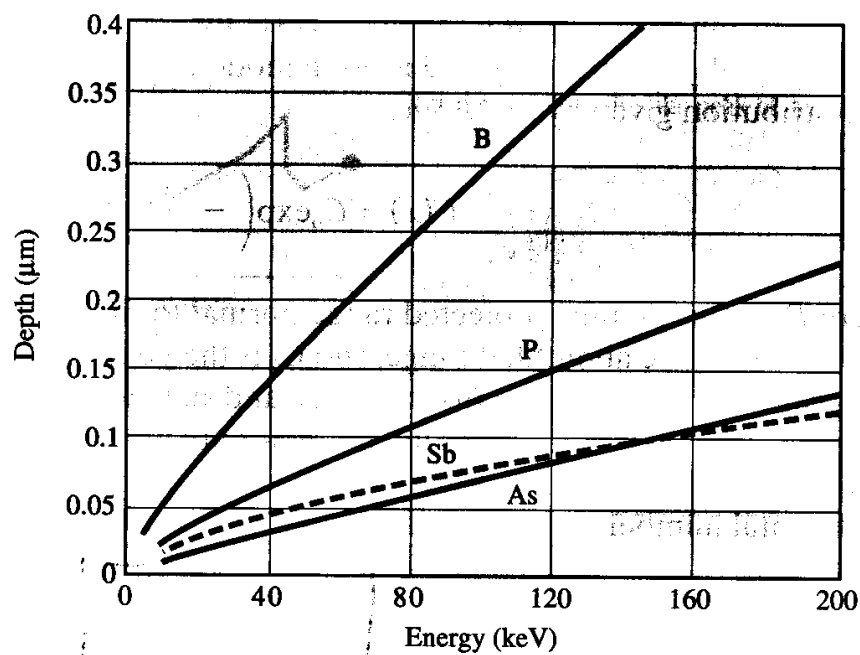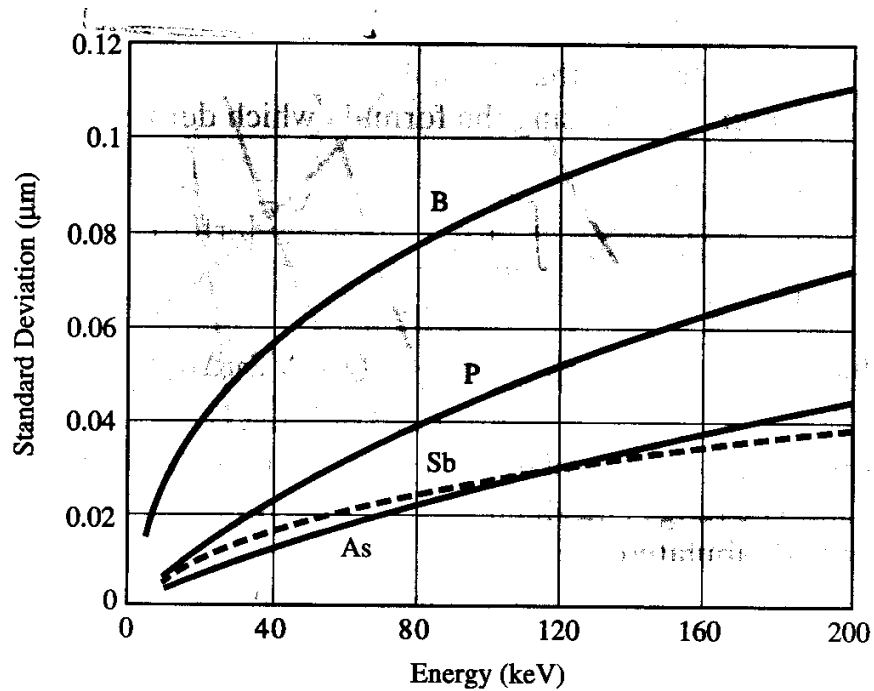- **The heavy ions with the smaller range have a more narrow distribution**

$$C(x) = C_P \exp\left(-\frac{(x - R_P)^2}{2DR_P^2}\right)$$

DR_P = straggle
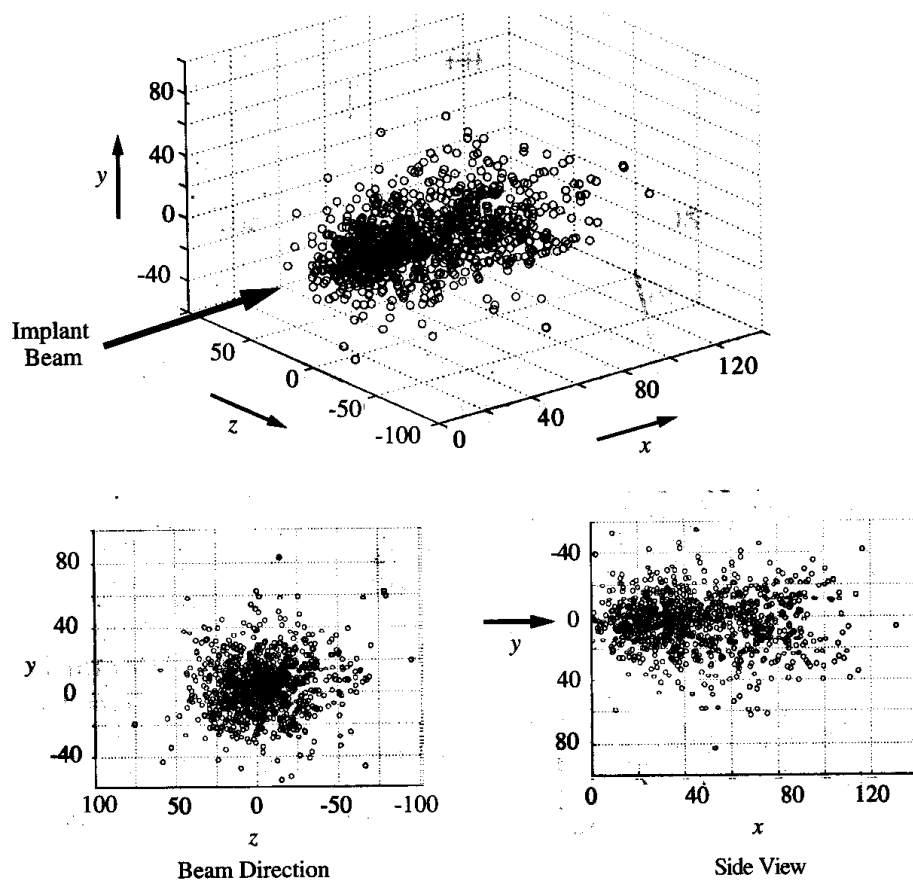
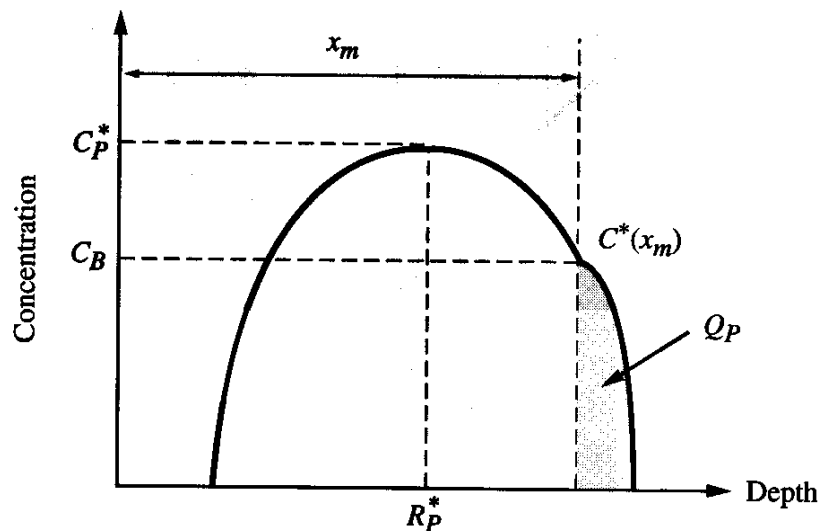• **Note that the profiles in Fig.8-2 are not perfectly symmetrical**

$$Q = \int_0^\infty C(x)dx$$

$$Q = \sqrt{2\pi}\Delta R_P C_P$$

Beam Direction

Side View

- **The 2-D distribution is often assumed to be composed of just the product of the vertical and lateral distributions**

$$C(x,y) = C_{vert}(x)\exp\left(-\frac{y^2}{2DR_{\wedge}^2}\right)$$

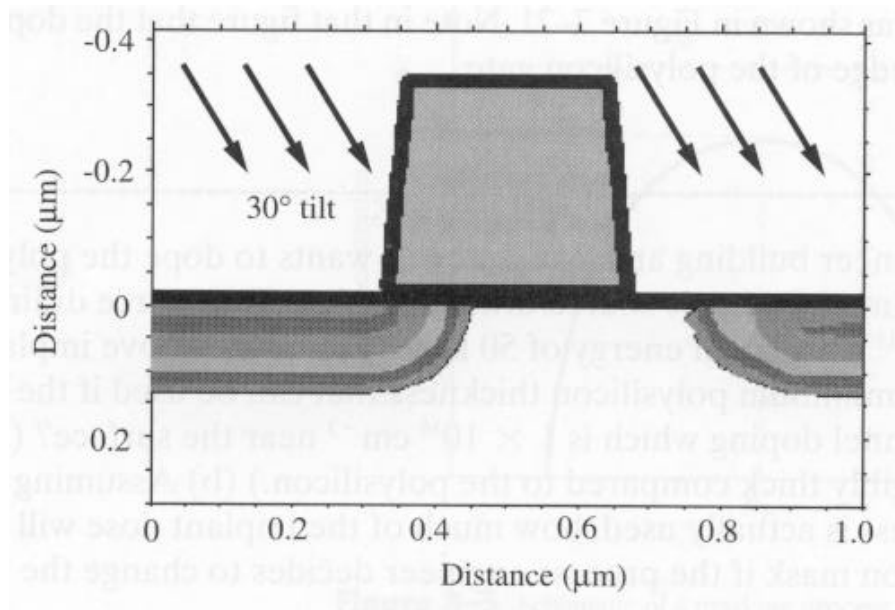- **Criterion for efficient masking**

$$C^*(x_m) = C_P^*\left(\exp' - \frac{(xm - R_P^*)^2}{2DR_P^{*2}}\right) \pounds C_B$$

$$X_m = R_P^* + DR_P^*\sqrt{2\ln\left(\frac{C_P^*}{C_B}\right)} = R_P^* + mDR_P^*$$

$$Q_P = \frac{Q}{\sqrt{2pDR_P^*}}\int_{X_m}^{\Upsilon}\exp-\left[\frac{x - R_P^*}{\sqrt{2}DR_P^*}\right]^2 dx$$

$$= \frac{Q}{2}\text{erfc}\left(\frac{x_m - R_P^*}{\sqrt{2}DR_P^*}\right)$$

Diffused junction · Poly gate · Gate oxide

30° tilt
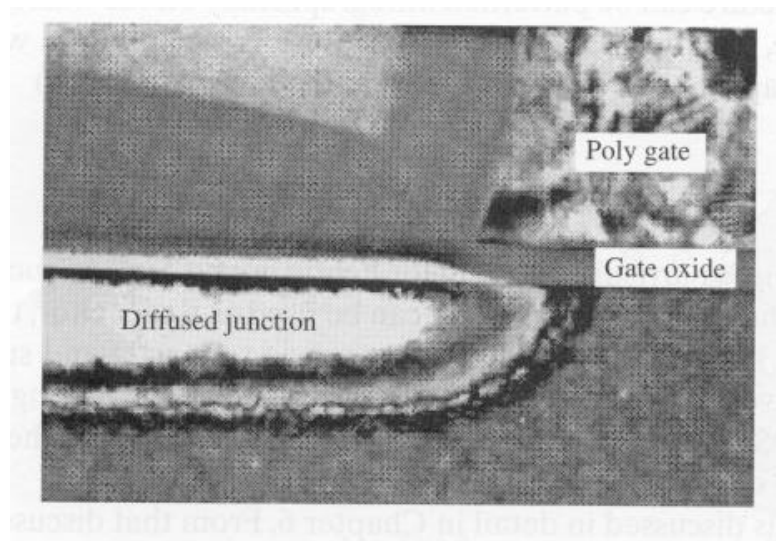
- $C(x) = C_P \exp\left(-\dfrac{(x - R_P)^2}{2\Delta R_P^2}\right)$ $\quad$ $C(x) = C(0)\exp\left(-\dfrac{x^2}{4Dt}\right)$

Implanted $\qquad$ **Diffused**

- $C(x,t) = \dfrac{Q}{\sqrt{2\pi(\Delta R_{P}^{2} + 2Dt)}}\exp\left(-\dfrac{(x - R_{P})^{2}}{2(\Delta R_{P}^{2} + 2Dt)}\right)$

Implanted

After Diffusion

$\sqrt{2Dt}$ ΔR_P

50 keV

100 keV

500 keV

1 MeV

Concentration (cm^{-3})

10^{20}

10^{19}

10^{18}

10^{17}

10^{16}

0   0.5   1   1.5   2

Depth (μm)
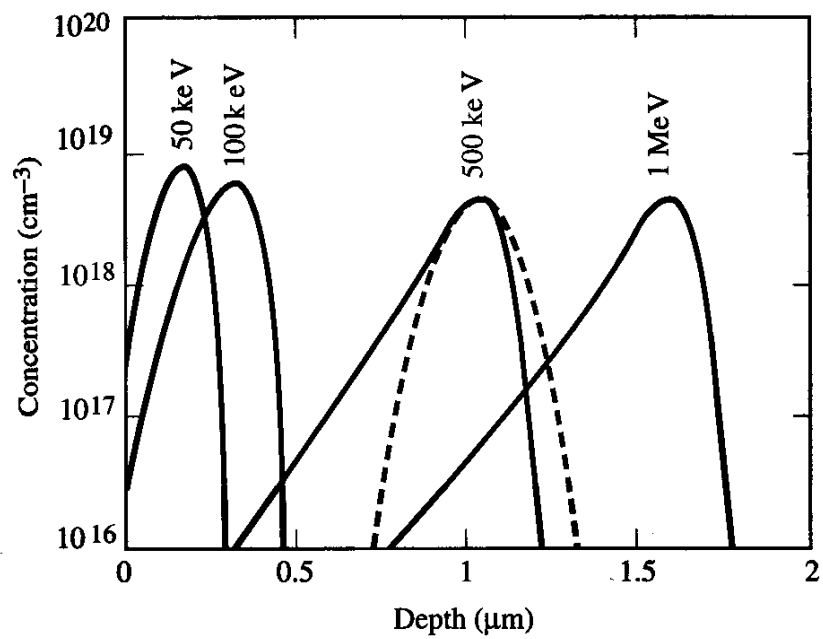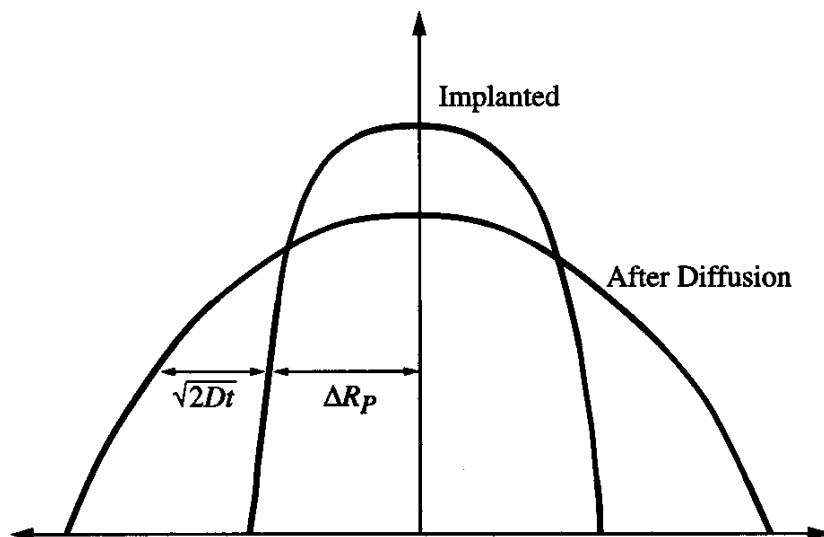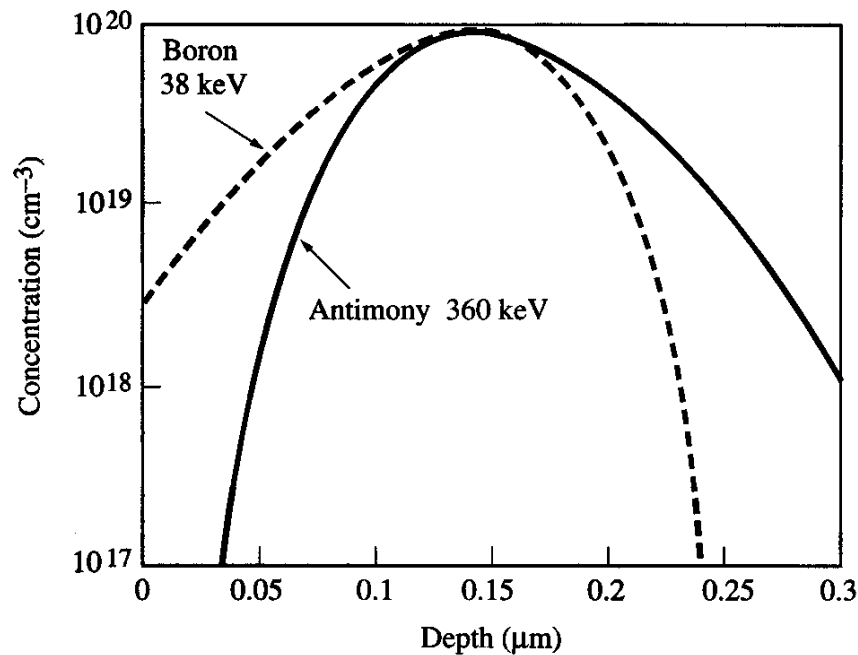
- **An arbitrary distribution can be described by a series of moments**

normalized first moment $= R_P = \dfrac{1}{Q} \int_{-\infty}^{\infty} xC(x)dx$

the second moment $= DR_P = \sqrt{\dfrac{1}{Q} \int_{-\infty}^{\infty} (x - R_P)^2 C(x)dx}$

the third moment $=$ skewness $= g = \dfrac{\int_{-\infty}^{\infty} (x - R_P)^3 C(x)dx}{Q DR_P^3}$

the fourth moment $=$ kurtosis $= b = \dfrac{\int_{-\infty}^{\infty} (x - R_P)^4 C(x)dx}{Q DR_P^4}$

- **In practice the equivalent moments are described by coefficients in a functional form known as Pearson's equation**

8.2.1 Implants in Real Silicon – The Role of the Crystal Structure
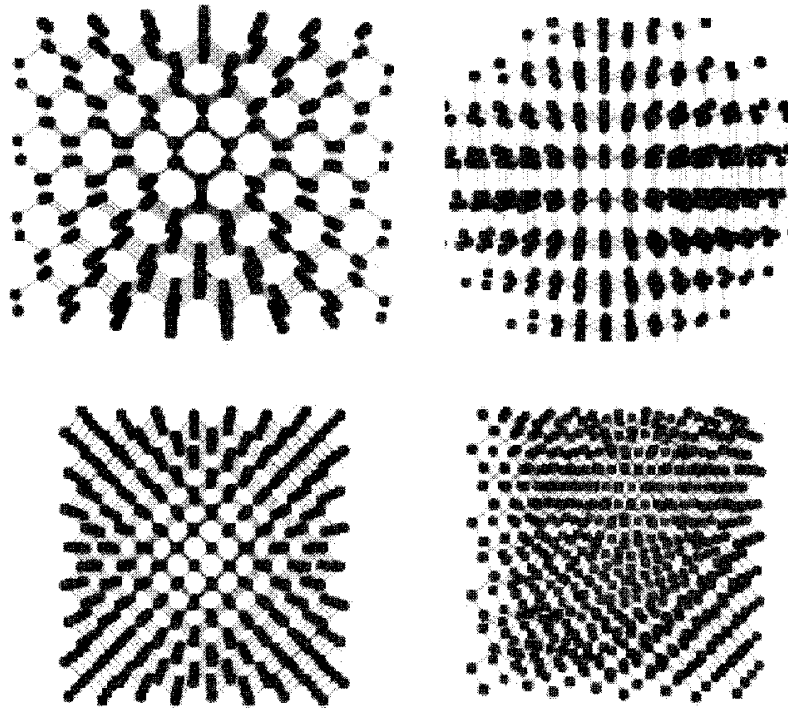
• **Even a wafer tilted and rotated to appear amorphous can allow a scattered ion to enter the channels**
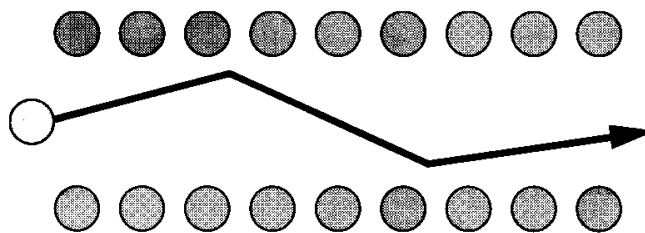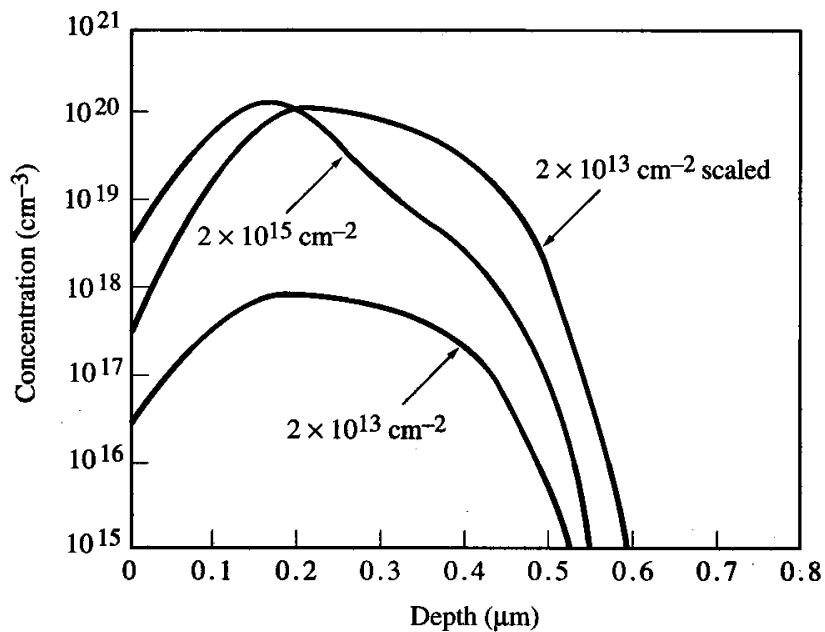
- **Dual-Pearson approach**
- **Simply scaling up a low-dose implant does not give the same profile as a high-dose implant. As the crystal gets damaged by the implanted ions, the channels are less evident to subsequent incoming ions**
- **A thin screen oxide which is amorphous is often used**

Dual-Pearson + Tilt/Rotation model   Monte Carlo model
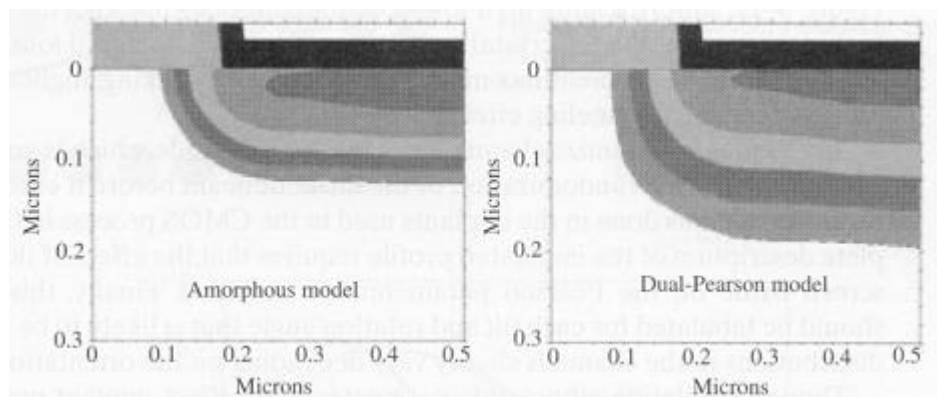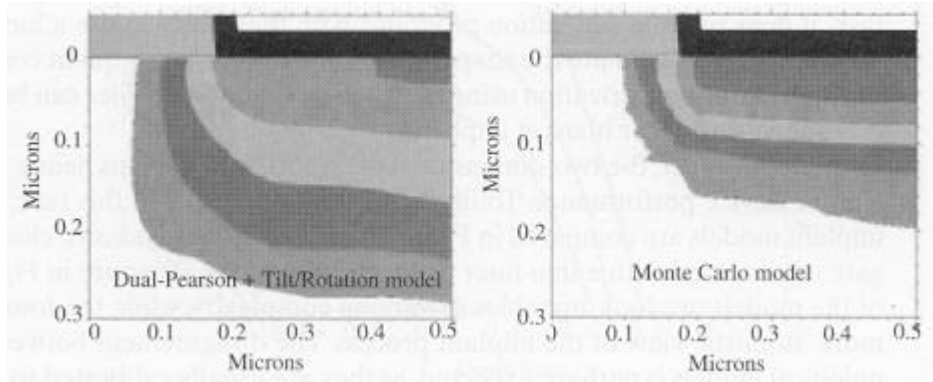
8.3 Manufacturing Methods and Equipment
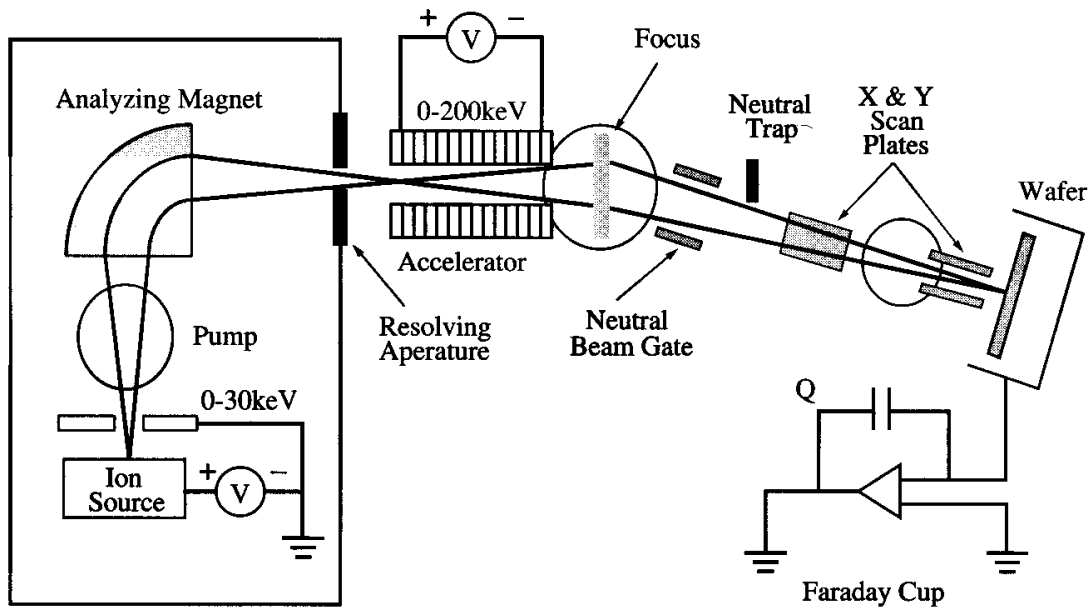
- **Source : a solid source that is vaporized or a gas source**
- **The gas from the feed source is ionized by energetic electrons boiled off a hot filament or by a plasma discharge**

- **Mass analysis** : $\dfrac{mv^2}{R} = q \cdot \vec{v} \times \vec{B}$

$$B = \alpha I$$

$$v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2qV_{ext}}{m}}$$

$$\sqrt{m} = \frac{q}{\sqrt{2E}}(\alpha r)I$$

- **The ion path typically undergoes an electrostatic deviation from the linear path just before final implantation**

$$Q = \frac{1}{A}\oint \frac{I}{q}dt$$

8.3.1 High-Energy Implants
- **The upper energy limit is determined by breakdown in systems with air insulation**
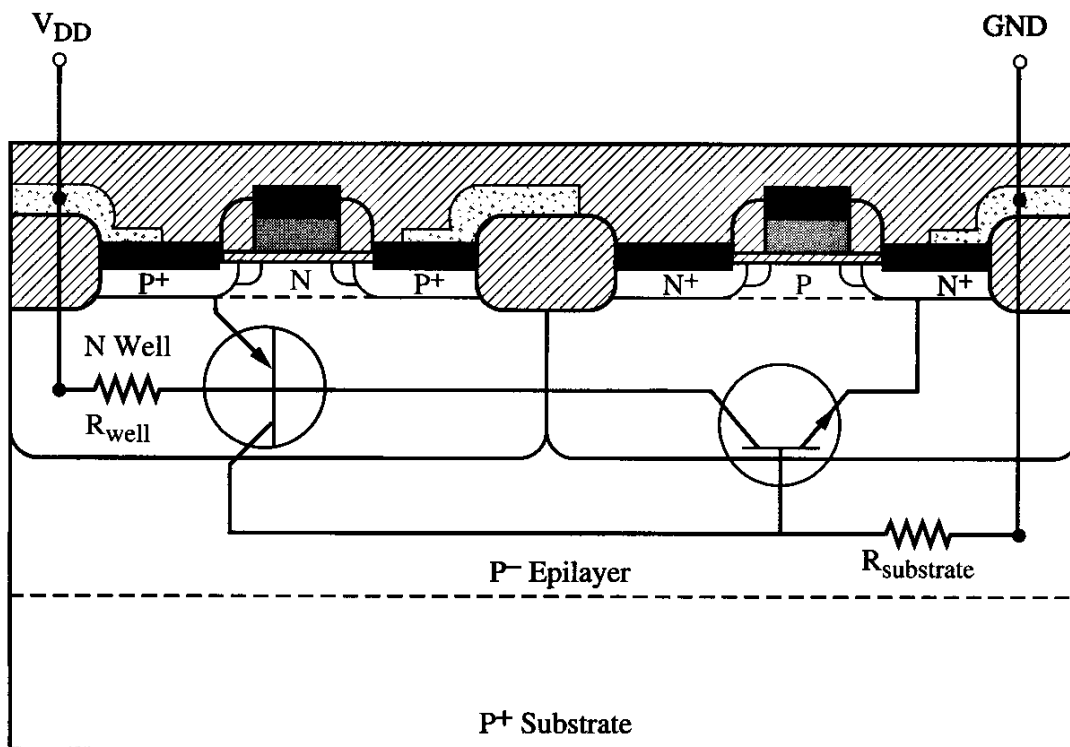
- **Simplify the well-formation process while simultaneously decoupling the isolation design from the transistor design**

8.3.2 Ultralow Energy Implants
- **The reason most current ion implanters cover an energy above 30keV is because the low-energy limit is set by the extraction voltage for the ions from the source plasma**
- **The absolute lower energy is determined by the energy needed to penetrate the lattice (~ 50eV for B)**

8.3.3 Ion Beam Heating

$$E_{dep} = V \int I dt = VQ$$

One important limiting temperature regime ˜ 120°C, where photoresists begin to flow, crack, and deteriorate

8.4 Measurement Methods
- **Because the ion implantation process creates damage, most dopants are not electrically active at the end of the implantation ? Profile measurement at this point must carefully distinguish between total chemical concentrations and the portion of the dopant that is electrically active**

Chap 10 Etching

10.1 Introduction
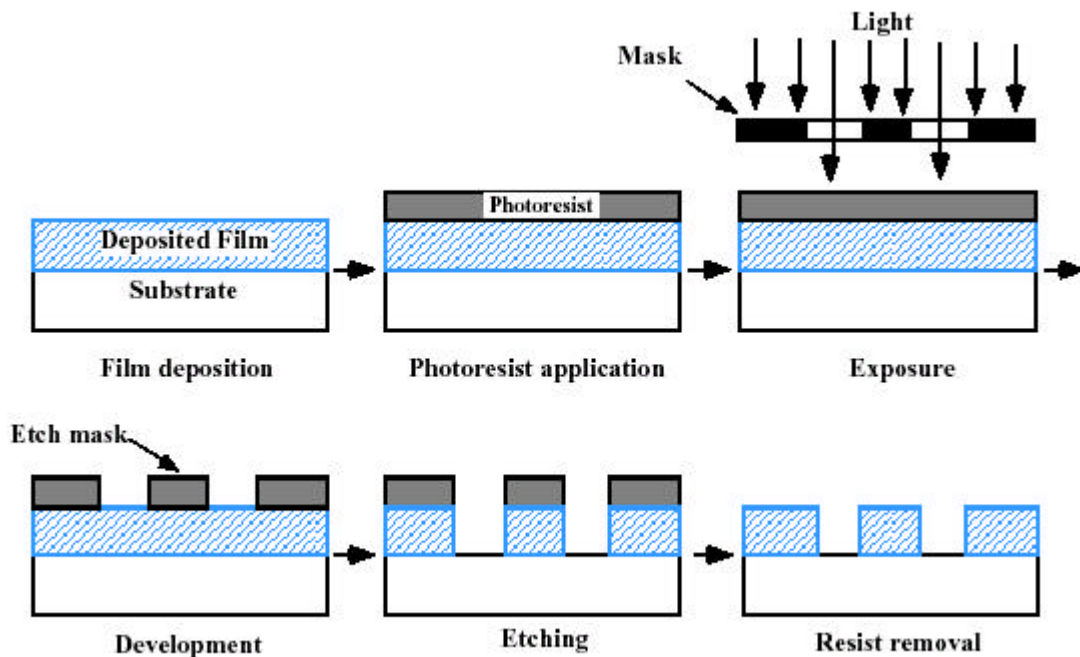
- **Oxide or nitride masks : hard mask**
- **Etching only partway through a layer is sometimes done but can be difficult to control uniformly over the wafer**
- **Wet etching : Fig 2-34**
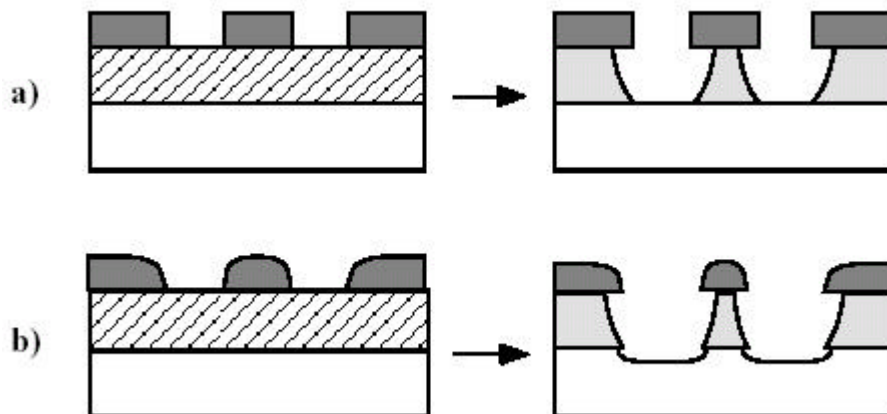
- **Selectivities in the range of 25-50 are usually considered reasonable**

More directional etching →

a) isotropic   b) anisotropic   c) completely anisotropic
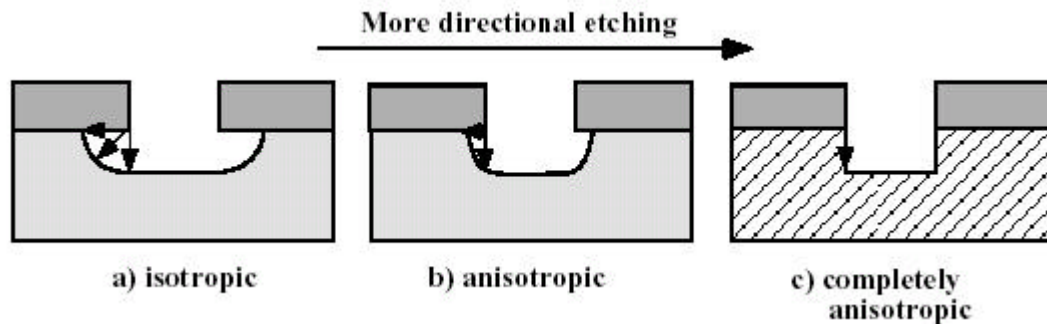
10.2 Historical Development and Basic Concepts

10.2.1 Wet Etching

- **$SiO_2 + 6HF \ ? \ \ H_2SiF_6 + 2H_2O$**

    ↑
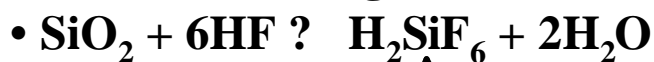
    water-soluble complex

- **A common etchant for silicon is a mixture of <u>nitric acid(HNO$_3$)</u> and HF**

    ↘

    partially decomposes to HO_2

   $Si + 2NO_2 + 2H_2O \ ? \ \ SiO_2 + H_2 + 2HNO_2$
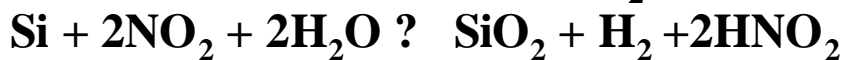
   The HF then dissolves the SiO_2

   $Si + HNO_3 + 6HF \ ? \ \ H_2SiF_6 + HNO_2 + H_2O + H_2$

- **NH4F is added to HF to help prevent depletion of the fluoride ions   "Buffered HF"**
                BHF
                "Buffered Oxide Etch"
                BOE
- **The addition of NH_4F also decreases the etch rate of photoresist and helps to minimize lifting of the resist**
- **CH_3COOH is often added to the nitric acid / hydrofluoric acid silicon etch to limit the dissociation of the nitric acid**

$$S = \frac{r_1}{r_2}$$

- **"Etch bias"**
- **10 to 20% overetches are common**

- ? m = mask erosion
- The extent of lateral etching will increase
- Mask erosion leading to extra undercutting can occur even for completely anisotropic etching

$$\text{degree of anisotropy} = A_f = 1 - \frac{r_{lat}}{r_{ver}}$$

$$A_f = 1 - \frac{b}{d} \quad \text{(in Fig 10 - 4)}$$

Table 10–1   Common wet chemical etchants for various thin films used in IC fabrication

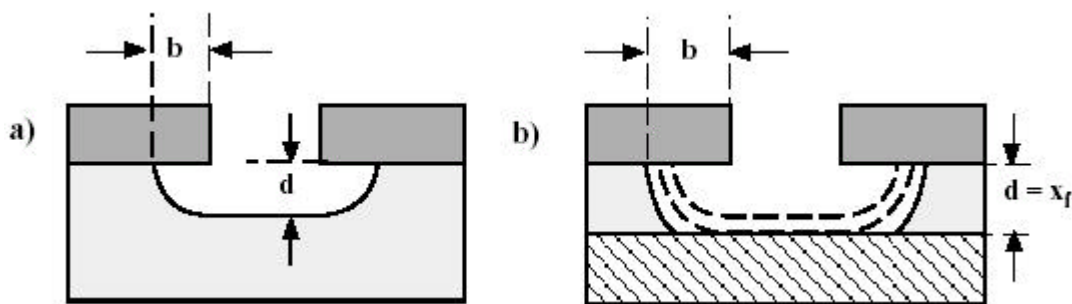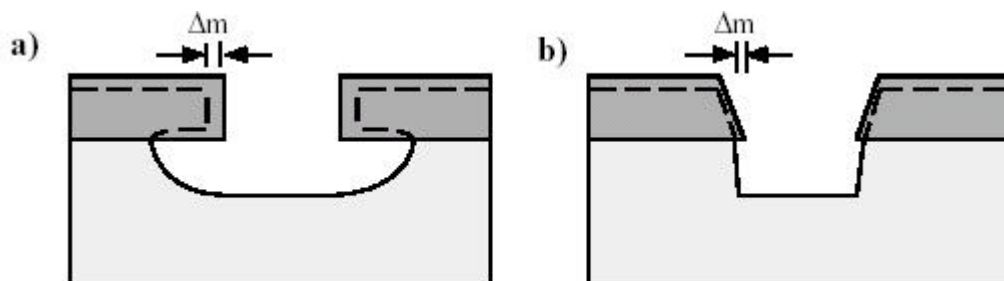| Material	Etchant	Comments
SiO_2	HF (49% in water) "straight HF"	Selective over Si (i.e., will etch Si very slowly in comparison). Etch rate depends on film density, doping.
	NH_4F:HF (6:1) "Buffered HF" or "BOE"	About $1/20$ th the etch rate of straight HF. Etch rate depends on film density, doping. Will not lift up photoresist like straight HF.
Si_3N_4	HF (49%)	Etch rate depends strongly on film density, O, H in film.
	H_3PO_4:H_2O (boiling @ 130–150°C)	Selective over SiO_2. Requires oxide mask.
Al	H_3PO_4:H_2O:HNO_3:CH_3COOH (16:2:1:1)	Selective over Si, SiO_2, and photoresist.
Polysilicon	HNO_3:H_2O:HF (+ CH_3COOH) (50:20:1)	Etch rate depends on etchant composition.
Single crystal Si	HNO_3:H_2O:HF (+ CH_3COOH) (50:20:1)	Etch rate depends on etchant composition.
	KOH:H_2O:IPA (23 wt. % KOH, 13 wt. % IPA)	Crystallographically selective; relative etch rates: (100): 100 (111): 1
Ti	NH_4OH:H_2O_2:H_2O (1:1:5)	Selective over $TiSi_2$.
TiN	NH_4OH:H_2O_2:H_2O (1:1:5)	Selective over $TiSi_2$.
$TiSi_2$	NH_4F:HF (6:1)	
Photoresist	H_2SO_4:H_2O_2 (125°C)	For wafers without metal.
	Organic strippers	For wafers with metal.

- **The etch rate depends on the specific composition of the etch solution, and the etch rate can vary by orders of magnitude for different compositions. The rates are strong functions of T**
- **KOH can be used to form v-grooves because the {111} planes intersect the surface at 54.7°**

10.2.2 Plasma Etching
Two reasons

Very reactive chemical species are produced
Directional or anisotropic etching is possible. (Due to the presence of ionic species and the electric fields)
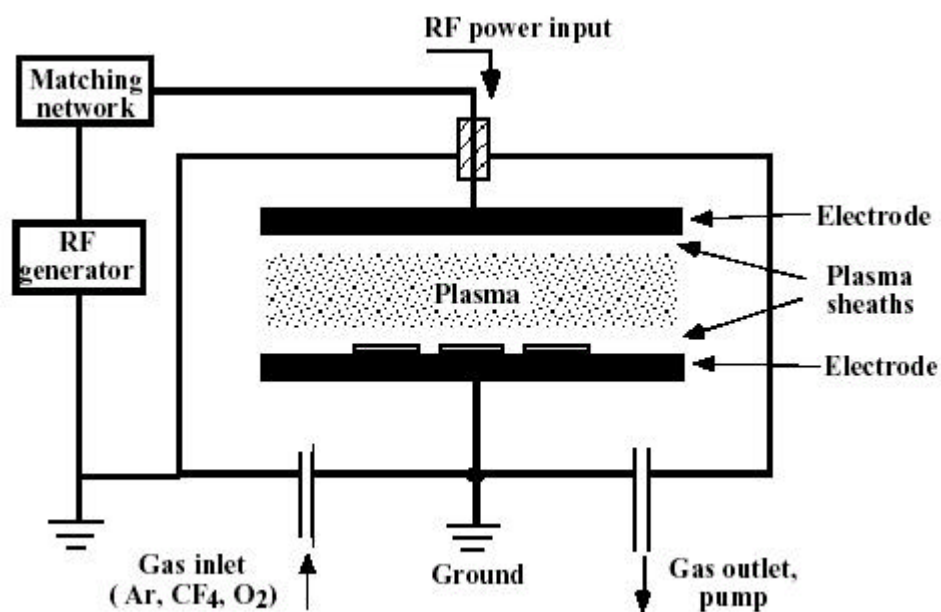
- **By applying a high electric field across two electrodes, some of the gas atoms are ionized, producing positive ions and free electrons and creating a plasma**
- **The energy is supplied by an RF generator, usually operating at 13.56MHz**
- **A voltage bias develops between the plasma and the electrodes U the difference in mobility of the electrons and the ions**
- **Initially, the more mobile electrons are lost to the electrodes at a faster rate than the slower ions   plasma being biased positively with respect to the electrodes**

Electrode (target)

Electrode

Equal area electrodes

V_p

Voltage

+

0

Distance

V_1

0

V_2

Unequal area electrodes
(smaller electrode at left)
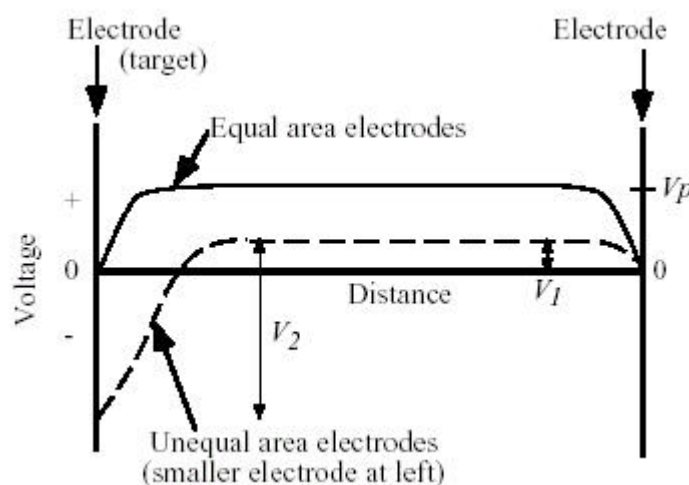
- **Sheaths = the regions next to each electrode where the voltage drops occur**
           = dark regions

- **Whereas the heavy ions respond to the average sheath voltage, the light electrons respond to the instantaneous voltage**
- **Due to the self-biasing, electrons only cross the sheath during a short period per cycle**
- **During most of the RF cycle the electrons are turned back at the sheath edge   the sheaths being deficient of electrons   sheath being dark**
  (lack of electron / atom collisions and subsequent relaxation by light emission)
- **The RF current density must be much higher at the smaller electrode in order to maintain current continuity**

Dissociation:
$$CF_4 + e^- \rightarrow$$
$$CF_3 + F + e^-$$

Ionization:
$$CF_3 + e^- \rightarrow CF_3^+ + 2e^-$$

Dissociative ionization:
$$CF_4 + e^- \rightarrow$$
$$CF_3^+ + F + 2e^-$$

Excitation:
$$CF_4 + e^- \rightarrow CF_4^* + e^-$$

Recombination:
$$CF_3^+ + F + e^- \rightarrow CF_4$$
$$F + F \rightarrow F_2$$
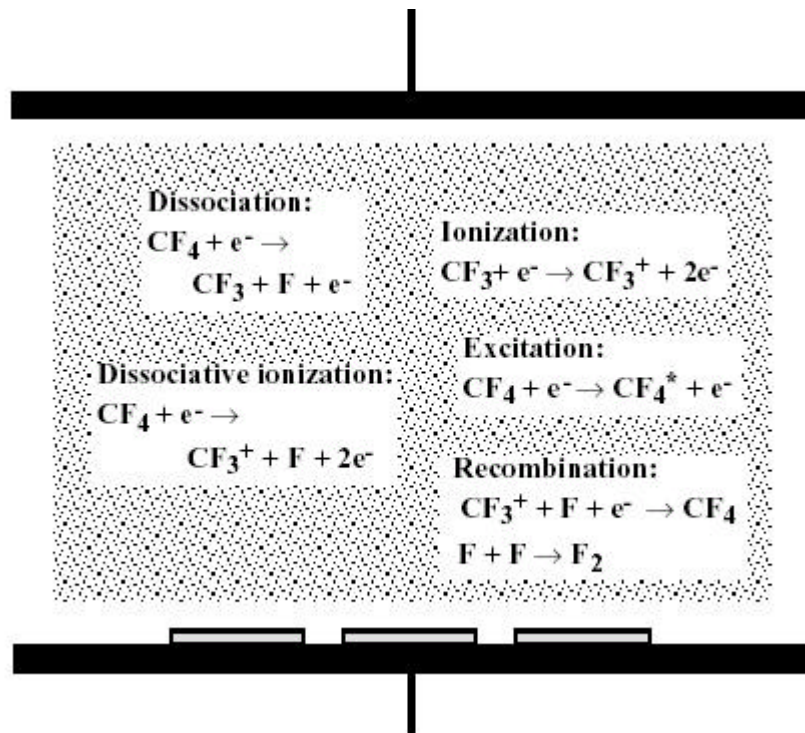
- **Typically there will be about 10^{15}cm^{-3} neutral species (1 to 10% of which may be free radicals) and 10^8-10^{12}cm^{-3} ions and electrons**
- **The plasma density and the ion energy are closely coupled**

10.2.2.1 Plasma Etching Mechanisms
- **Reactive neutral chemical species and the ions**

     chemical component   physical component
     Reactive neutral species : chemical etching
     Ions : Physical etching or sputtering
     Reactive neutral species and ions act in a synergistic
     fashion : ion-enhanced etching

Chemical Etching
- **Free radicals = electrically neutral species that have incomplete bonding**

$$e^- + CF_4 \ ? \quad CF_3 + F + e^-$$

Etchant (free radical) creation
$e^- + \text{OO} \rightarrow \text{O}$

Etchant transfer

Byproduct removal

Mask

Etchant adsorption   Etchant/film reaction

Film

$$4F + Si \ ? \quad SiF_4$$
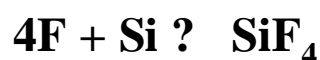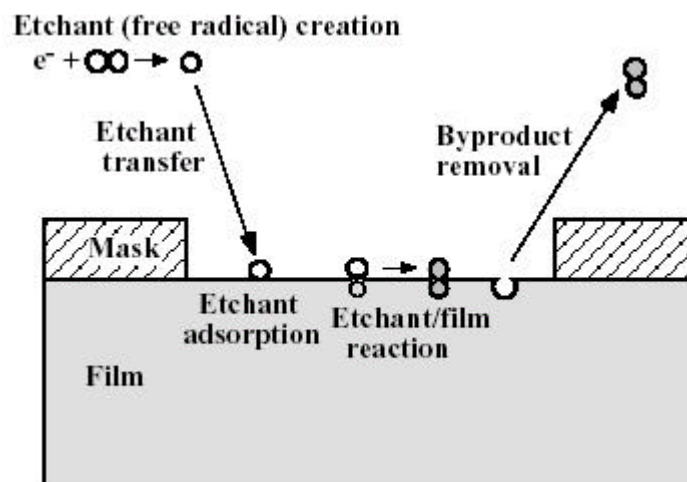
- **Gas additives can be used to increase the production of the reactive etch species and thereby increase the chemical etching rate**
- **The oxygen reacts with dissociated CF_4 species (CF_3 or CF_2, for example), which reduces the recombination of those species with F ? increase the amount of free F**
- **However if too much O_2 is added, the etchant becomes too diluted or the surface is oxidized, and the etching decreases**
- **The incoming fluxes of species from the plasma to the wafer surface including the angular distribution of the various fluxes. Cos^n? distribution**
  - **$n = 1$ describes an isotropic distribution**
  - **$n > 1$ describes a more directed distribution**

$$S_C = \frac{F_{reacted}}{F_{incident}} = \text{sticking coefficient}$$

Reactive neutral species

a)

Mask

Film
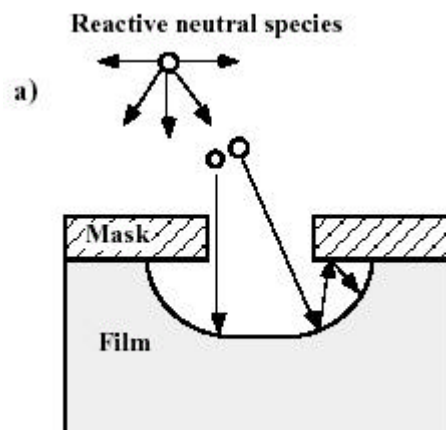
Physical Etching

- **Voltage drop between the plasma and each electrode & the resulting electric field ?   positive ions will be accelerated toward each electrode**
- **The flux of ions is much more directional**
  ?   etching is more anisotropic
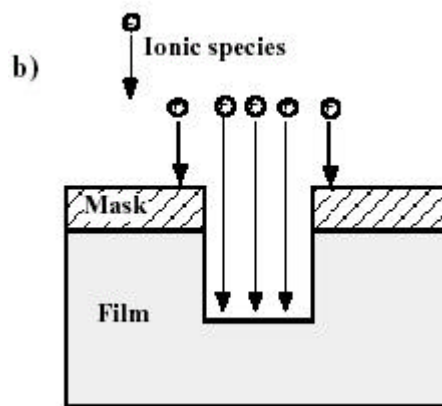
- **It is assumed that once each ion strikes the surface, it does not strike the surface again somewhere else**
  ? $S_C = 1$
- **Sputtering yield = number of atoms or molecules ejected from the target per incident ion**
- **Sputter yield is a function of incident angle**
- **When ionized reactive species such as Cl^+ and CF_3^+ are involved in sputtering, chemistry can also be important in determining the effective sputtering yield. Such effects can enhance the sputtering yield, although the magnitude of these effects is usually small compared to ion-enhanced etching**

Ion-Enhanced Etching
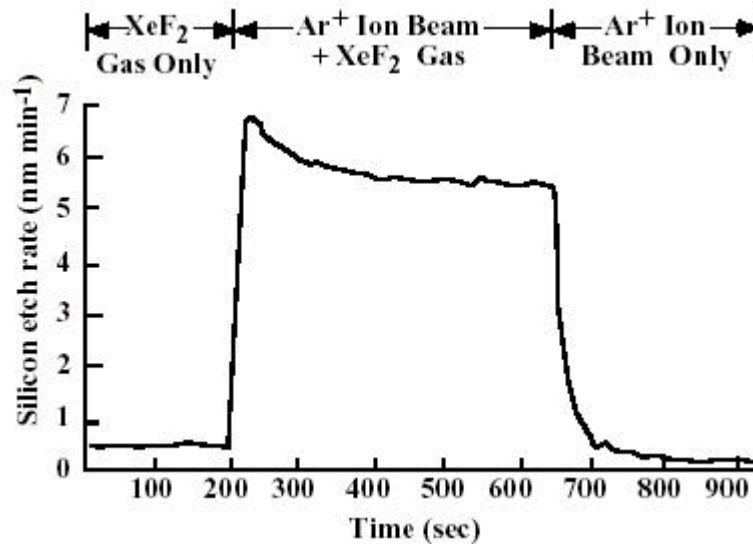
- **The profile for ion-enhanced etching is much more like the case for physical etching alone**
- **Gas chemistries and etch conditions are usually chosen to promote ion-enhanced etching and to suppress independent chemical and physical etching**
- **The ion bombardment enhances one of the steps of chemical etch processes, such as surface adsorption, etching reaction and formation of byproduct, or removal of byproduct or unreacted etchant**
- **The inhibitors are often intentionally produced by providing sources in the gas which enhance their formation so that more directional etching is achieved**
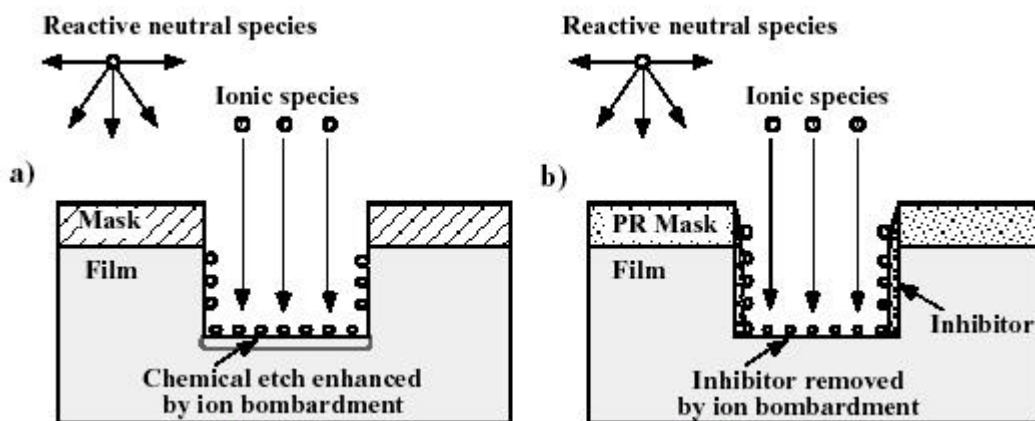
• **When inhibitors form or are deposited during etching, sloped sidewalls can result if the inhibitor formation or deposition rate is very high relative to the etch rate of the inhibitor and substrate**

Mask Film		Mask Film
	Inhibitor deposition or formation	
	Etch	
	Inhibitor deposition or formation	
	Etch	
	Final profile	
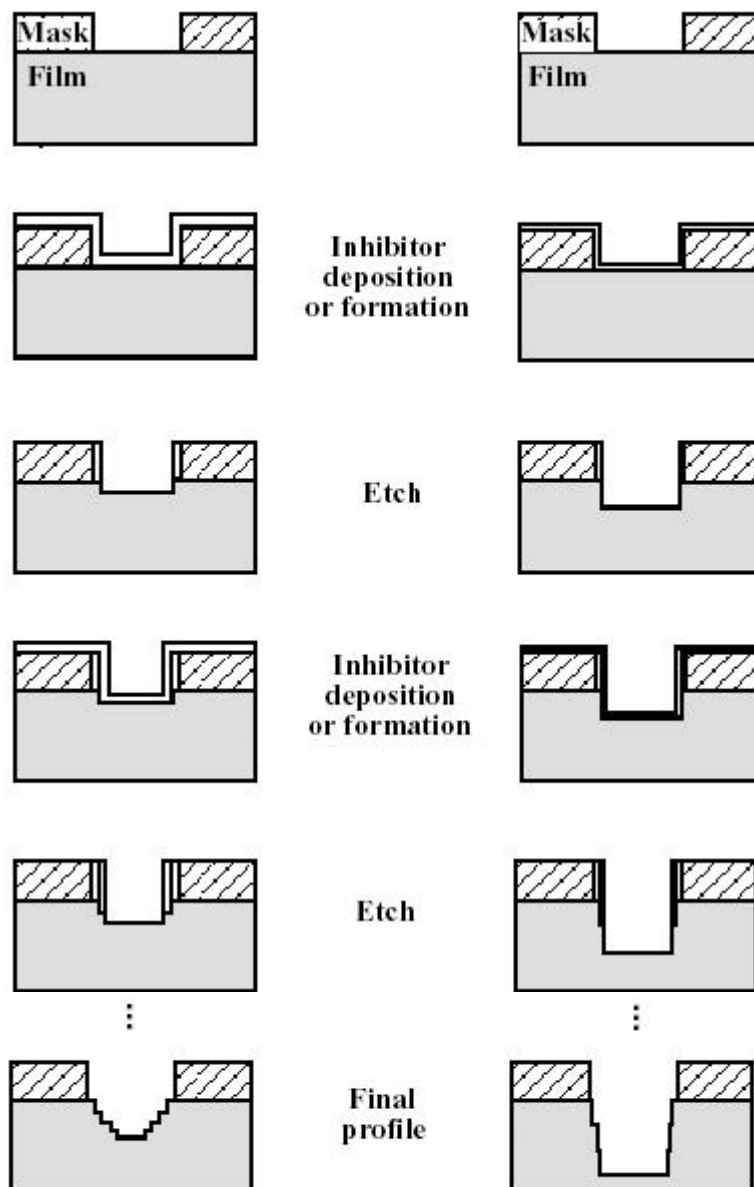
10.2.2.2 Types of Plasma Etch Systems
Plasma Etching in Barrel Etchers
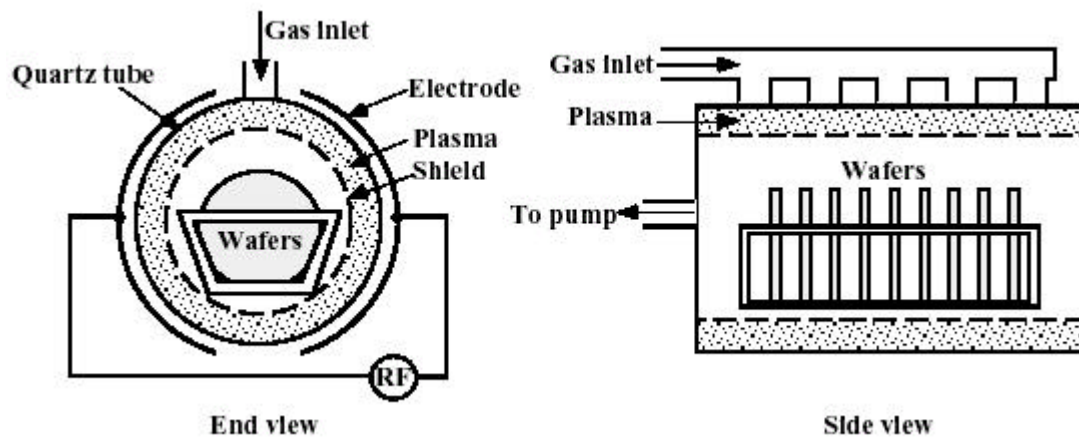
- **No ionic bombardment occurs**
- **Isotropic**
- **Etch uniformity is not very good**
- **Photoresist removal, using and O_2 plasma   (photoresist) ashing**

- **Downstream plasma etchers**
    - **plasma upstream is generated in one chamber**
    - **wafers are placed in a separate but connected chamber**
    - **the neutral reactive chemical species can diffuse from the plasma in one chamber to the wafers in another, while ions do not**
    - **called "afterglow etchers"**
    - **nonmasked etching etching steps, such as removing silicon nitride masks used for LOCOS processes**
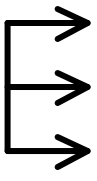
Plasma Etching in Parallel Plate Systems - Plasma Mode
 • **Much better etch uniformity than the barrel etcher**

RF power input

Matching network

RF generator

Plasma

Electrode

Plasma sheaths

Electrode

Gas inlet (Ar, CF₄, O₂)

Ground

Gas outlet, pump

Electrode (target)

Electrode

Equal area electrodes

V_p

Voltage

0

Distance

V_1

0

V_2

Unequal area electrodes (smaller electrode at left)
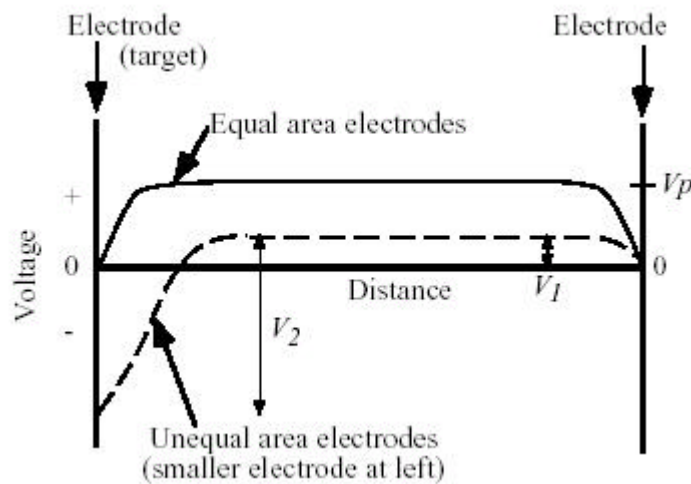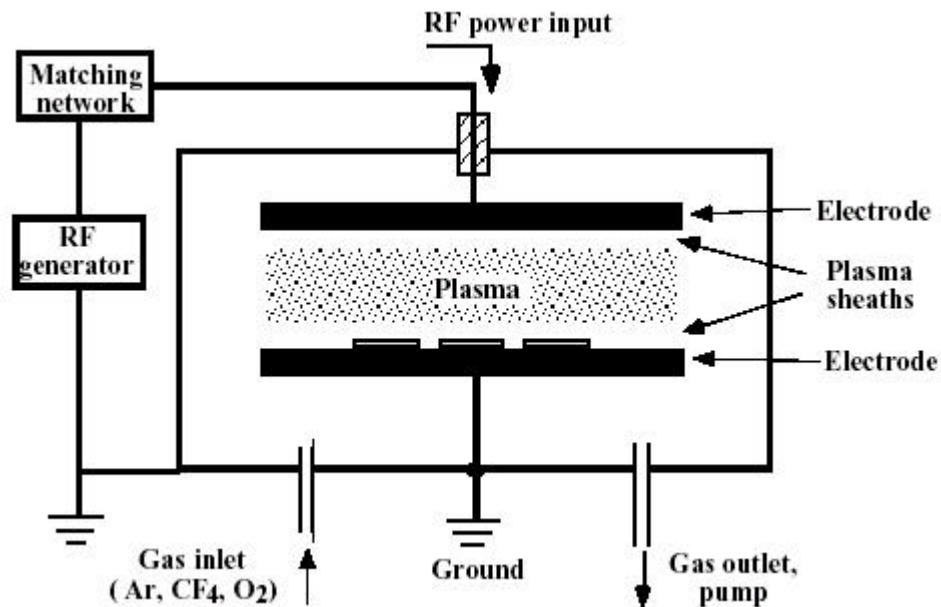
 • **With the large voltage drop to the top electrode, significant sputtering of that electrode can occur, causing contamination problems**

Plasma Etching in Parallel Plate Systems – Reactive Ion Etching Mode

- **A much larger voltage drop occurs from the plasma to the wafers, in the 100-700V range, resulting in more energetic ion bombardment**
- **Even more directional etching can be attained by lowering the pressure**
- **Lower pressure**
  - **fewer ion collisions**
  - **increases the sheath voltage**
  - **decreases the plasma density**
- **10-100mtorr**
- **Magnetic fields are often added to enhance plasma density and lower operating pressures**
- **Vertical RIE systems. Hexode batch etcher**
- **Triode systems**
- **Higher energy ions striking the surface can cause radiation or lattice damage, charging, and trenching**

Etching in High-Density Plasma Systems

- **HDP**
- **Separate the plasma density and ion energy by using a second excitation source to control the bias voltage**
- **Density = $10^{11} – 10^{12}$ ions / cm^3**
- **ECR (Electron Cyclotron Resonance) and ICP (Inductively Coupled Plasma)**
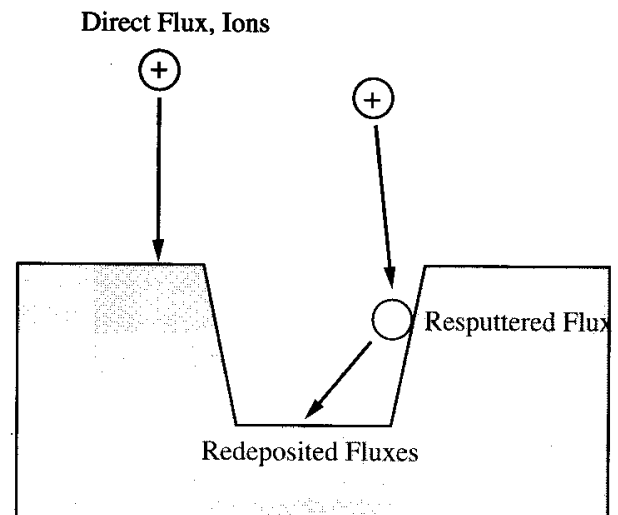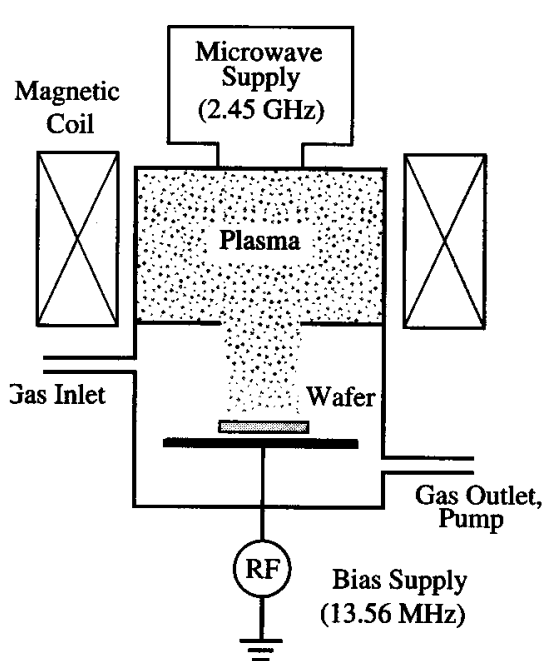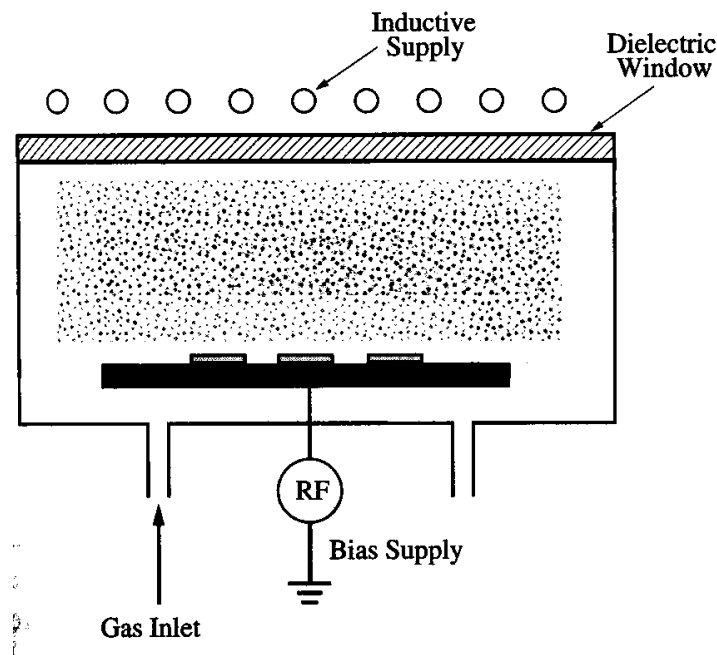
- **Very high plasma densities ? lower pressures (1-10mtorr)**
- **Ion bombardment damage can be kept low while maintaining high etch rates and good anisotropic etching**
- **Lower ion energy gives better selectivity**

Sputter Etching and Ion Milling
 • **Purely physical etching methods**
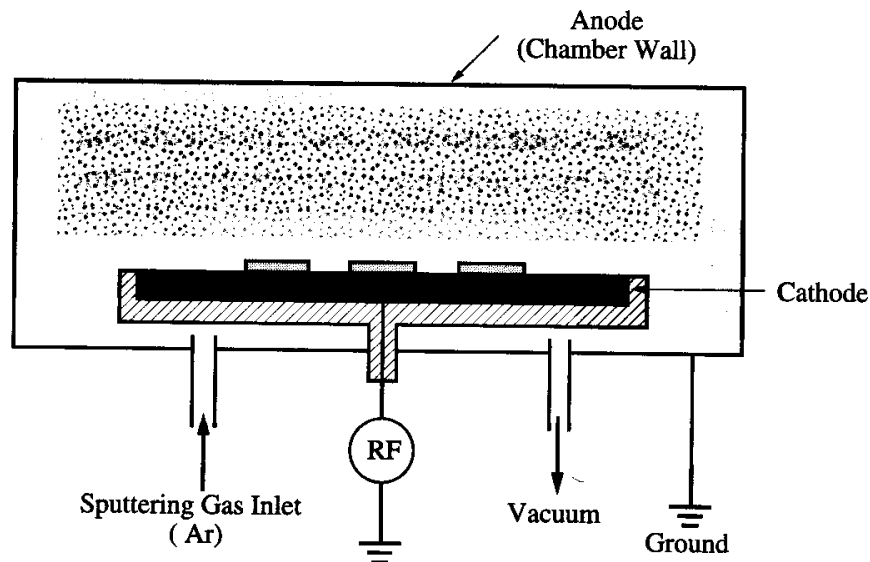
• **Ion energies > 500eV**
• **All materials can be etched**
• **Sputtering rate = etch rate : depends on the sputtering yield**
• **The sputter yields of most materials by Ar ions are fairly similar**
• **The best selectivity ~ 2**
• **Microtrenching**
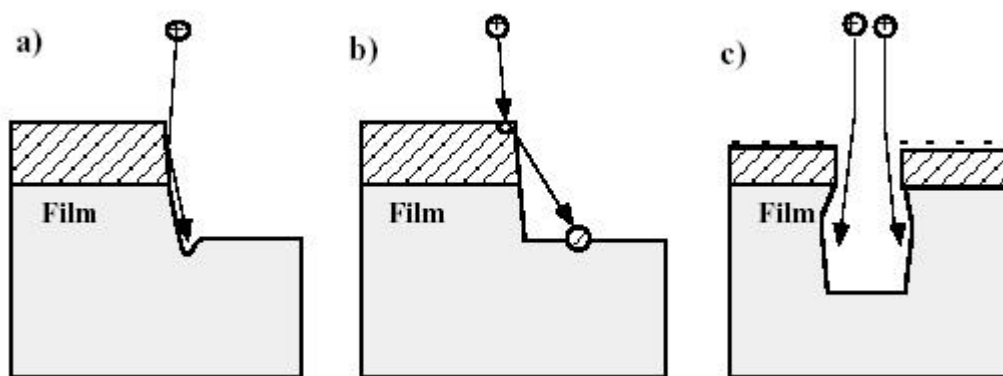
- **Lattice or radiation damage**
- **Ion milling : a confined plasma is used to generate a broad beam of Ar^+ ions**
- **Use a set of grids to extract and accelerate ions from the plasma chamber toward the wafer**
- **A separate electron source is used to supply electrons to neutralize the ion beam**
- **RIBE = Reactive Ion Beam Etching : an amount of reactive species may be added to, or replace, the Ar**
- **FIB = Focused Ion Beam : ion beams are focused and then used to sputter very small areas : commonly used to repair masks**

10.2.2.3 Summary of Plasma Systems and Mechanisms

Pressure | Energy | Selectivity | Anisotropy

Sputter Etching and Ion Beam Milling — Physical Processes

High Density Plasma Etching

Reactive Ion Etching

Plasma Etching

Wet Chemical Etching — Chemical Processes

Ionic species

Reactive neutral species
• free radicals important

Charging
+ + + +

Mask Erosion

Mask

Film

Undercutting

Chemical etching
• Isotropic, very selective.

Trenching

Physical etching
•Anisotropic, non-selective.

Sidewall-inhibitor Deposition
• Sources: etch byproducts,
    mask erosion, inlet gases.
• Removed on horizontal surfaces
    by ion bombardment.
• A possible mechanism in ion
    enhanced etching.

Ion Enhanced Etching
• Needs both ions and reactive neutrals.
• May be due to enhanced etch reaction
    or removal of etch byproduct or
    inhibitor.
• Anisotropic, selective.

• **PECVD systems are similar to parallel plate etch systems operating in the plasma mode**

10.3 Manufacturing Methods

10.3.1 Plasma Etching Conditions and Issues
 • **RF power, pressure, gas compositions, and flow rates**
 • **Power densities : 0.1 ~ 5W/cm^2**
 • **Excitation voltages : 100 ~ 1500 volts RMS**
 • **RF power ?** $\longrightarrow$ **plasma density ?**
      $\longrightarrow$ **self-bias or sheath voltage ? ? ion energy ?**
 • **Ion energies : 10 ~ 700 eV**
 • **In HDP systems : power density = 0.1 ~ 3W/cm^2**

- Ion energy = 10 ~ 500 eV
- Pressure ⎡ 10 ~ 100mtorr in standard RIE systems
  ⎣ 1 ~ 10mtorr in HDP systems
- As pressure increases ⎡ Plasma densities ?
  ⎣ However, above a certain pressure, plasma densities ? (the collisions between the gas molecules and electrons limit the energy of the electrons and thereby limit the ionization rate)
- Etch rate a flux of active species (neutral chemical species and the ionic species)
- Power ? ? ion flux = (ion concentration) × (velocity) ?
- Effective sputtering yield a $\sqrt{\text{ion energy}}$
- In parallel plate systems, ⎡ power ? ? (ion energy)
  ⎢ ? sputtering yield ?
  ⎣ pressure ? ? ion energy ?

- Pressure ? ? chemical flux ?
- Decreasing the pressure too far ⎡ below about 10mtorr for RIE
  ⎣ below about 1mtorr for HDP

  will result in too low a plasma density and too low an etch rate
- Flow rate ⎡ ? : etch rate ?
  ⎣ ?? : etch rate ? (the residence time may become less than the lifetime of the active species)

- **In Al etching, the system, including the chamber walls, is heated to 35 – 65°C to help keep the species volatile**
- **Sidewall inhibitor deposition actually decreases as the temperature goes up in most cases**
- **Sloped sidewalls can also be produced by allowing a certain amount of mask erosion to occur and using a tapered mask**
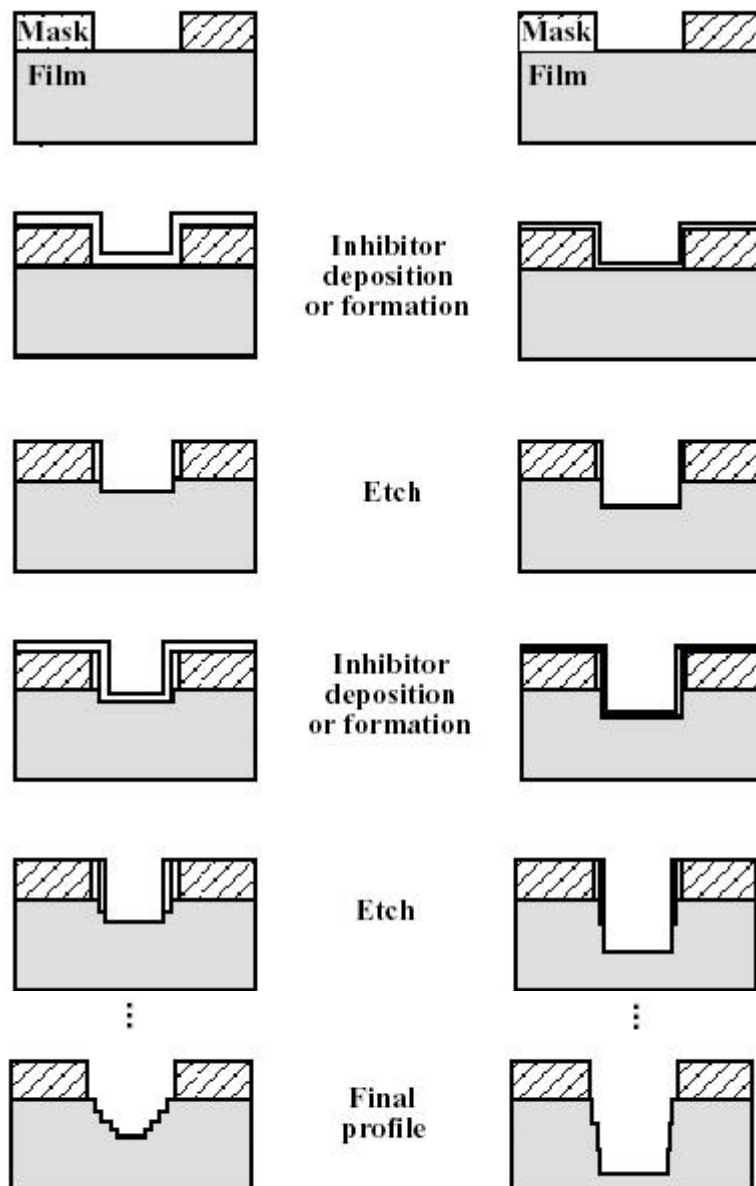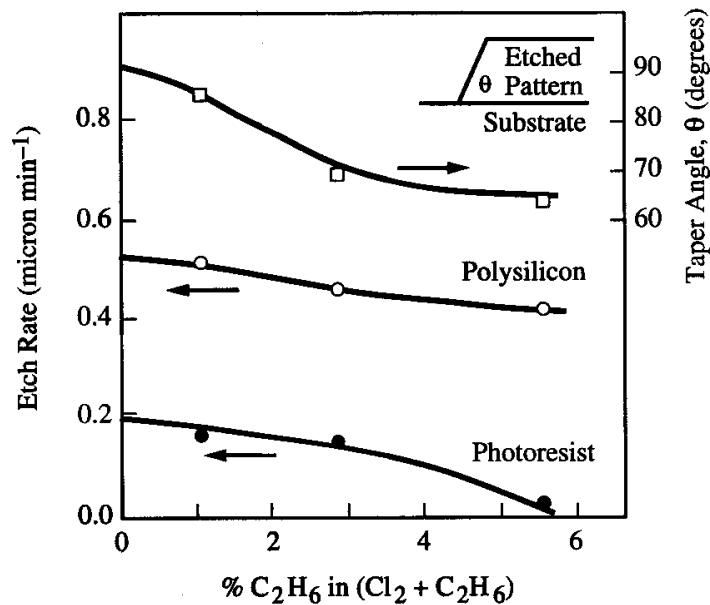
- **The deposition of an inhibitor layer often shows a negative activation energy. The desorption of the deposited inhibitor layers increase with temperature**
- **Sometimes wafers develop "bulls-eye" patterns where the outside etches faster than the inside (depletion effects as the gas flows from the outside to the inside)**
- **Loading effect** ⌐ **macroscopic loading**
  └ microscopic loading
- **ARDE (Aspect Ratio Dependent Etching) = RIE "lag"**
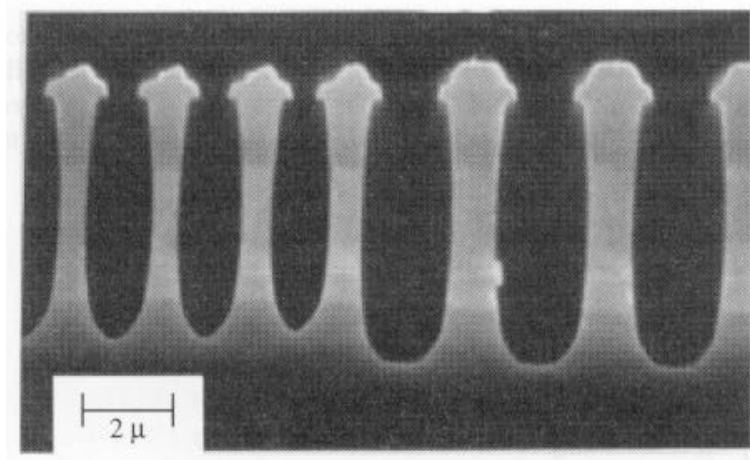
(1) Depletion or trapping of the reactant species, or other conductance limitations, as the species travel to the bottom of the trench

(2) Distortion of ion paths due to charging

(3) Shadowing effects involving either neutrals or ions

• **The etch rate is a function of the density of the film and the doping of the film**
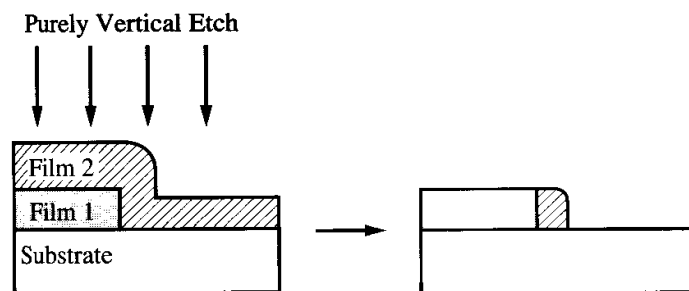
• **Contamination and particulates can be reduced by reducing the pressure**

10.3.2 Plasma Etch Methods for Various Films

• **Cl, F, Br**

(1) Etch selective to underlying films

(2) Anisotropic etching

(3) Volatility of main etch byproducts

• **Volatility depends on how tightly bound the species to the surface**

Table 10-2.   Boiling points of typical etch products (After [10.12]).

Element	Chlorides	Boiling Point (°C)	Fluorides	Boiling Point (°C)
Al	$AlCl_3$	177.8 (subl.)	AlF_3	1291 (subl.)
Cu	CuCl	1490	CuF	1100 (subl.)
Si	$SiCl_4$	57.6	SiF_4	− 86
Ti	$TiCl_3$	136.4	TiF_4	284 (subl.)
W	WCl_6	347	WF_6	17.5
	WCl_5	276	WOF_4	187.5
	$WOCl_4$	227.5		

Manufacturing Methods

Material	Etchant	Comments
Polysilicon	SF_6, CF_4	Isotropic or near isotropic (significant undercutting); poor or no selectivity over SiO_2
	CF_4/H_2, CHF_3	Very anisotropic, non-selective over SiO_2
	CF_4/O_2	Isotropic, more selective over SiO_2
	HBr, Cl_2, $Cl_2/HBr/O_2$	Very anisotropic, most selective over SiO_2
Single crystal Si	same etchants as polysilicon	
SiO_2	SF_6, NF_3, CF_4/O_2, CF_4	Can be near isotropic (significant undercutting); anisotropy can be improved with higher ion energy and lower pressure; poor or no selectivity over Si
	CF_4/H_2, CHF_3/O_2, C_2F_6, C_3F_8	Very anisotropic, selective over Si
	$CHF_3/C_4F_8/CO$	Anisotropic, selective over Si_3N_4
Si_3N_4	CF_4/O_2	Isotropic, selective over SiO_2 but not over Si
	CF_4/H_2	Very anisotropic, selective over Si but not over SiO_2
	CHF_3/O_2, CH_2F_2	Very anisotropic, selective over Si and SiO_2
Al	Cl_2	Near isotropic (significant undercutting)
	$Cl_2/CHCl_3$, Cl_2/N_2	Very anisotropic; BCl_3 often added to scavenge oxygen.
W	CF_4, SF_6	High etch rate, non-selective over SiO_2
	Cl_2	Selective over SiO_2
Ti	Cl_2, $Cl_2/CHCl_3$, CF_4	
TiN	Cl_2, $Cl_2/CHCl_3$, CF_4	
$TiSi_2$	Cl_2, $Cl_2/CHCl_3$, CF_4/O_2	
Photoresist	O_2	Very selective over other films

10.3.2.1 Plasma Etching Silicon Dioxide
- F

  $4F + SiO_2$? $SiF4 + O_2$
- **The key to making the etching of SiO_2 very anisotropic as well as much more selective over Si is to reduce the amount of F free radical production and increase the carbon content**
- **One way to reduce the relative amount of F free radicals is by adding H_2 to the CF_4 gas. The H reacts with F to produce HF**

10.3.2.2 Plasma Etching Polysilicon
- **Byproduct volatility, selectivity, and anisotropy**
- **Presence of the ubiquitous native oxide, requiring, an initial "breakthrough" etch step**
- **Anisotropic and selective etching can be achieved simultaneously using Cl-based etchants. Cl_2, HCl or $SiCl_4$ can be used. These have a lower purely chemical component than F-containing etchants**
- **Fairly anisotropic even without a polymer inhibitor layer present**
- **Selectivity of Si to SiO_2 can be quite high > 100**
- **The anisotropy can be enhanced even more by adding a small amount of O_2**
- **O_2 reacts with the Si film, or with etch reaction byproducts that have adsorbed on the sidewall to form a nonpolymer, SiO_2-based inhibitor layer. The O_2 also helps with selectivity over oxide by removing any carbon that comes from photoresist erosion**

- Keeping the wafer temperature low also improves the anisotropy by enhancing inhibitor deposition
- High n^+ levels can increase the polysilicon etch rte by up to 25 times, and can increase the spontaneous etching and undercutting
- Addition of SF_6 reduces trenching
- Br-based : HBr, Br_2 : etching with a low purely-chemical component and without a polymer inhibitor, and are even more anisotropic and selective over oxide. Trenching is less of a problem
- Etch rate (Br) < Etch rate (Cl) < Etch rate (F)
- Br-based etchants are often used in a mixture with Cl_2
- Adding $_{O2}$ promotes inhibitor formation. The O_2 also helps with selectivity over oxide by removing any carbon that might result from PR erosion
- Breakthrough step : During the first 5 to 10 seconds of the poly etch, one can add an etchant such as CF_4 or increase the RF power
- Over etch step is often done at a lower RF power to increase the selectivity over oxide
- A final postetch "cleanup" step is done to remove any sidewall layer material ⎡ polymeric layer : O_2 plasma + HF dip ⎣ inorganic layer : HF dip
- STI : Cl- or Br-based etchant can give good selectivity over SiO_2 or Si_3N_4

- **Using Cl alone can result in harmful ion-induced trenching at the bottom corners. The slope can be tailored by including gas additives, such as O_2, to promote inhibitor deposition**
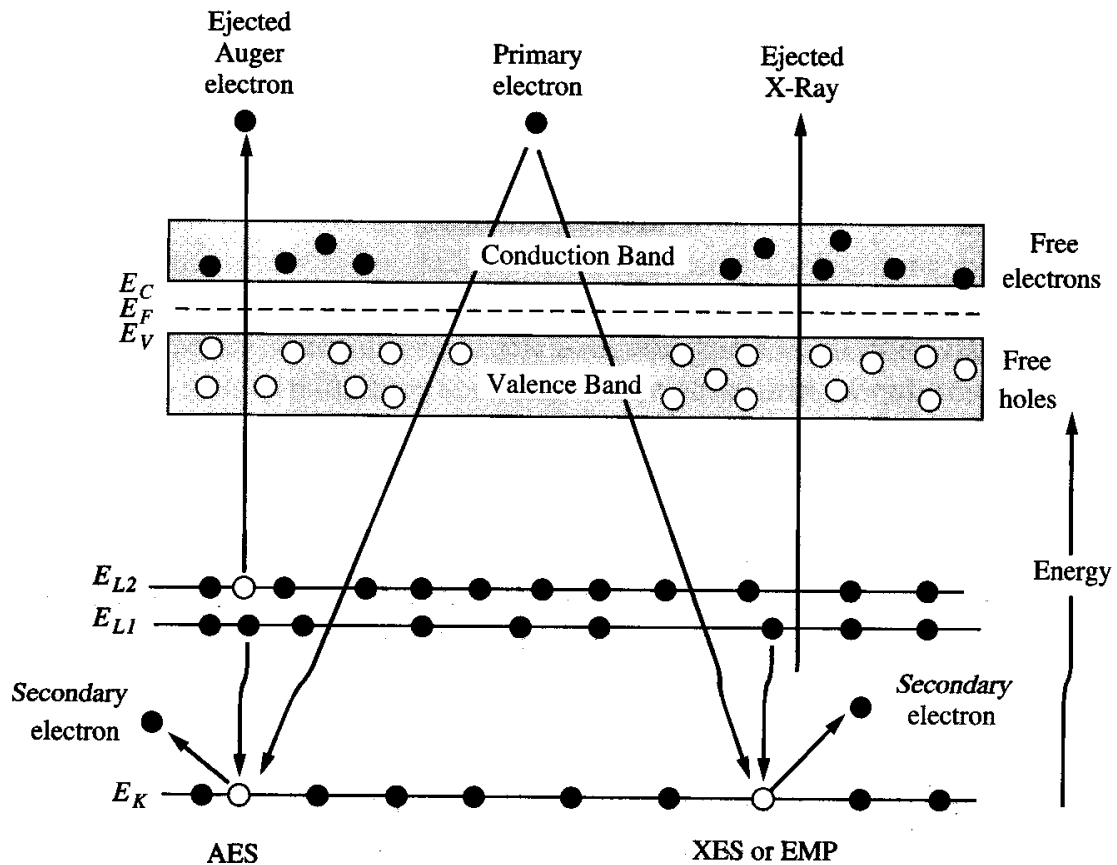
10.4 Measurement Methods
- **Composition and contamination measurements**
- **AES (Auger Electron Spectroscopy) and XPS (X-ray Photoelectron Spectroscopy) can be used to detect and measure chemical species left on the film or in the near-surface region**
- **XPS is often used to give bonding information and can distinguish whether carbon detected on the surface is bonded to fluorine in $C-F_2$ structures or to the silicon in the substrate with C-Si bonding, for example**
- **Physical damage, in terms of dislocations, trenching, and surface roughening, can be measured by TEM or SEM**
- **Endpoint detection**
- **An in situ thickness measurement technique for optically transparent films, such as SiO_2, is interferometry**

$$\Delta x_f = \frac{1}{2n}$$

- **For nontransparent films, such as metals, techniques using reflectivity differences between the film and the layer underneath can be used**

- **The most common methods for endpoint detection are those which monitor the reacting species or reaction products**

Ejected Auger electron

Primary electron

Ejected X-Ray

E_C
E_F
E_V

Conduction Band

Free electrons

Valence Band

Free holes

E_{L2}

E_{L1}

Energy

Secondary electron

Secondary electron

E_K

AES

XES or EMP

- **Optical spectroscopy or mass spectroscopy : takes its information from the gas phase and thus average over a much larger region**
- **The technique of optical emission spectroscopy is also used in diagnostics of plasma etch processes**