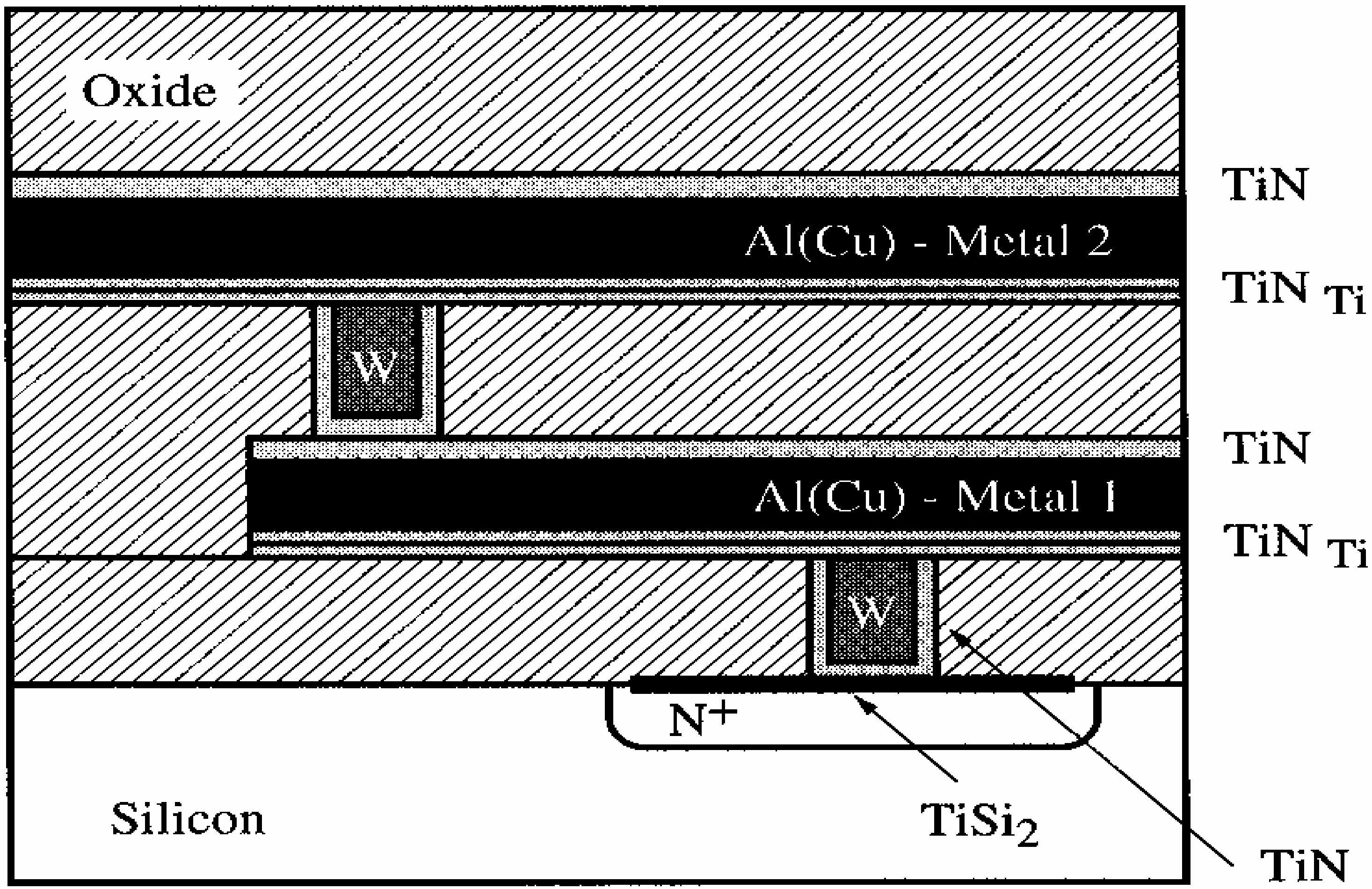
Electromigration



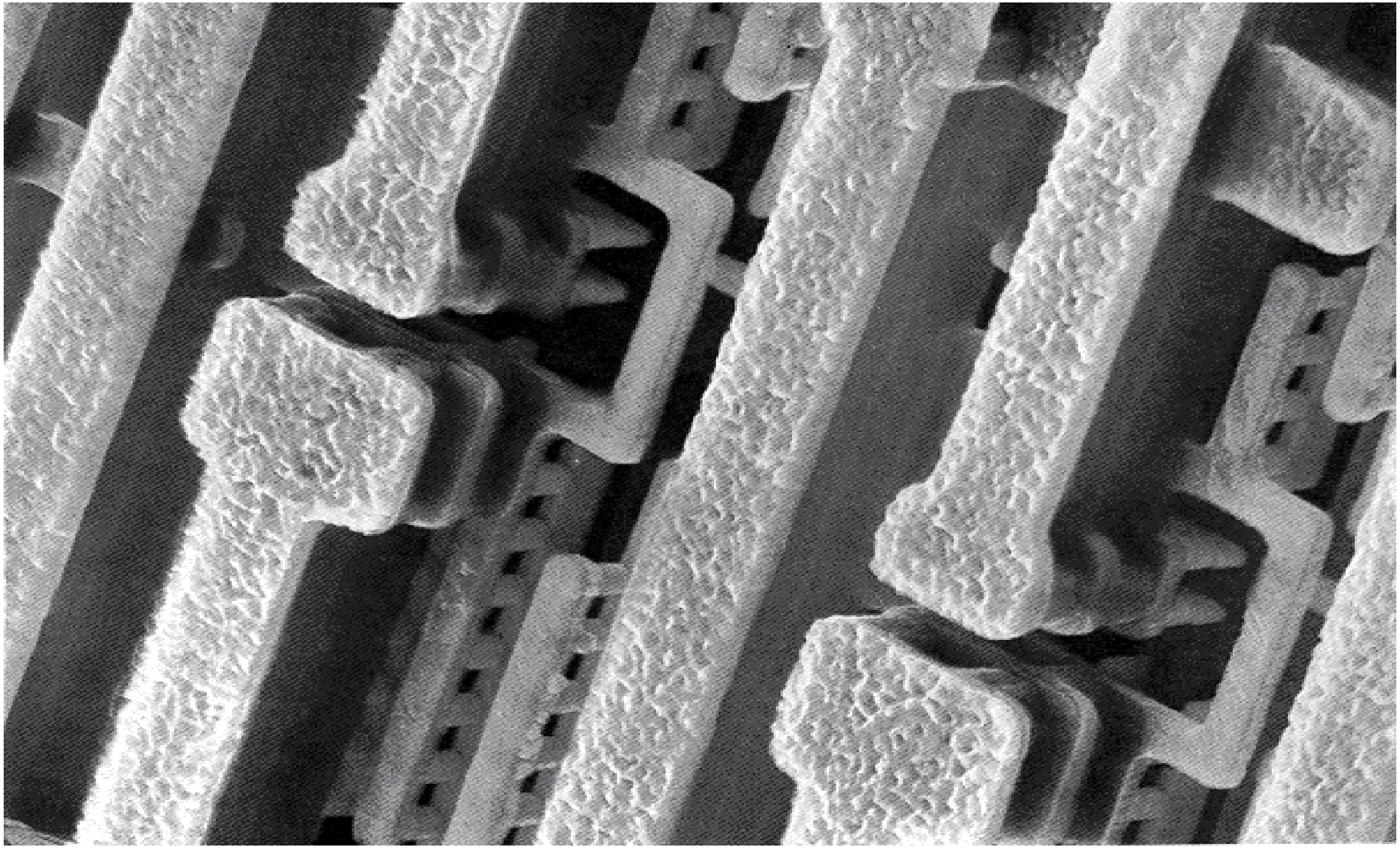
Open and Short Circuit



Multilayer Interconnection

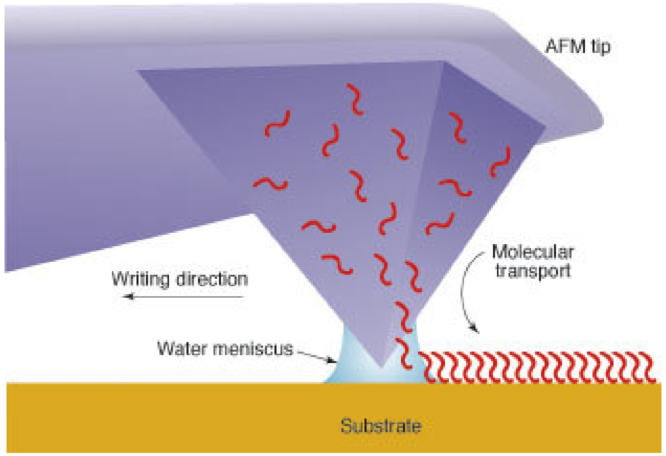


City on a Chip



Dip-Pen Nanolithography

- Scanning probe-based lithography technique using probe tip like a pen
- Tip is dipped in chemical “ink” and transfers nanoparticles, biomolecules, etc. to substrate through contact “writing”
- Resolution: 15 nm or better



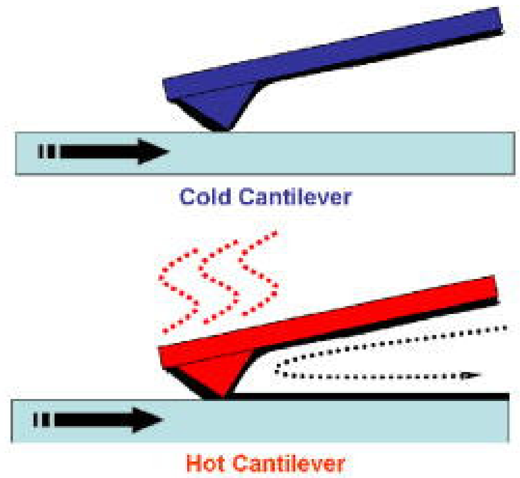
Dip-Pen Nanolithography

- Conventional DPN requires inks that are mobile at ambient conditions
  - Deposition rate controlled by changing ambient conditions (temperature, humidity) or heating/cooling substrate; dynamic control difficult
  - Unable to ‘turn-off’ deposition, causing contamination and smearing
  - Metrology not possible without unintended deposition or prior cleaning of probe tip
  - Emphasis on organics and biomolecules, not conductive metals

Thermal DPN

- Heating element integrated into cantilever
- Allows use of “inks” that are solid in ambient conditions
- Deposition easily turned on/off by modulating heating element
- Surface imaging possible without smearing/contamination

(a)



Direct deposition of continuous metal nanostructures by thermal dip-pen nanolithography

B.A. Nelson and W.P. King, Georgia Tech
A.R. Laracuente, P.E. Sheehan, and L.J. Whitman, Naval Research Lab

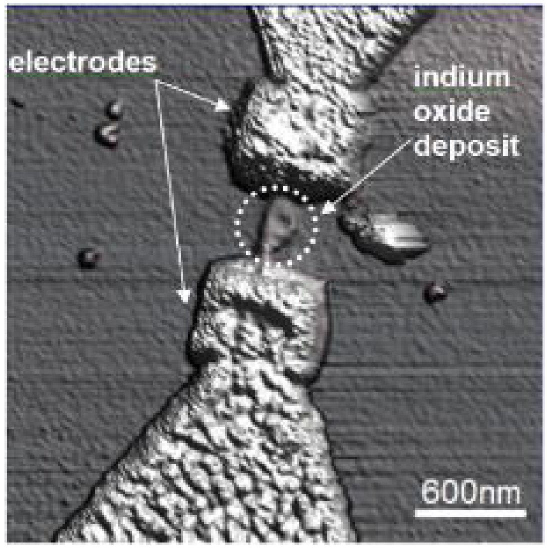
- Applied Physics Letter, January 2006

Experiments

- Silicon AFM cantilever with embedded microscale heater
- Estimated ~20 nm radius of curvature
- Thermal time constant of 1 - 10 µs
- Temperature sensitive resistance (2 - 7 kΩ for 25 - 550 °C) used for calibration
- Indium as deposition metal (melting point = 156.6 °C)
- Loading: Indium substrate scanned with 500 nN contact force at 6 µm/s with tip temperature of ~1030 °C

Experiments

- Continuous lines deposited by reheating cantilever while contacting substrate
- Dimensions depend on tip loading, temperature, speed, and repetitions
- Successful deposition for:
  - 250 - 800 °C
  - 0.01 - 18 μm/s
  - 32 - 128 raster scans
  - Borosilicate glass, quartz, silicon substrates

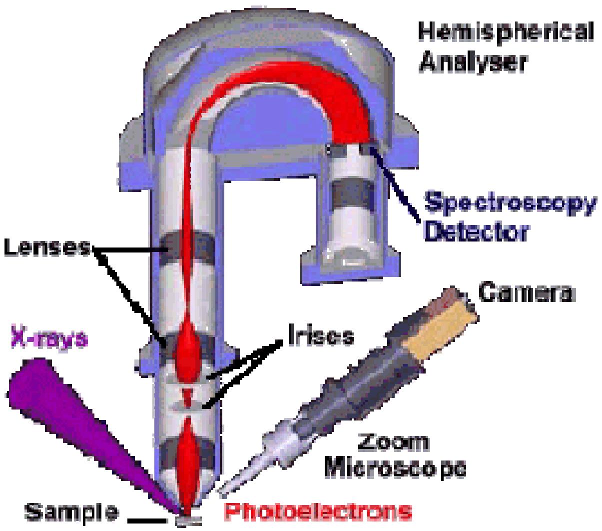


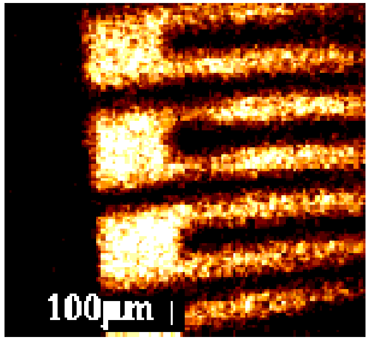
- 50 - 300 nm thick, 3 - 12 nm high
- Imaging with cooled, coated tip had no effect on deposited lines

Conclusions

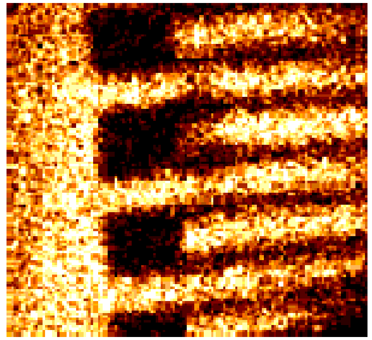
- Traditional DPN capabilities expanded by tDPN
- tDPN adds dynamic control of deposition, ability to scan with loaded tip, use of solid metal “inks”
- Technique could be used to perform *in situ* inspection and repair of nanoelectronics
- Parallel deposition/metrology possible with cantilever arrays

Imaging XPS





Si



SiOx

- Scan Analyzer
- Parallel Direct Imaging
- X-ray microprobe/Zone plate

Present: Submicron resolution