Course name:
Growth and Characterization of Nano-electronic Materials (EE728)

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Etching

EE669 VLSI Technology

Reference: Textbook: Silicon VLSI Technology by Plummer, Deal and Griffin, Chapter 10

Dry etching

- **Advantages**

- Eliminates handling of dangerous acids and solvents
- Isotropic or anisotropic/vertical etch profiles
- Directional etching without using the crystal orientation of Si
- Reliable pattern transfer into underlying layers
- High resolution and cleanliness
- Less undercutting
- Better process control

- **Disadvantages:**

- Some gases are quite toxic and corrosive.
- Re-deposition of non-volatile compound on wafers.
- Expensive equipment ($200-500K for R&D, few million for industrial tools).

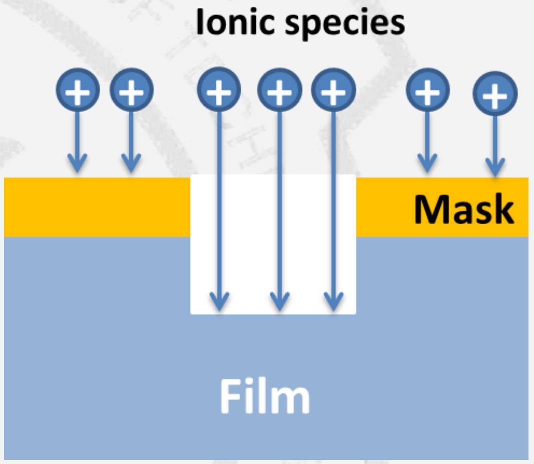
- **Types of dry etching:**

- Non-plasma based: Spontaneous reaction of suitable reactive gas mixture.
- Plasma based: Radio frequency (RF) power to drive chemical reaction.

Dry Etching

Dry etching

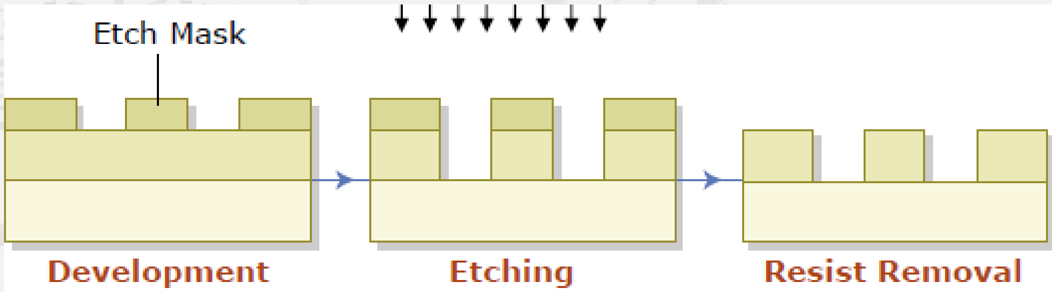
- Dry etching (which has largely replaced wet) based on highly anisotropic sputtering process and may include reactive ions, so can also be chemical and selective



- Wet etching was used exclusively till 1970's
- Etch bias: bad for small scale features

- Need better definition of small features therefore dry etching, accelerated ions from *plasma*

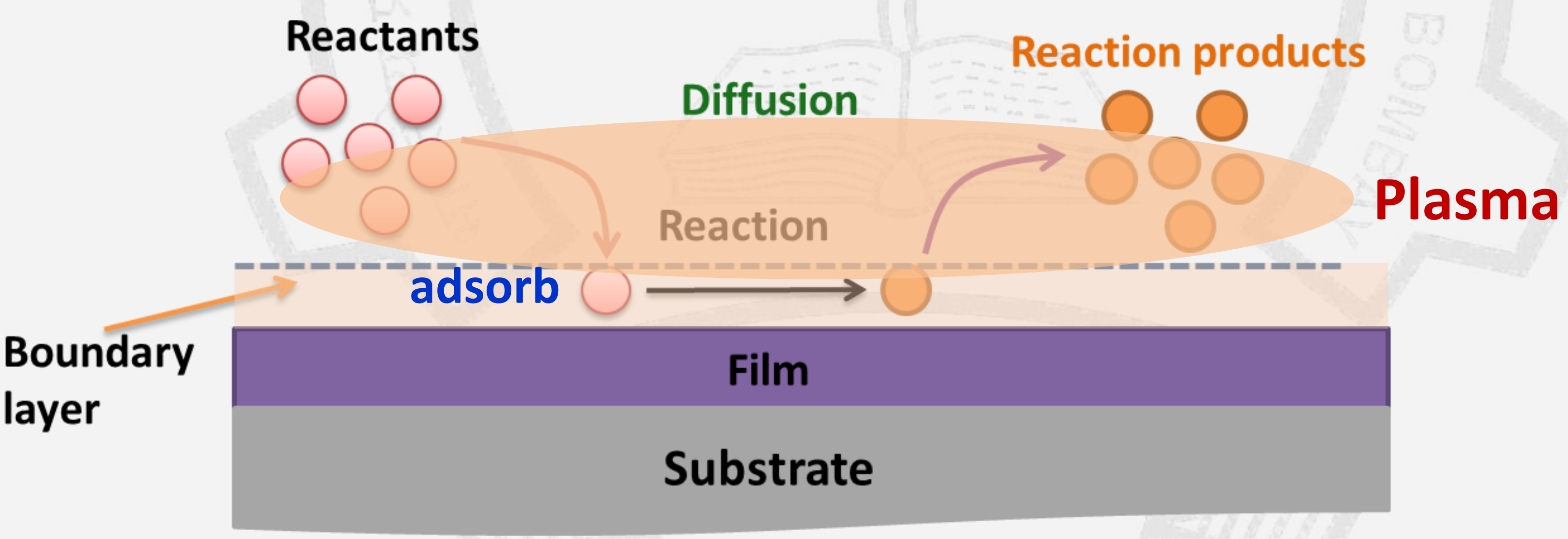
- Widely used SiN passivation layer found difficult to wet etch (HF used but it attacks SiO_2),



- Reactive species in *plasma* found to accelerate dry etching: $CF_4 + O_2$ in plasma much better, and does not attack PR

Plasma-based etching

- Directional etching due to presence of ionic species in plasma and (self-) biased electric field. (The self-bias electric field is not applied *externally*, but is created *spontaneously* in RF plasma)
- Two components exist in plasma
  - Ionic species result in directional etching.
  - Chemical reactive species result in high etch selectivity.
- Control of the ratio of ionic/reactive components in plasma can modulate the dry etching rate and etching profile.

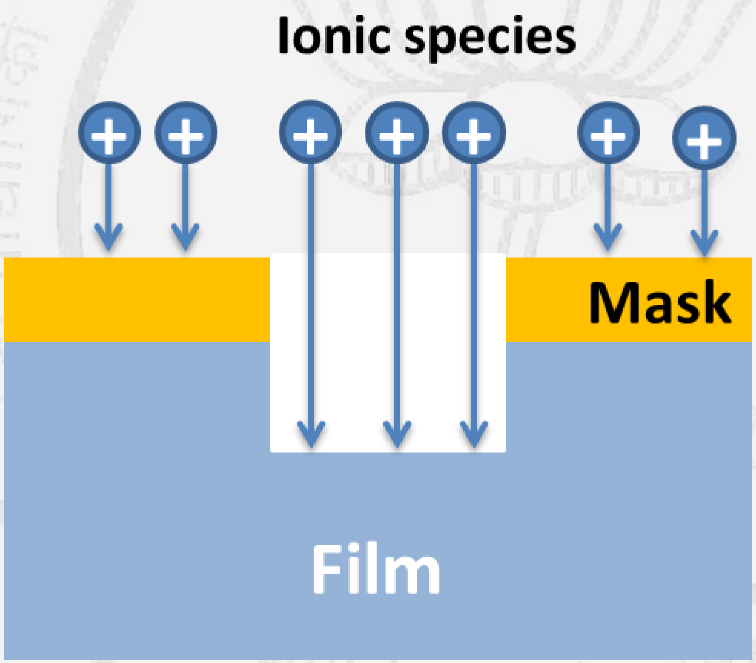


$$Si(s)+4F(g)=SiF_4(g)$$

Dry etch

Dry etch (*Physical: ions, momentum transfer*) anisotropic, not selective
Sputter etching.

More widely used for small features

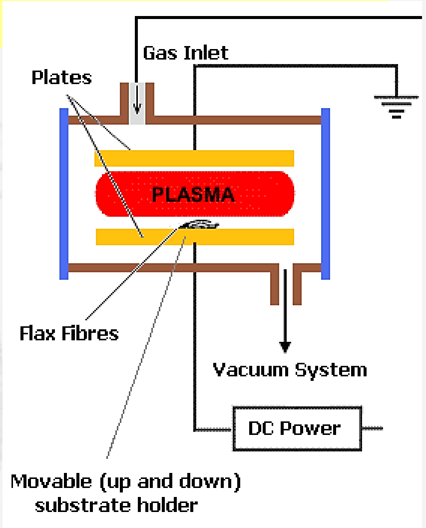


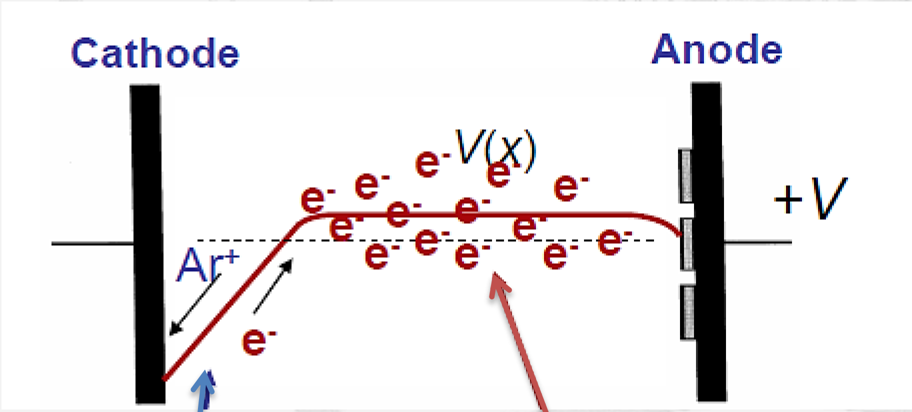
Combination (*Physical* & *Chemical*) Ion-enhanced or Reactive Ion Etching (RIE) combines best of *directionality* and *selectivity*

Plasma: How does it work??

DC plasma: Created by an electrical discharge between two electrodes. A plasma support gas is necessary, and Ar is common gas.

Working pressure: 1mTorr – 100 mTorr





Fewer *e*-s found in high-field, dark spaces

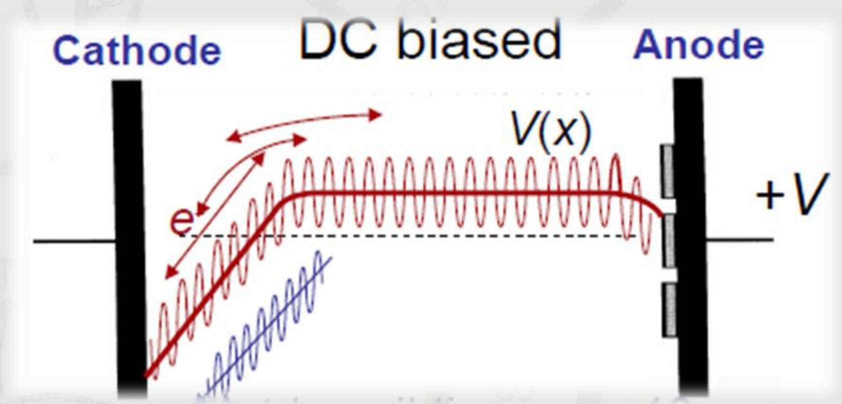
Electrons largely confined to positive potential, high conductivity, $V \approx 0$

RF plasma

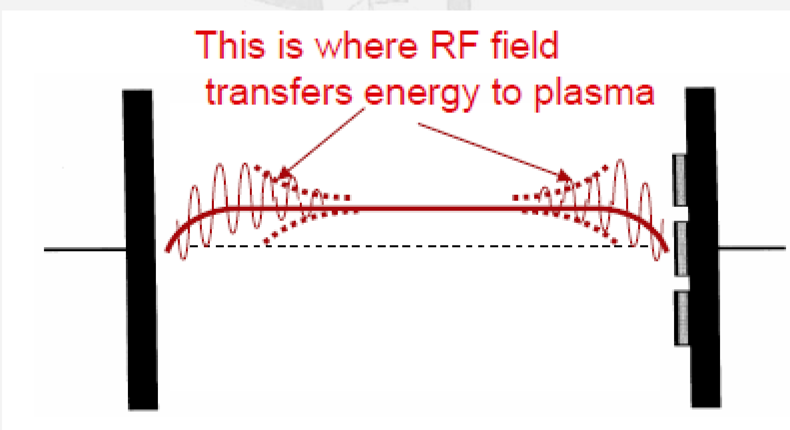
Radio frequency plasmas (rf plasmas) are formed in a flow of gas by an externally applied radio frequency field.

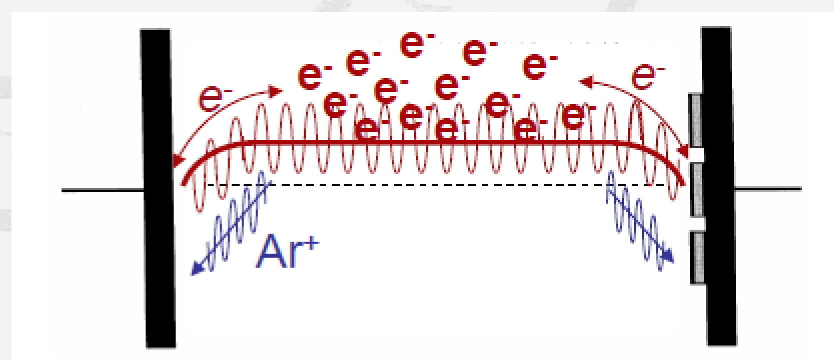
f= 13.6 MHz , τ≈12 ns

***e*-transit time over 10 cm: *t* ≈ 10ns.**
***e*-follows the RF field**



Ar+ transit time over 10 cm, *t*≈2μs
Ar^+ drifts with DC field





Energy pumped in from edges of plasma

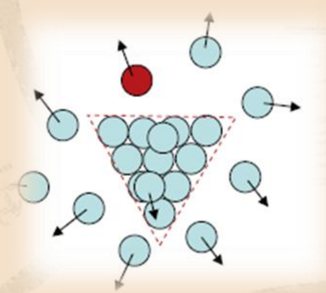
Dry etch

It combines

Physical etch
nobles: Ar^+

+

reactive ions, free radicals, i.e. elec. neutral and incomplete bonding: CF_3,F, Cl



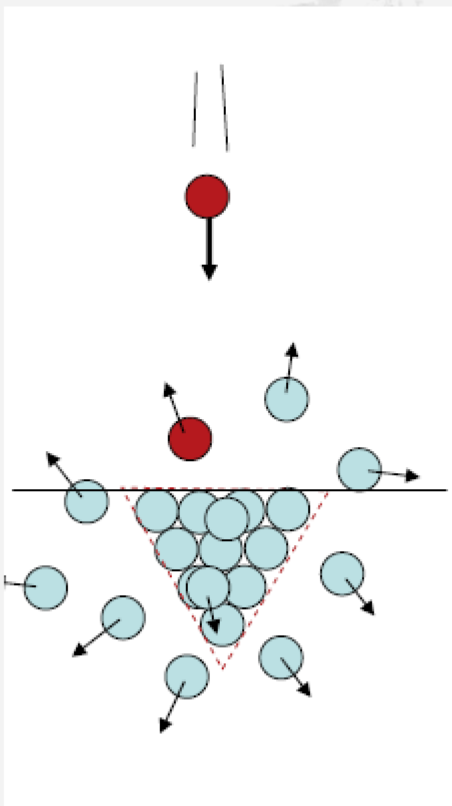
CF_4 (g) gives F(g)

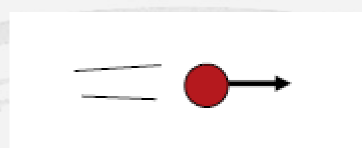
Physical etching

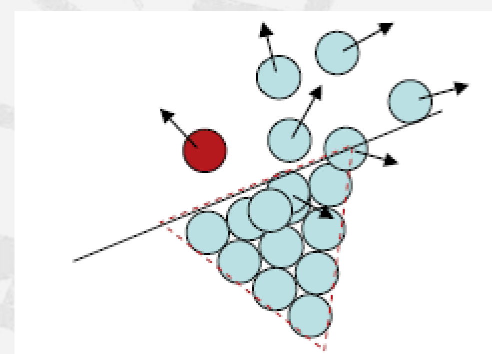
Physical etching involves *directional momentum transfer by Ar+, Cl+ etc.*

Sputter yield depends on angle of incidence, helping planarization

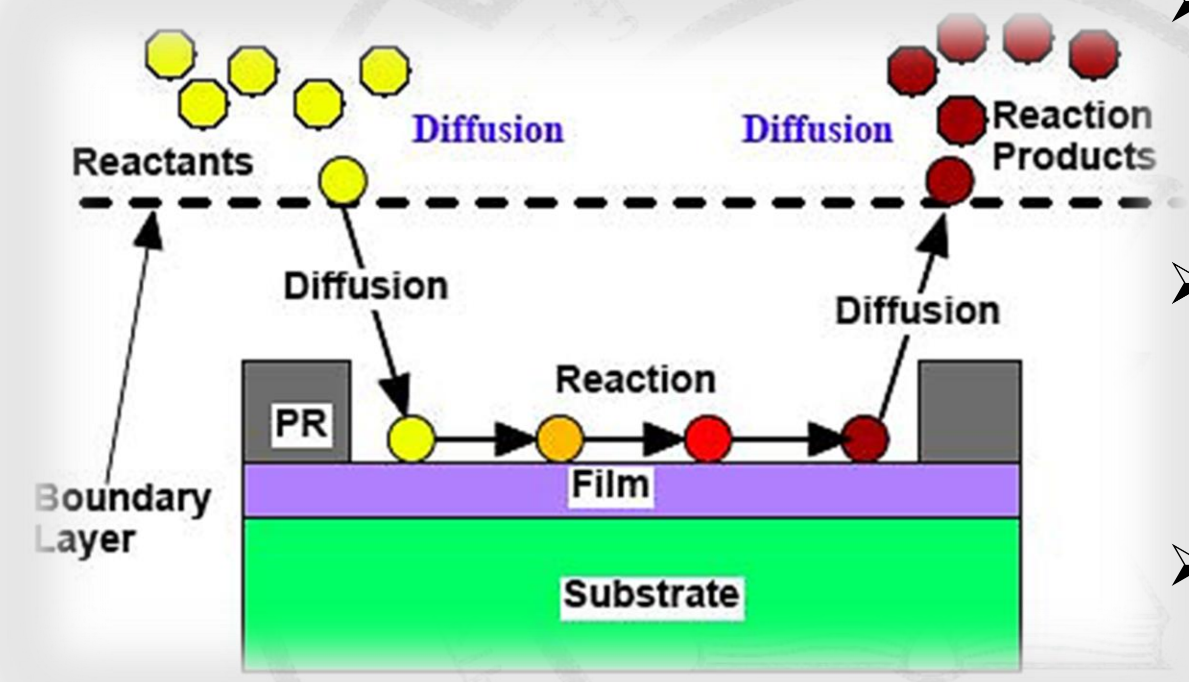
Because momentum is transferred with every collision, sticking is essentially unity, *S* ≈1. This enhances anisotropic character







Chemical etching involves *transport* and *reaction*

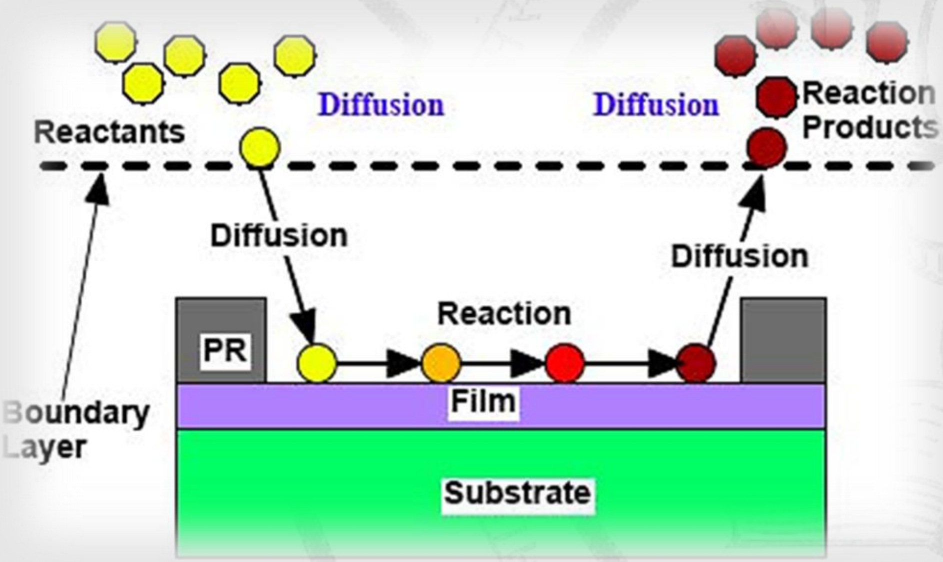


- Species diffuse through boundary layer and along surface of wafer
- Thermally activated reaction at surface gives soluble species.
- Products diffuse through boundary layer, transported away

- Advantages: high selectivity due to chemical reactions

Disadvantages: Isotropic (except for Si), poor process control (can be transport or reaction limited, just like CVD),strong T-dependence

Chemical etching involves *transport* and *reaction*



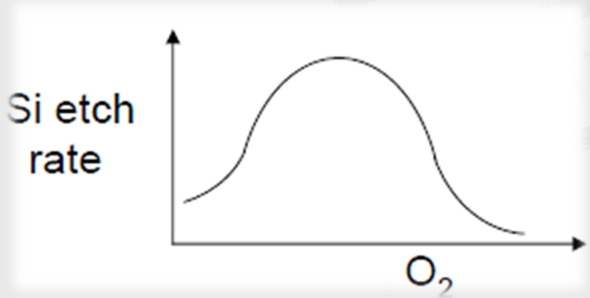
We know: CF_4(g) gives F(g)

$$4F\ (g) + Si = SiF_4\ (g)$$

Therefore, CF_4(g) can etch Si

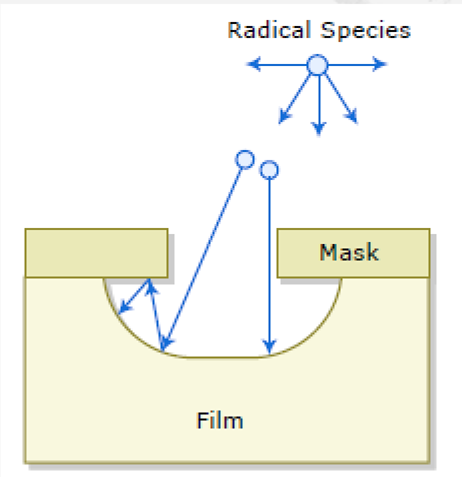
- **Adding O_2 enhances Si etch:**
  - **O_2 combines with CF_3, CF_2**
  - **Reducing their recombination with F .**

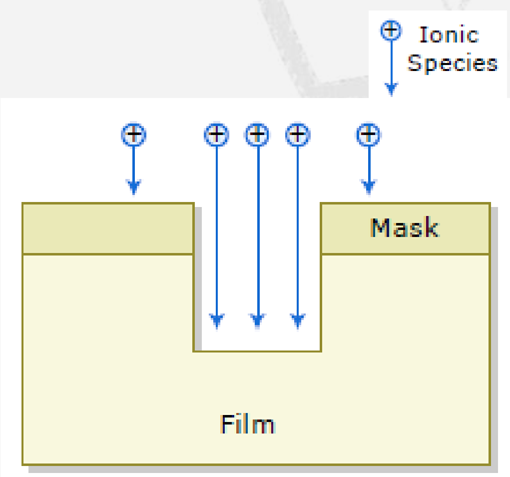
But too much O_2 oxidizes Si



Chemical etching

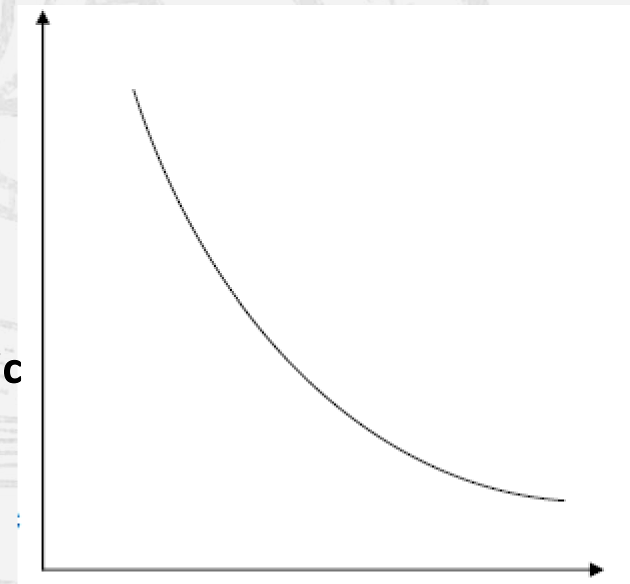
Even though free radicals are highly reactive, multiple steps required result in low effective sticking coefficients, *S* ≈ 0.01. This increases isotropic character of etch. Benefit remains *selectivity*





Isotropic
S << 1

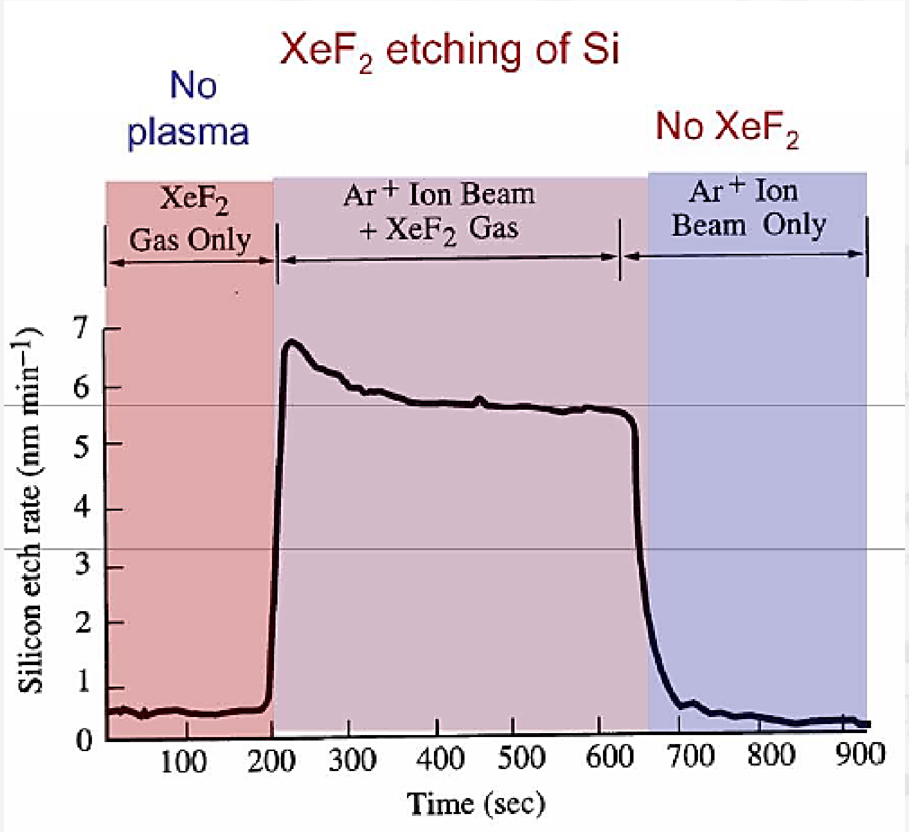
Anisotropic
S ≈ 1

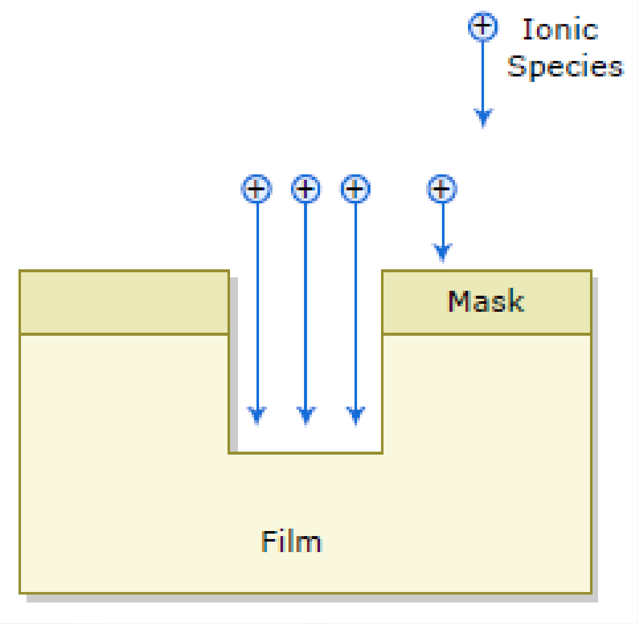


Sticking coef.

Ion-enhanced chemical etching

Physical and chemical processes not just independent of each other
Introduction of Ion-beam can enhance chemical etching



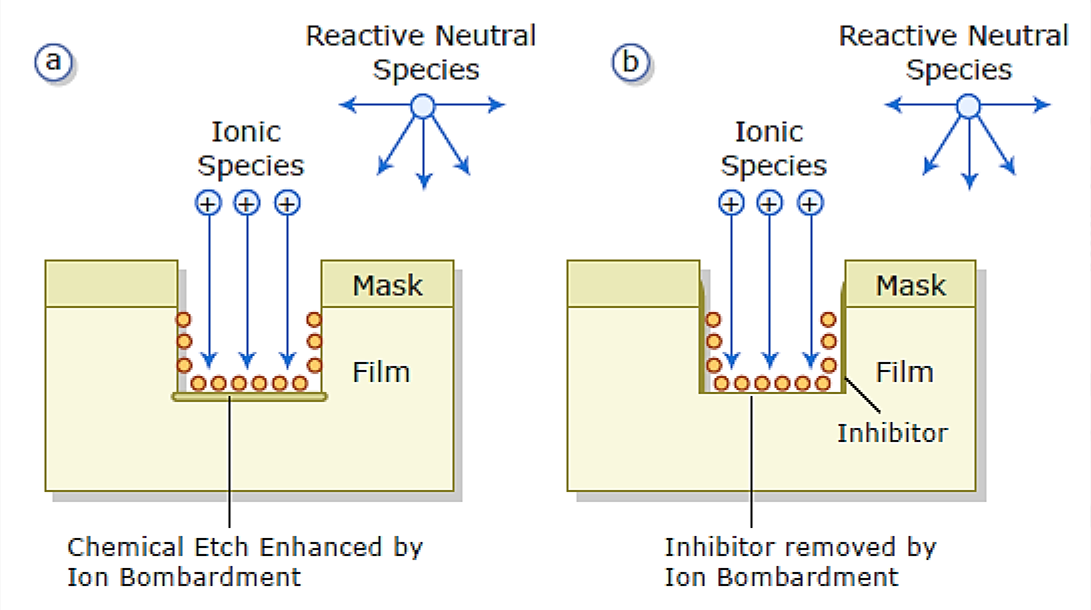


Anisotropic + Selective

Ion-enhanced chemical etching

Why does rate of one process depend on the other being present?

- Work on mix of gas as well as ion energy & rate to select desired wall profile

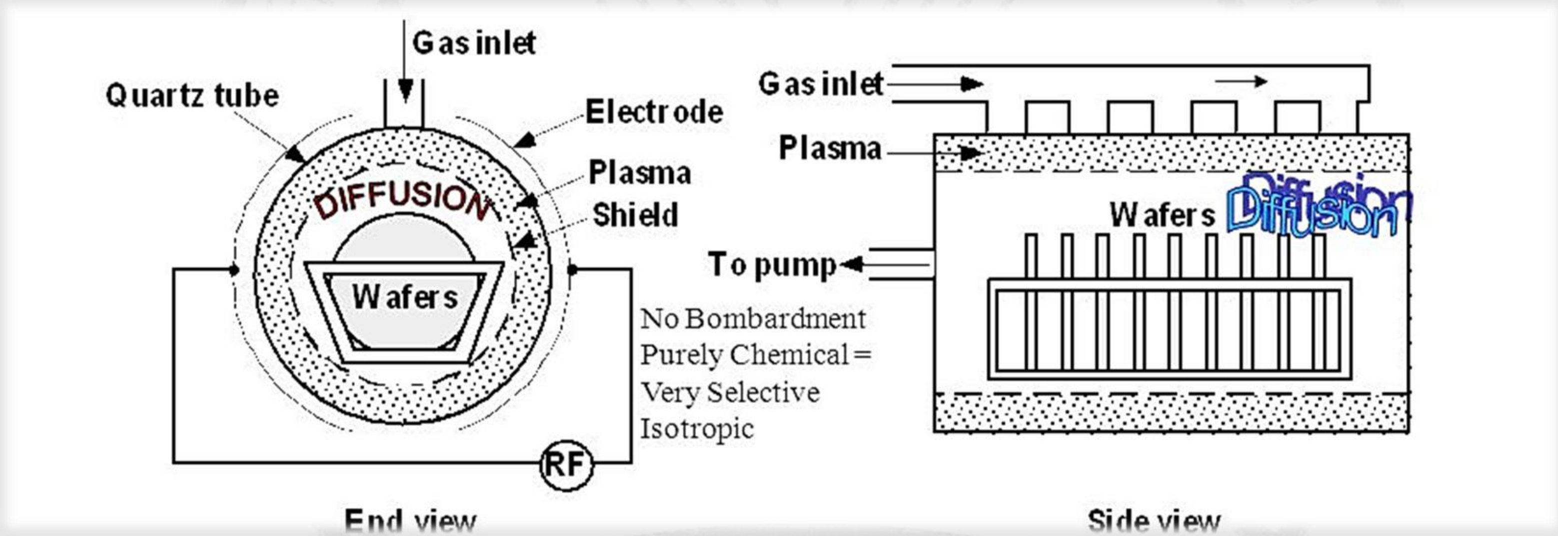


Possible mechanisms:

1. Ions break bonds, render XeF_2 more reactive
2. Ions increase formation of volatile byproducts
3. Ion beam may sputter away byproducts

Important suggestion: consider, classify various combinations, configurations of physical and chemical etch

Barrel etcher: chemical etching only; shield keeps ion bombardment from wafers. Isotropic and selective like pure *wet* etch, but in gas phase



Little damage; Poor uniformity edge to center

Used most for PR removal by O_2: Barrel "asher"

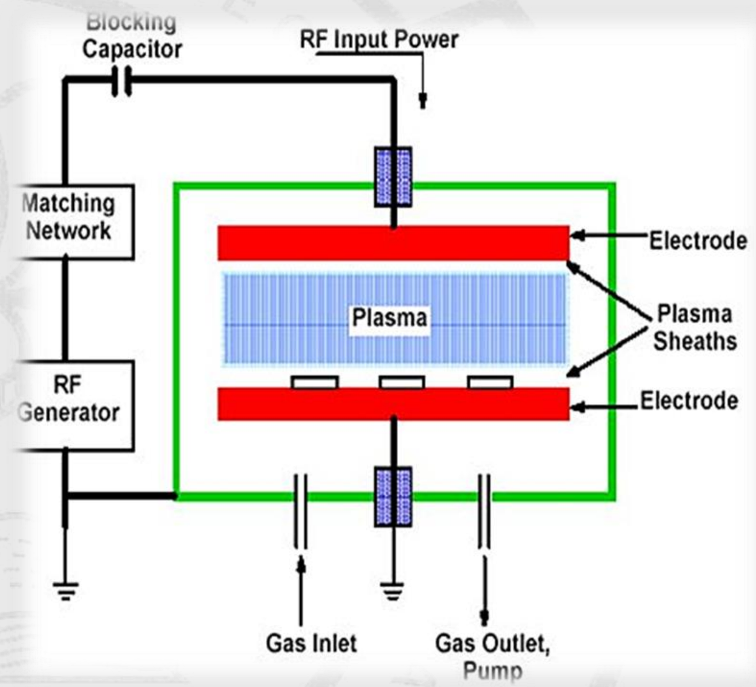
Polymer + O_2 => CO_2 + H_2O

Parallel plate: *plasma mode* etching

Similar to PECVD

EXCEPT that *etch gas is used instead of noble gas*.

Larger wafer electrode (which defines *plasma mode*) gives weaker *ion bombardment of wafers*(more uniform etch than barrel)



Both *physical & chemical* etch occur

More *uniform* etch than barrel etcher

At higher *pressure, physical* etch contributes less

Parallel plate; reactive ion etching(RIE) mode:

More appropriately called “reactive and ion“ etching

CF_4 plasma

- Smaller etch electrode, greater voltage drop above wafers; incoming ions are more energetic
- Greater voltage drop gives greater etch anisotropy and greater physical etch, less selectivity
- Lower gas pressure(10 -100 mT) increases mean-free path, increases anisotropy.
- Triode sputtering system: separate power supply to separate ion generation from wafer bias voltage

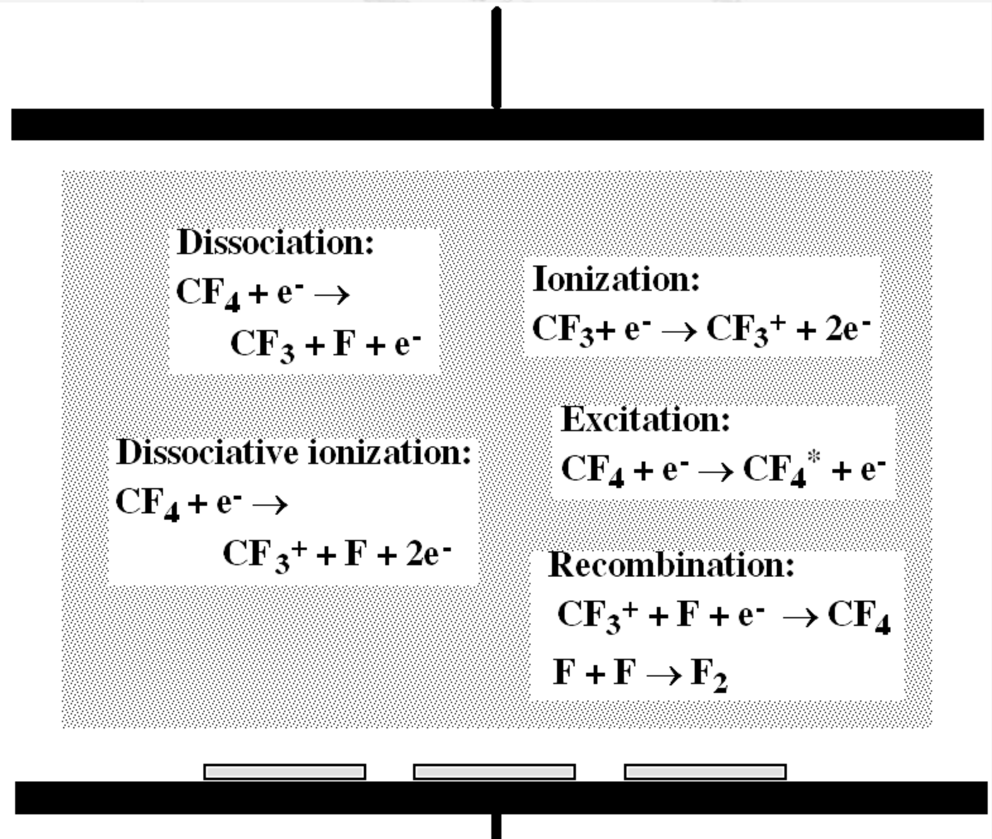
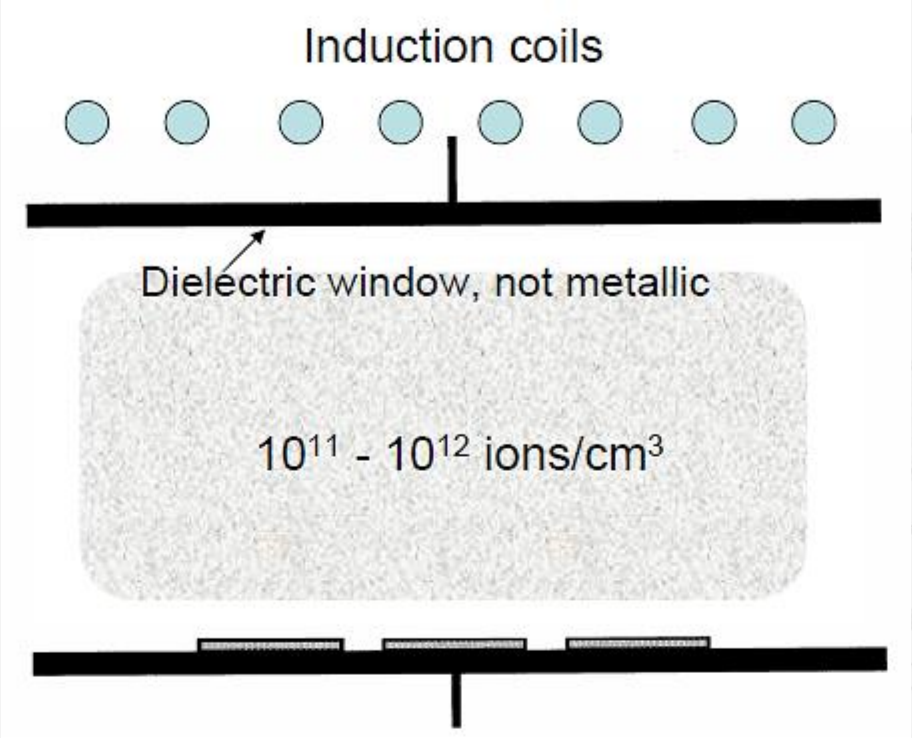


Figure 10-9

Aggressive

High-density plasma systems

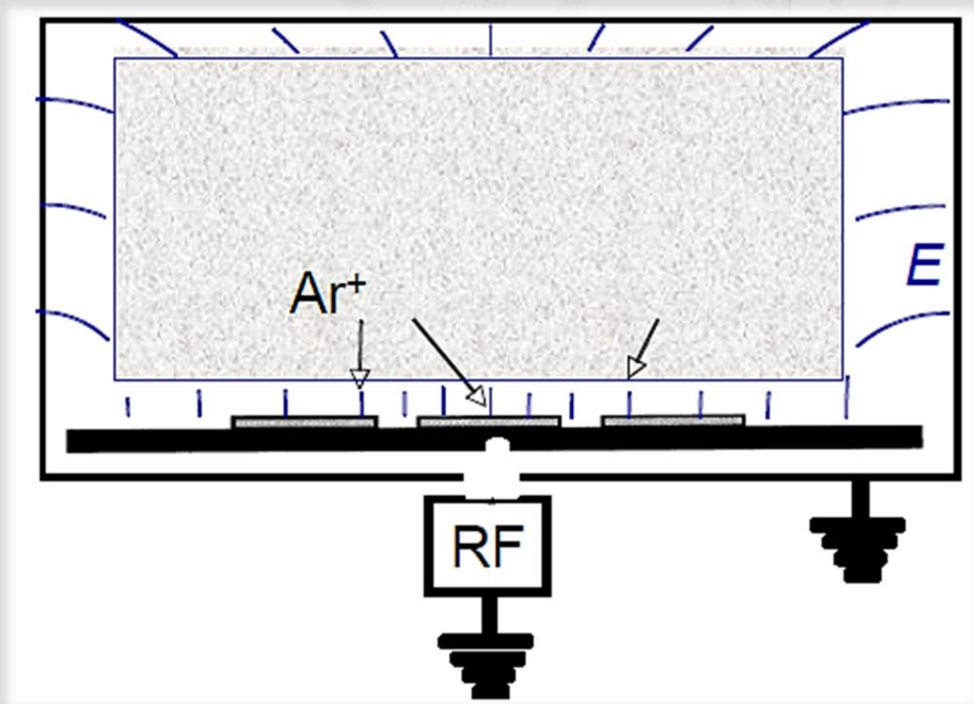
Secondary excitation source that is not capacitively coupled; instead inductively coupled plasma (ICP); growing popularity



- **Plasma density no longer depends on pressure. High plasma density can be achieved at lower pressures (1 -10 mT).**
- **Lower gas pressure means more anisotropy…but also more substrate damage**

Sputter etching & ion milling

Nearly *completely physical*(not chemical) etching; no reactive gas



Wafers here in position of target in sputter deposition

Anisotropic etch with low selectivity

Review of etching process

		Pressure	Etch rate	Energy (eV)	Selectiv'y	Anisot'y
Physical	Sputter etch Ion milling	1mT-1 T	enhanced		low	high
	HDPE 0.1-3 W/cm^2	1- 10 mT	enhanced	10-500	high	high
	RIE	10-100 mT	enhanced		high	high
	Plasma etch	10-100 mT	low	low	moderate	moderate
	Barrel etcher	10-100 mT	moderate	10 - 700 eV	high	low
Chemical	Wet etch	*irrelevant*	enhanced		high	low