Lecture 5: Micromachining

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Recap: Last Class

- E-beam lithography
- X-ray lithography
- Ion beam lithography
- Oxidation

Today's Class

- Clean room fundamentals
- Si wafer preparation
- Chemical etching process
- Anisotropic Etching
- Silicon micromachining
  - Surface micromachining
  - Bulk micromachining
  - How to produce devices

Clean Room Fundamentals

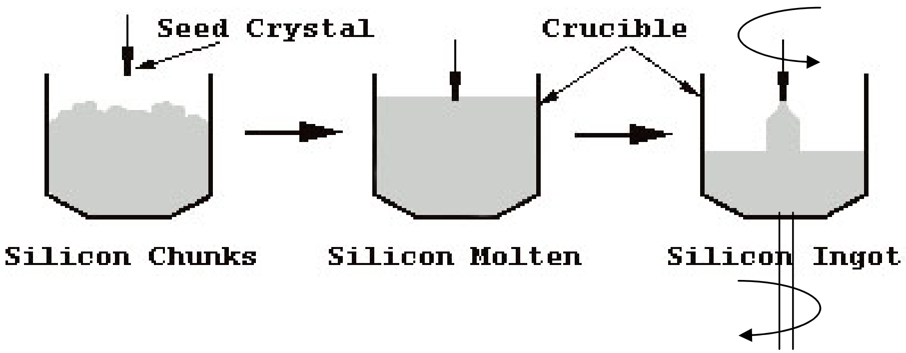
- Need
- Class of a clean environment
- Class X clean room → not more than X particles (of size 0.5μm or larger) per cubic foot of air
- How this cleanliness is produced and maintained??

Clean Room Fundamentals

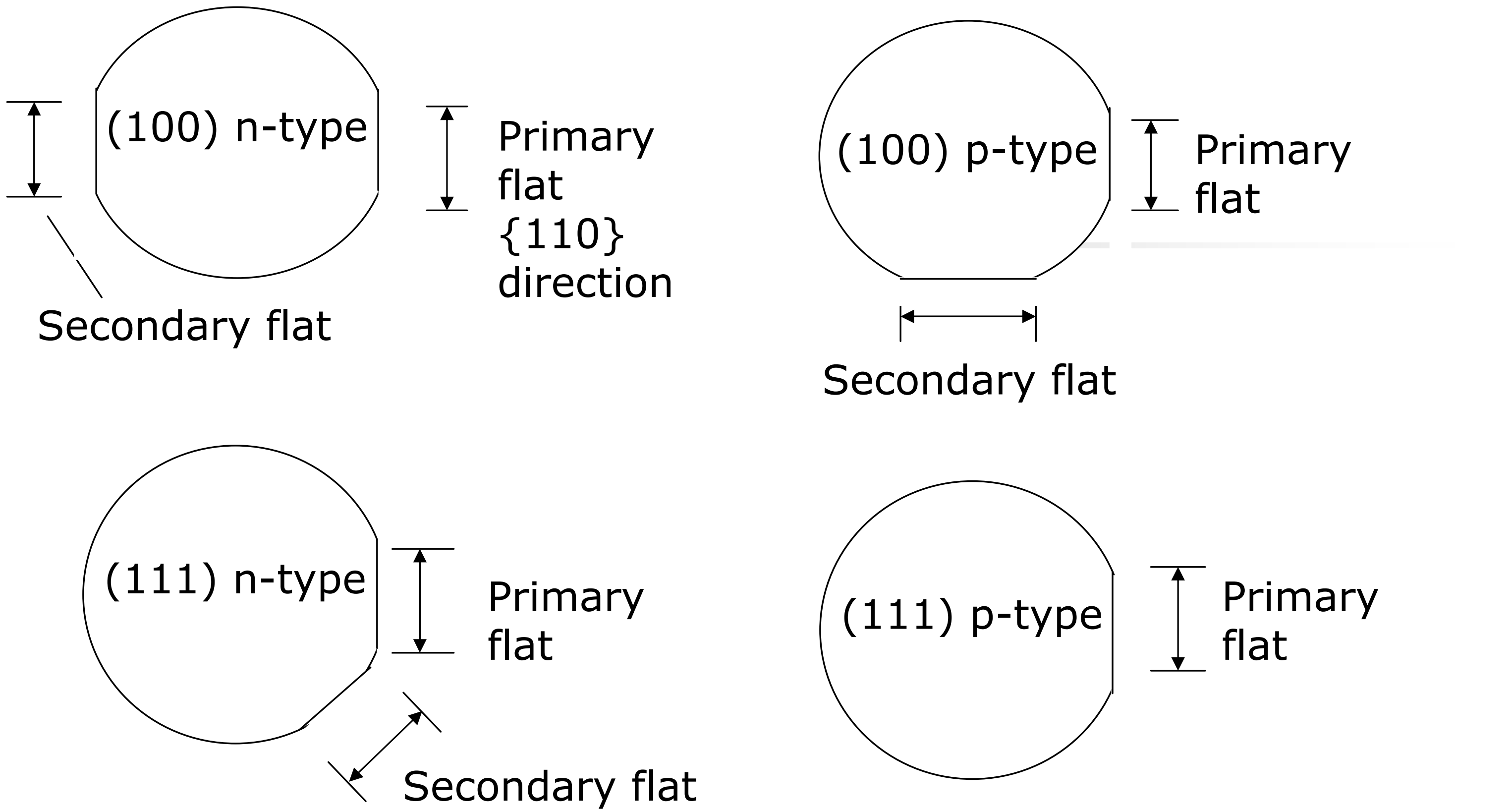
- Air conditioning plant
- HEPA filters air recirculation through these filters

Si-wafer preparation

- Czochralski process



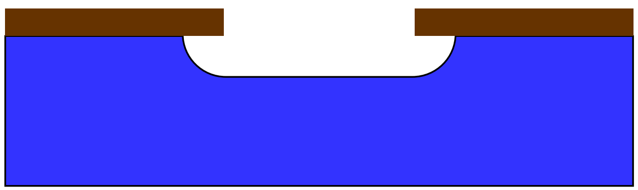
- Cutting, CMP, cleaning



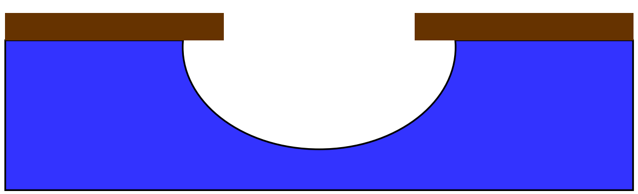
Primary and Secondary wafer flats are used to identify orientation and type.

Chemical Etching

Without agitation (5)



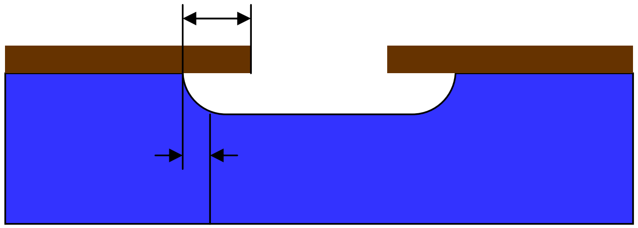
With agitation (20)



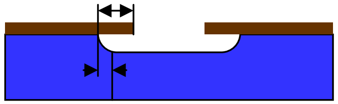
- Isotropic etching
  - Etchant: HNA mixture.
  - HNA can dissolve 550μm thick silicon wafer in about 20 min.
  - HNA mixture removes silicon equally in all directions.
  - SiO_2 etch: 10-30nm/min

Chemical Etching

Without agitation (5)



- Isotropic etching
  - Undercut
  - Etch bias
- Materials & etchants*



Etch Stop Mechanisms

- Time etch stop
- Dopant B+ (heavy dope) as etch stop
  - Pg 45 Spoek
- Thin films
- Electrochemical etch stop

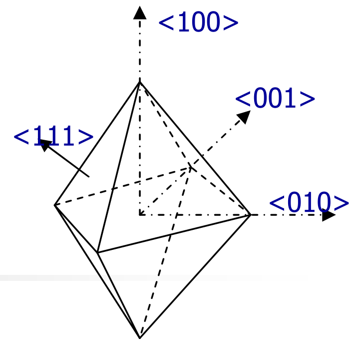
- Anisotropic Etching planes

Chemical Etching

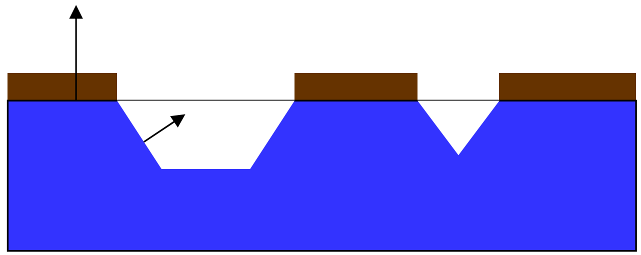
Choice of etchant:

- Etch rate
- Topology of the surface to be etched
- Etch selectivity of mask material and other materials
- Toxicity
- Ease of handling

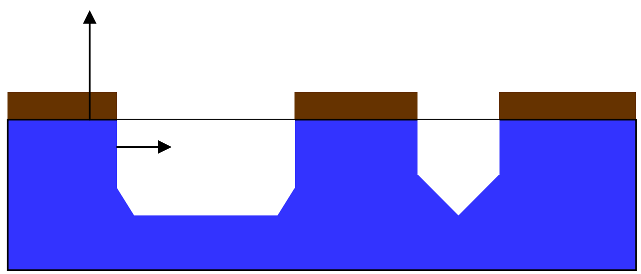
Chemical Etching



<100> surface wafer

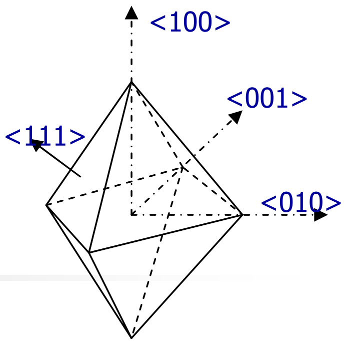


<110> surface wafer



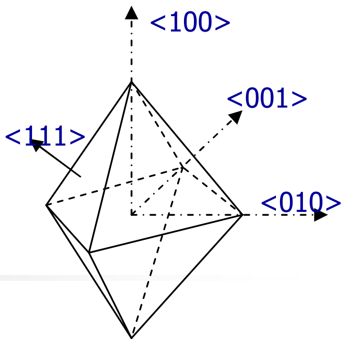
- Anisotropic bulk etching
  - Etchant: KOH, EDP (ethylen diamine pyrocatechol), TMAH (Tetra methyl ammonium hydroxide)
  - <111> direction has lower etching rates than <100>
  - Can produce grooves, slanted/vertical walls

Chemical Etching



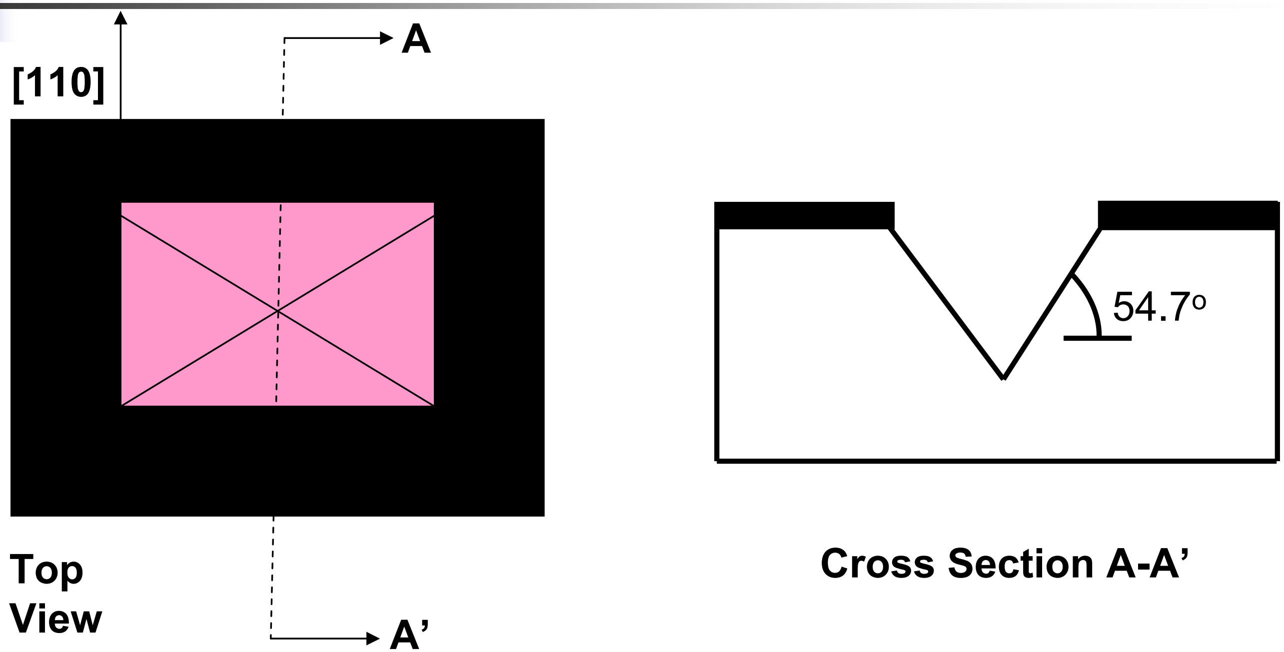
- Silicon crystal geometry*
- Examples of use of the crystal geometry in etching
- Fundes regarding etch shapes under different conditions*

Anisotropic Etching

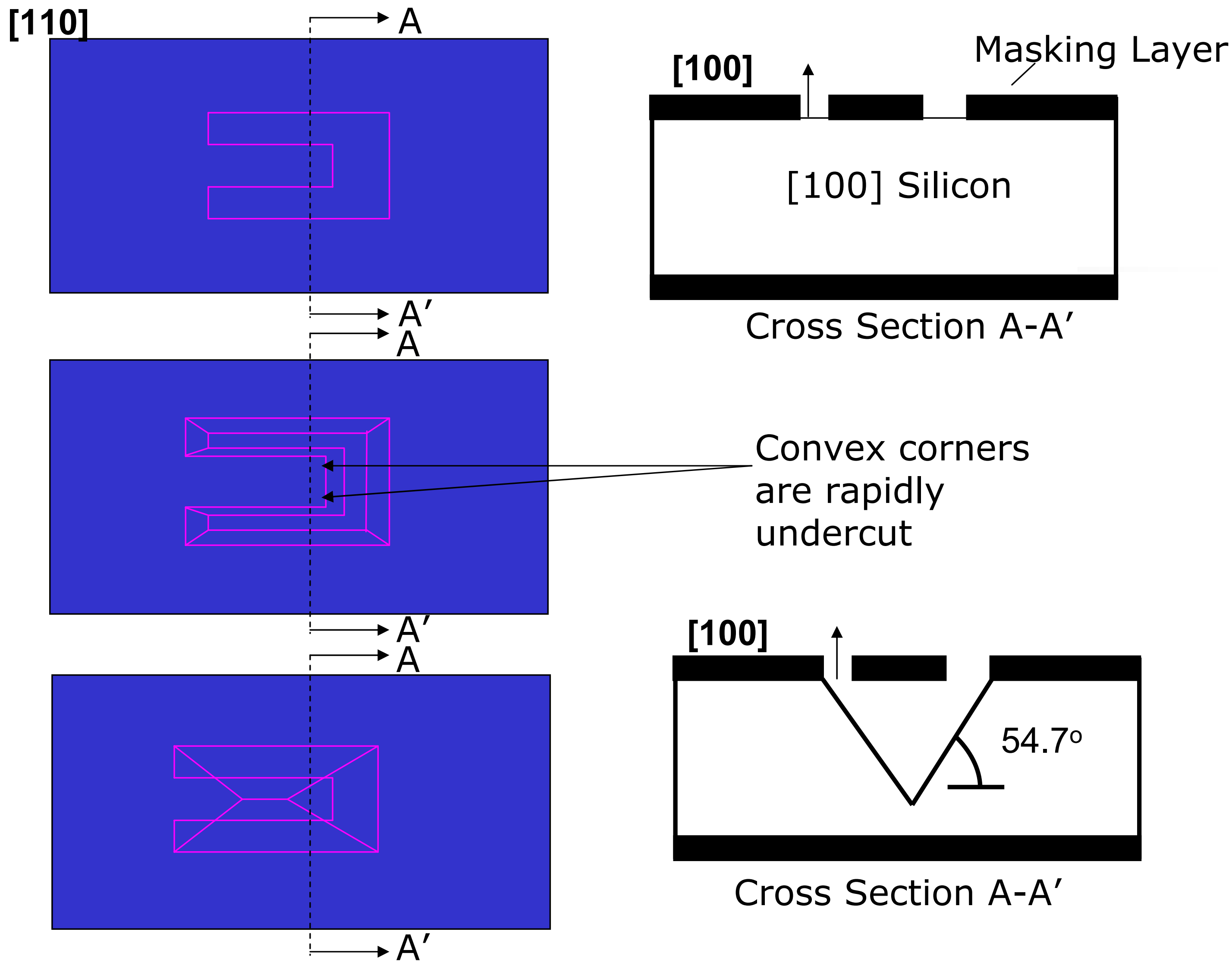


KOH, EDP and TMAH

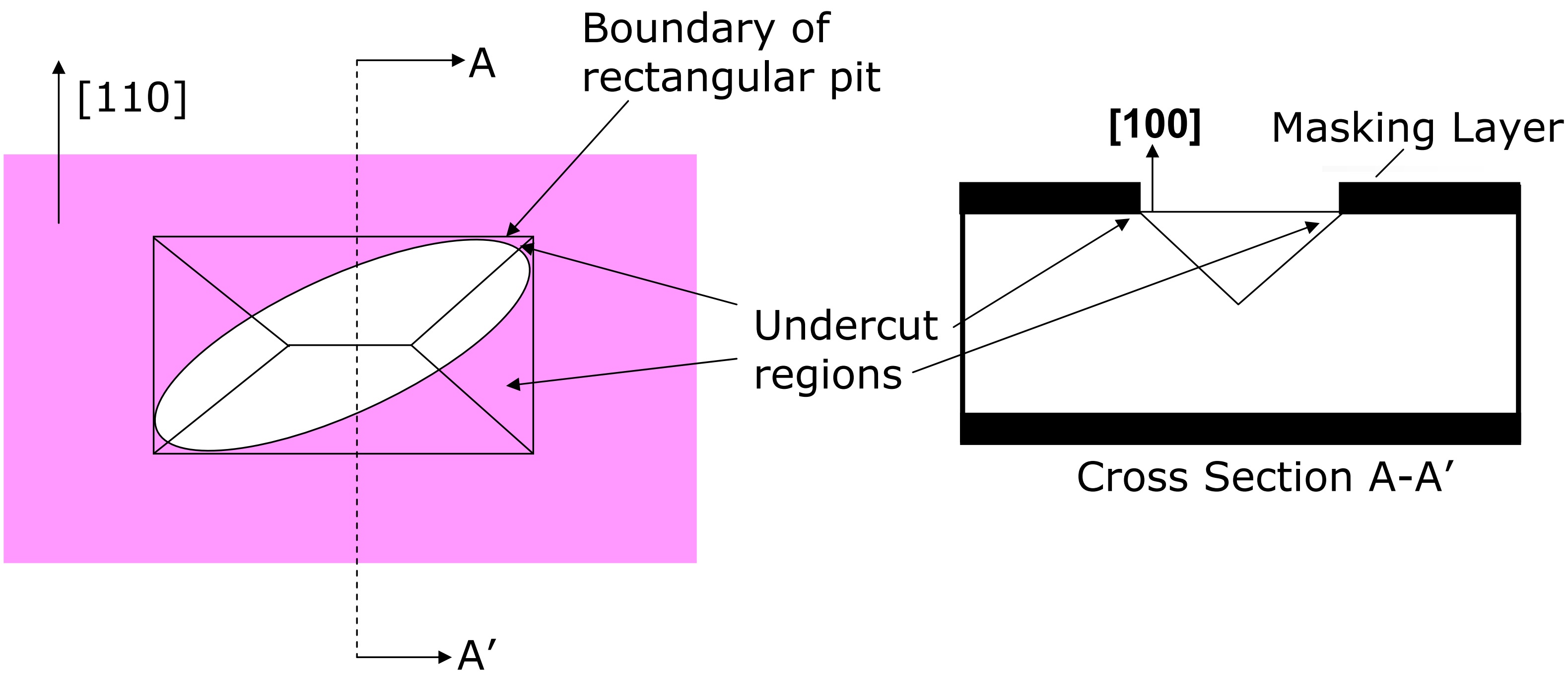
- EDP etches oxide 100 times slower than KOH,
- KOH, TMAH dangerous to eye
- KOH less dangerous than EDP & TMAH
- Etch curves*: 5hrs to etch 300μm thick wafer
- H2 bubbles during KOH etching of Si
- EDP ages quickly in contact with oxygen producing red brown color, vapor is harmful
- HF dip is necessary for EDP: native oxide problem



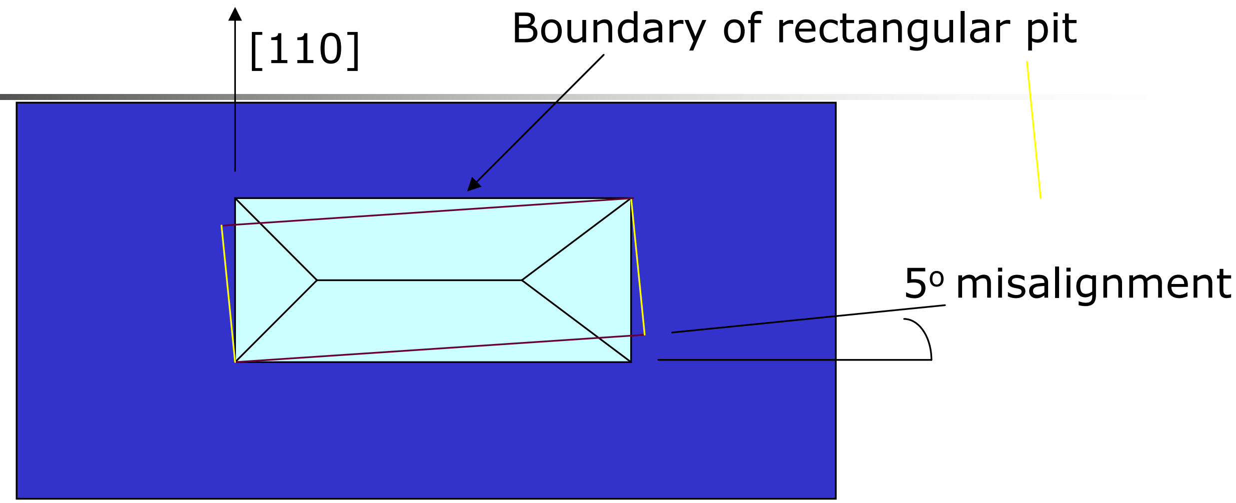
A square <110>-oriented mask feature results in a pyramidal pit.



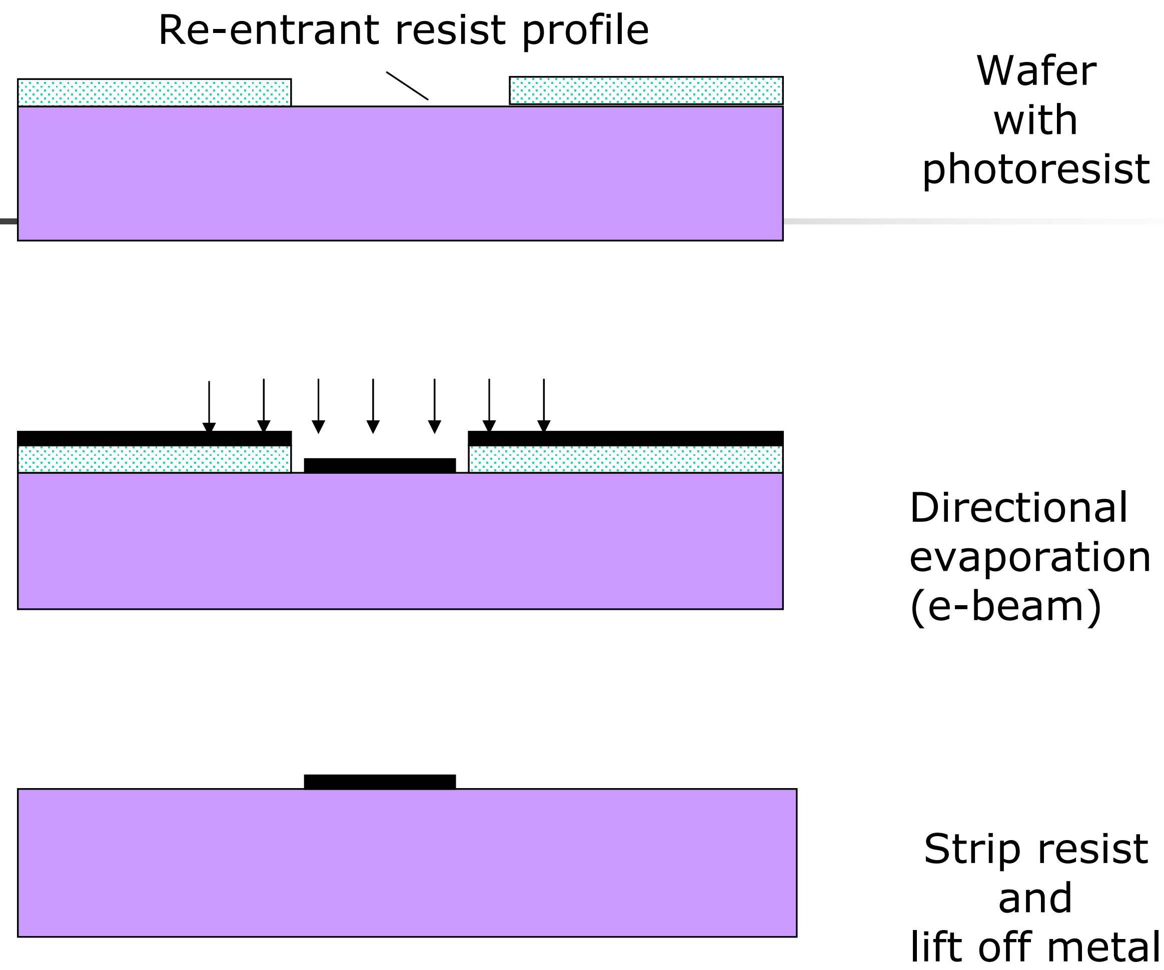
Convex corners where {111} planes meet are not stable. They are rapidly undercut. This permits creation of suspended structures.



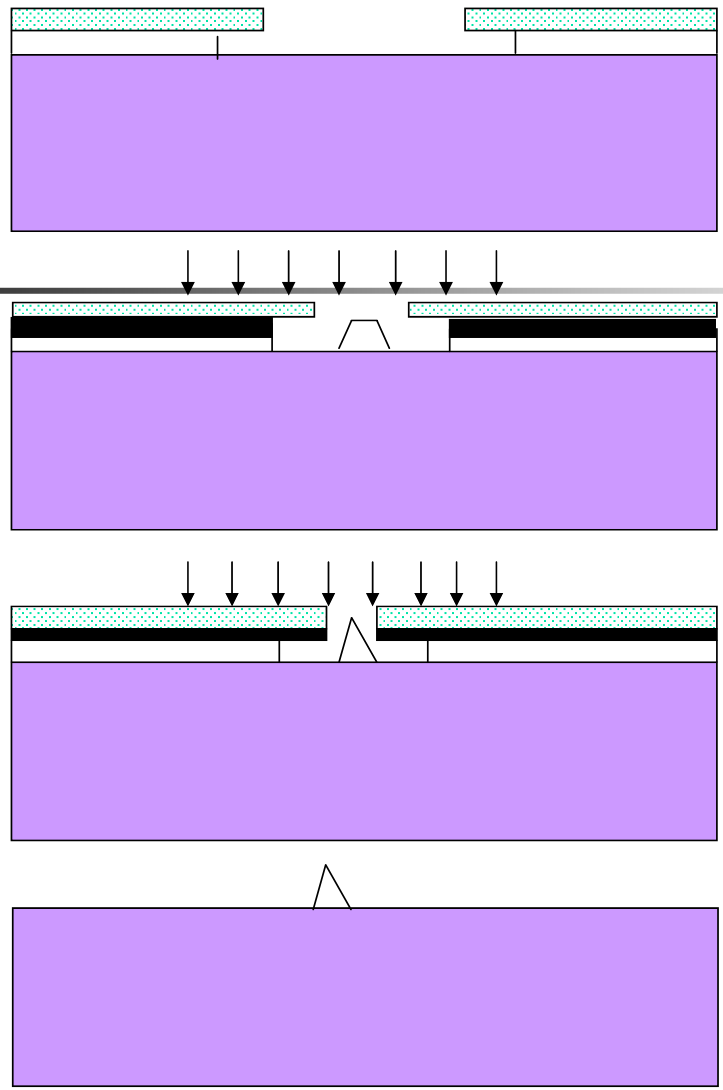
Any mask-layer feature, if etched long enough, will result in a rectangular V-groove pit beneath a rectangular that is tangent to the mask features, with edges oriented along <110> directions.



The effect of misalignment is to enlarge the etched region. This figure shows the effect of a 5o misalignment for a rectangular feature.



Illustrating the lift-off method for patterning evaporated metals



Wafer with double-layer undercut masking

Directional evaporation gradually closes opening

At closure, a sharp tip is formed

After lift-off

The use of a modified lift-off process to create sharp tips.

Conclusions

- Chemical etching
  - Isotropic
  - Anisotropic
- Bulk and Surface micromachining
- Etch stop mechanisms
- Liftoff process

Next class

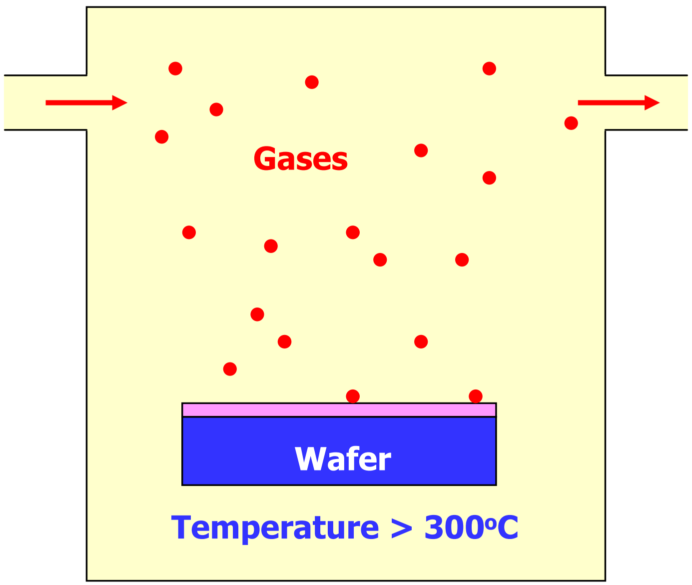
- Plasma based processes
  - Plasma etching
  - RIE

  - Sputtering
  - PE CVD

Wafer Cleaning Process

- Need
- CMP- Chemical mechanical polishing
- RCA cleaning

Chemical Vapor Deposition (CVD)



- Chemical reaction in vacuum chamber
- High temperatures (>300ºC)
- Polysilicon, SiO_2, Si_3N_4, tungston, titanium, copper etc. can be deposited
- Low pressure CVD (LPCVD)
- Plasma Enhanced CVD: low temperatures
- Pressure, temp, gas flow

$$x = \frac{B}{A}(t + \tau)$$

For small time t, and

$$x = \sqrt{B(t + \tau)}$$

for large time t, where χ is the thickness of the oxide layer in the silicon substrate in micrometers at time t, in hours. A and B are constants, and the parameter τ can be obtained by:

$$\tau = \frac{\left(\dfrac{d_0^2 + 2Dd_0}{k_s}\right)}{2DN_0}$$

where

- D=diffusivity of oxide in silicon, e.g.,
- D=4.4 x 10^{-16}cm2/s at 900oC
- d_o=initial oxide layer (~200 in dry oxidation,=0 for wet
- oxidation)
- k_s=surface reaction rate constant
- N_o=concentration of oxygen molecules in the carrier
- gas
- =5.2 x 10^{16}molecules/cm^3 in dry o_2 at 1000^oC and
- 1atm
- =3000 x 10^{16} molecules/cm^3 in water vapor at the
- same temperature and pressure
- N_1=number of oxidizing species in the oxide
- =2.2 x 10^{22} SiO_2 molecules/cm^3 in dry O_2
- =4.4 x 10^{22} SiO_2 molecules/cm^3 in water vapor