Lecture #34

HW#10 is posted online -- use 11/16 version!

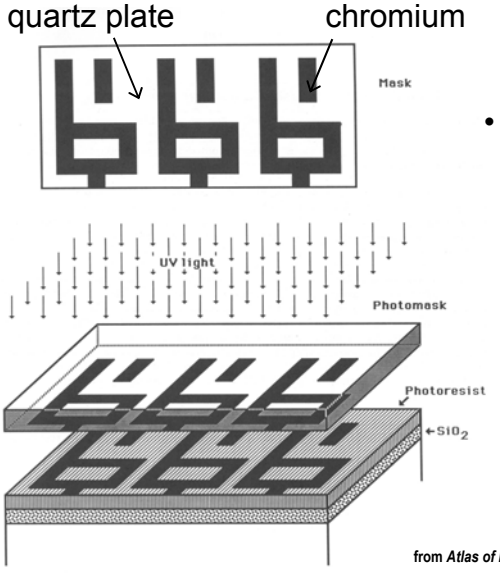
OUTLINE

- **Modern IC Fabrication Technology**
  - Lithography trends
  - Plasma processing
  - Rapid thermal annealing
  - Chemical mechanical polishing

Reading (Rabaey *et al*.)

(Finish Chapter 2.2)

Photolithography

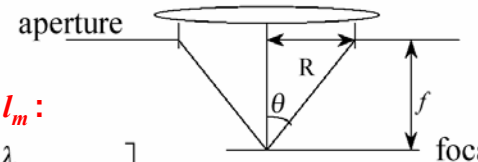


- 2 types of photoresist:
  - positive tone:
    portion exposed to light will be dissolved in developer solution
  - negative tone:
    portion exposed to light will NOT be dissolved in developer solution

from *Atlas of IC Technologies* by W. Maly

Projection Printing Considerations

(1) Resolution



minimum feature size ≡ l_m :

$$l_m = k_1 \frac{\lambda}{NA} \qquad \left[0.6 \frac{\lambda}{NA} \; typical \right]$$

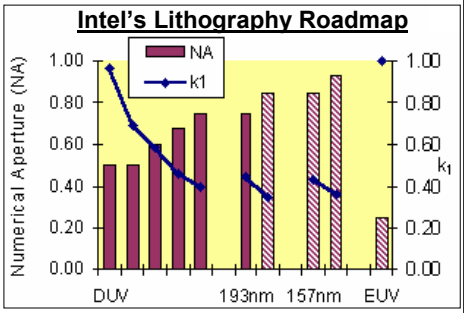
$NA \equiv numerical \;\; aperture \;\; of \;\; lens.$

$= \sin\theta$

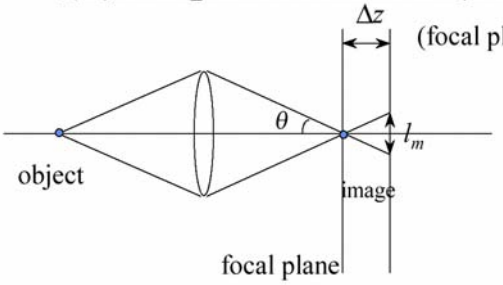
$k_1 =$ a constant

Small l_m is desired!

Intel's Lithography Roadmap



(2) Depth of Focus (DOF)



depth of focus ≡ Δz :

$$\Delta z = k_2 \frac{\lambda}{(NA)^2} \qquad 0.5 < k_2 < 1$$

$$\approx \frac{\pm l_m/2}{\tan\theta} \approx \frac{\pm l_m/2}{\sin\theta} = \pm \frac{\lambda}{2(NA)^2} \quad for \;\; small \;\; \theta$$

Large Δz is desirable.

Lithography Trends

- **Lithography determines the minimum feature size and limits the throughput that can be achieved in an IC manufacturing process. Thus, lithography research & development efforts are directed at**

  1. achieving higher resolution

  → shorter wavelengths

  365 nm → 248 nm → 193 nm → 13 nm

  "i-line" "DUV" "EUV"

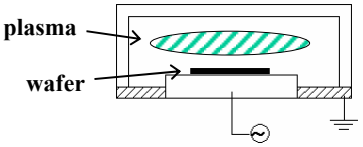
  2. improving resist materials

  → higher sensitivity, for shorter exposure times (throughput target is 60 wafers/hr)0

Plasma Processing

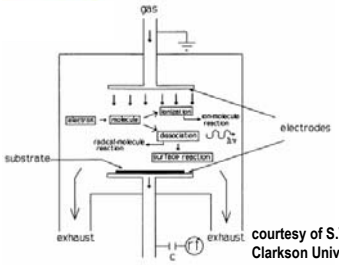
- **Plasmas are used to enhance various processes:**
  - CVD: Energy from RF electric field assists the dissociation of gaseous molecules, to allow for thin-film deposition at higher rates and/or lower temperatures.
  - Etch: Ionized etchant species are more reactive and can be accelerated toward wafer (biased at negative DC potential), to provide directional etching for more precise transfer of lithographically defined features.

Reactive Ion Etcher



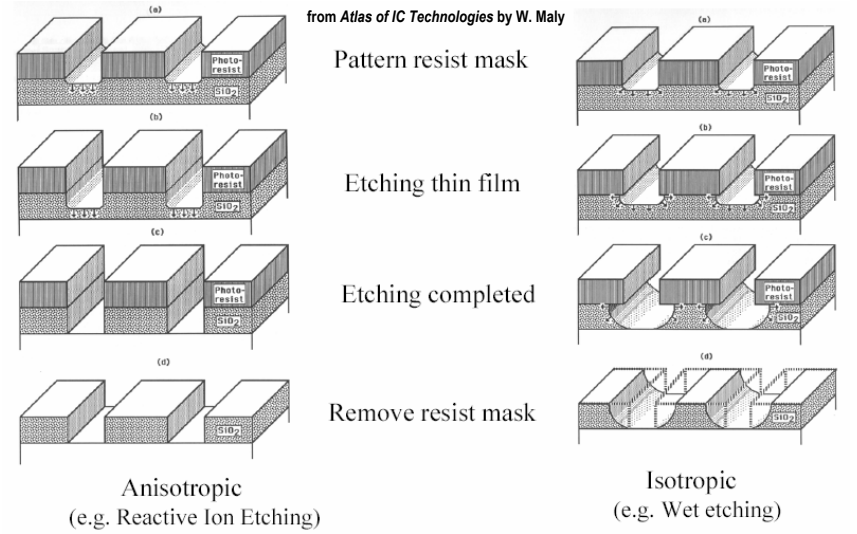
RF: 13.56 MHz

Parallel-Plate Plasma Reactor



courtesy of S.V. Babu, Clarkson University

Dry Etching *vs.* Wet Etching



✓ better control of etched feature sizes

✓ better etch selectivity

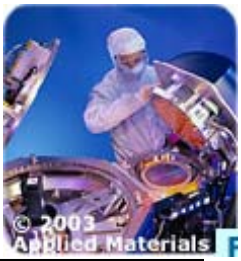
Rapid Thermal Annealing (RTA)

Sub-micron MOSFETs need ultra-shallow junctions (x_j<50 nm)

→ Dopant diffusion during "activation" anneal must be minimized

→ Short annealing time (<1 min.) at high temperature is required

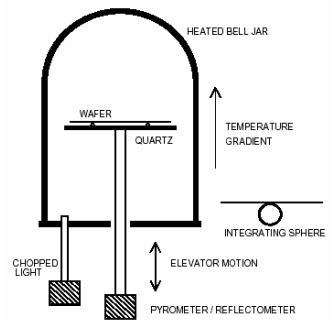
- Ordinary furnaces (*e.g.* used for thermal oxidation and CVD) heat and cool wafers at a slow rate (<50°C per minute)
- Special annealing tools have been developed to enable much faster temperature ramping, and precise control of annealing time
  - ramp rates as fast as 200°C/second
  - anneal times as short as 0.5 second
  - typically single-wafer process chamber:



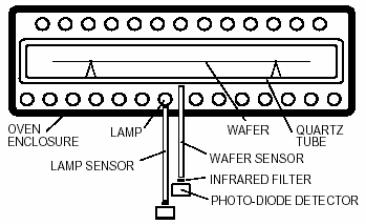
Rapid Thermal Annealing Tools

- There are 2 types of RTA systems:
  1. Furnace-based
     - steady heat source + fast mechanical wafer transport
  2. Lamp-based
     - stationary wafer + time-varying optical output from lamp(s)

Furnace RTA



Lamp RTA

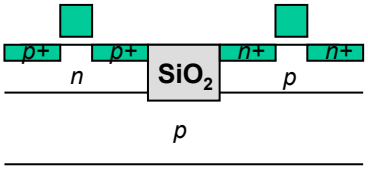


A.T. Fiory, *Proc. RTP2000*

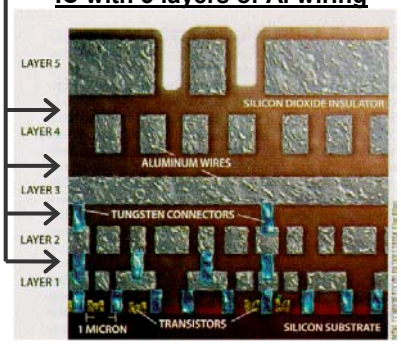
Chemical Mechanical Polishing (CMP)

- ***Chemical mechanical polishing*** is used to planarize the surface of a wafer at various steps in the process of fabricating an integrated circuit.
  - interlevel dielectric (ILD) layers
  - shallow trench isolation (STI)
  - copper metallization
    "damascene" process

Oxide Isolation of Transistors

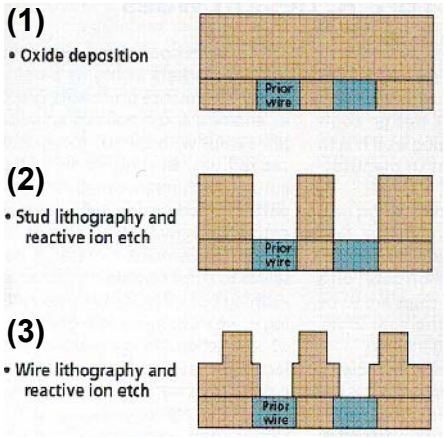


IC with 5 layers of Al wiring

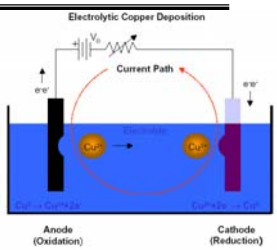


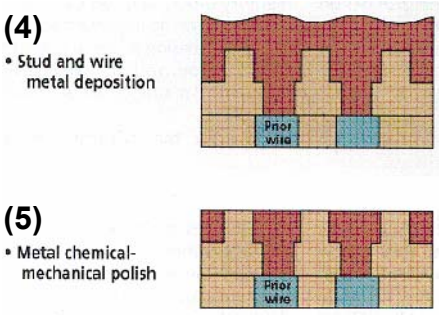
Copper Metallization

"Dual Damascene Process"
(IBM Corporation)



courtesy of Sung Gyu Pyo, Hynix Semiconductor

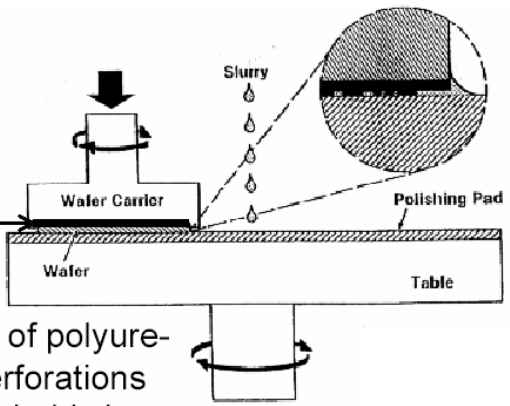




CMP Tool

- Wafer is polished using a slurry containing
  - silica particles (10-90nm particle size)
  - chemical etchants (*e.g.* HF)

- Backing film provides elasticity between carrier and wafer



- Polishing pad made of polyurethane, with 1 mm perforations
  - rough surface to hold slurry