Plasma Etch for IC Fabrication

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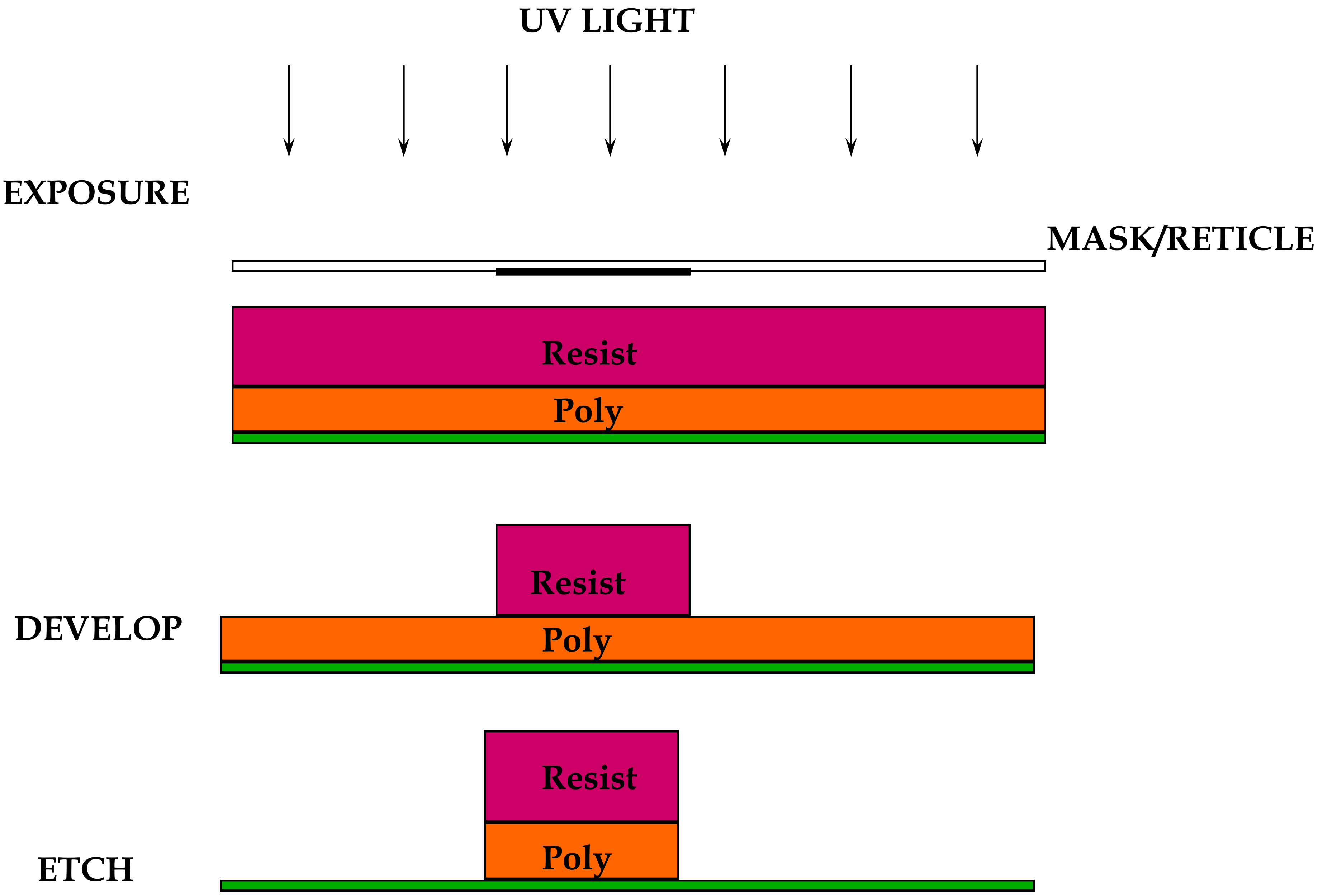
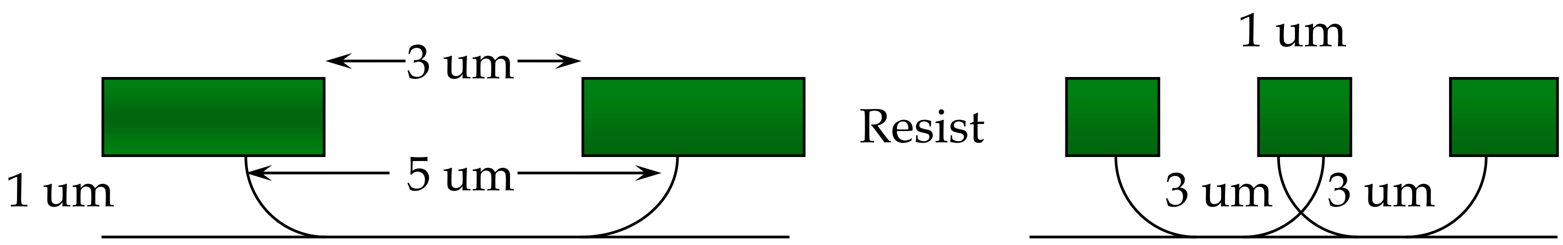
- Dry Etch
  - Plasma Etch
  - RIE
  - High Density Plasmas
- Etch Model
- Etch Issues
  - Polymer formation
  - Selectivity
  - Uniformity
- Applications


UV LIGHT
EXPOSURE
MASK/RETICLE
Resist
Poly
Resist
DEVELOP
Poly
Resist
ETCH
Poly

Etching

WET ETCHING

DISADVANTAGES



- **Because the etch is purely chemical wet etches are isotropic i.e. vertical and lateral etch rates equal**
- **The main limitation is size of detail which can be etched consistently**
- **In some cases it is difficult for etchant to reach bottom of detail and for by-products to be removed**
- **Can be difficult to control temp,pH etc.**

Dry Etch Processes

- Plasma etch (Barrel Etch System)
- Plasma etch parallel plate
- Reactive Ion Etch (RIE)
- High Density Plasma (HDP)
  - Inductively Coupled Plasma (ICP)
  - Magnetic Zero Resonant Induction (M0RI)
  - Electron Cyclotron Resonance (ECR)
- Ion Milling

Dry Etch Processes

- Introduction
- Plasma/RIE (Dry) Etching
- Polymer Formation
- Applications
  - Nitride Etch
  - Polysilicon Etch
  - Contact Etch
  - Aluminium Etch

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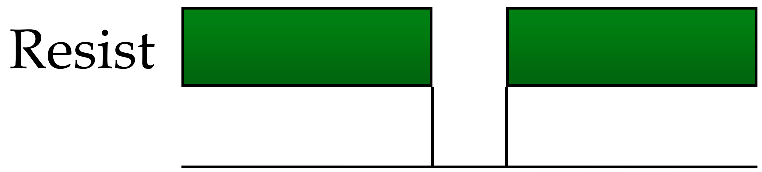
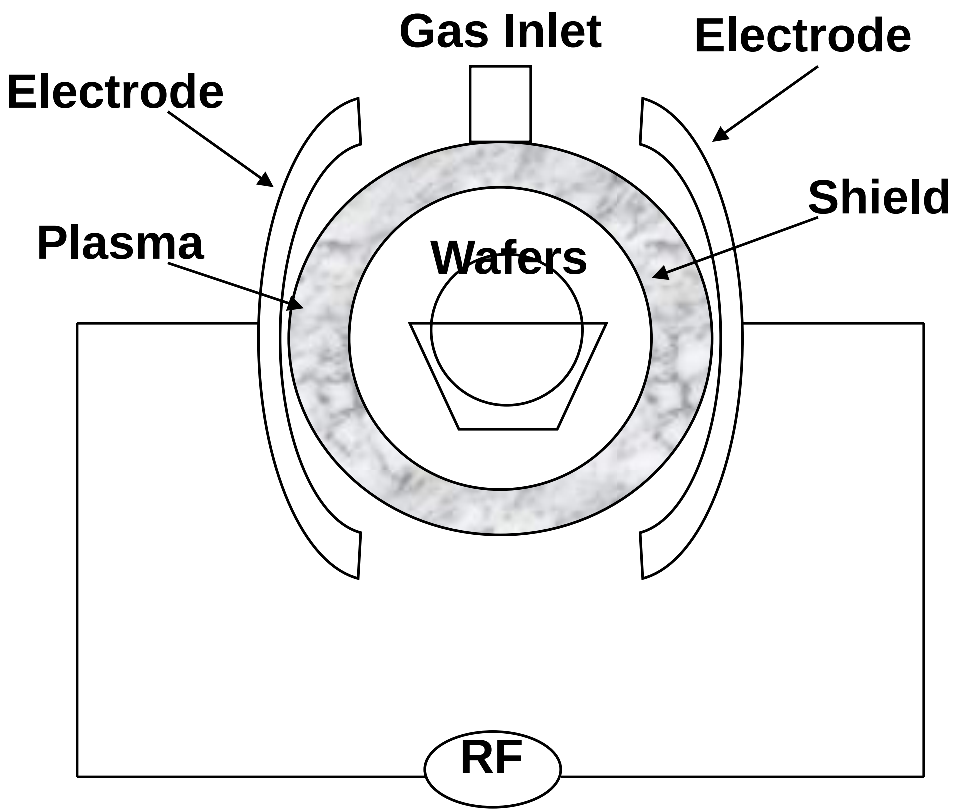
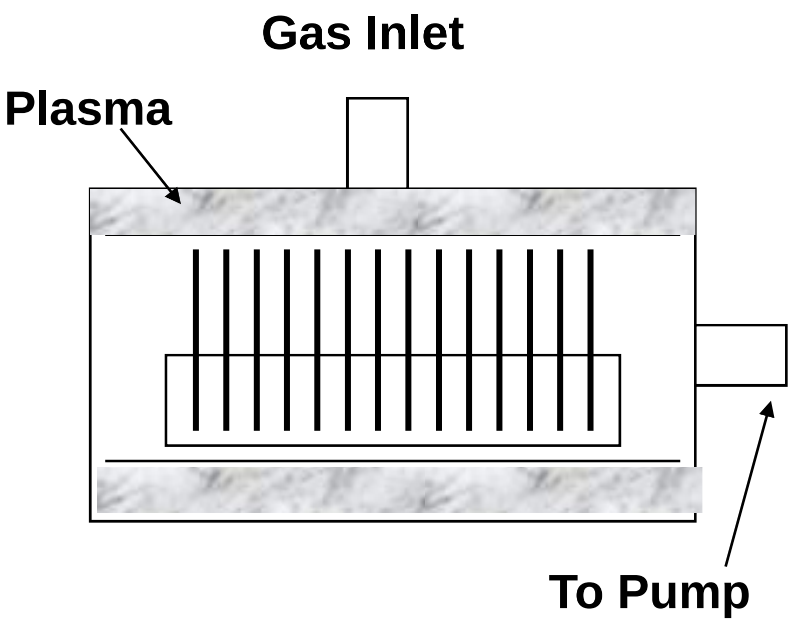
DRY ETCHING



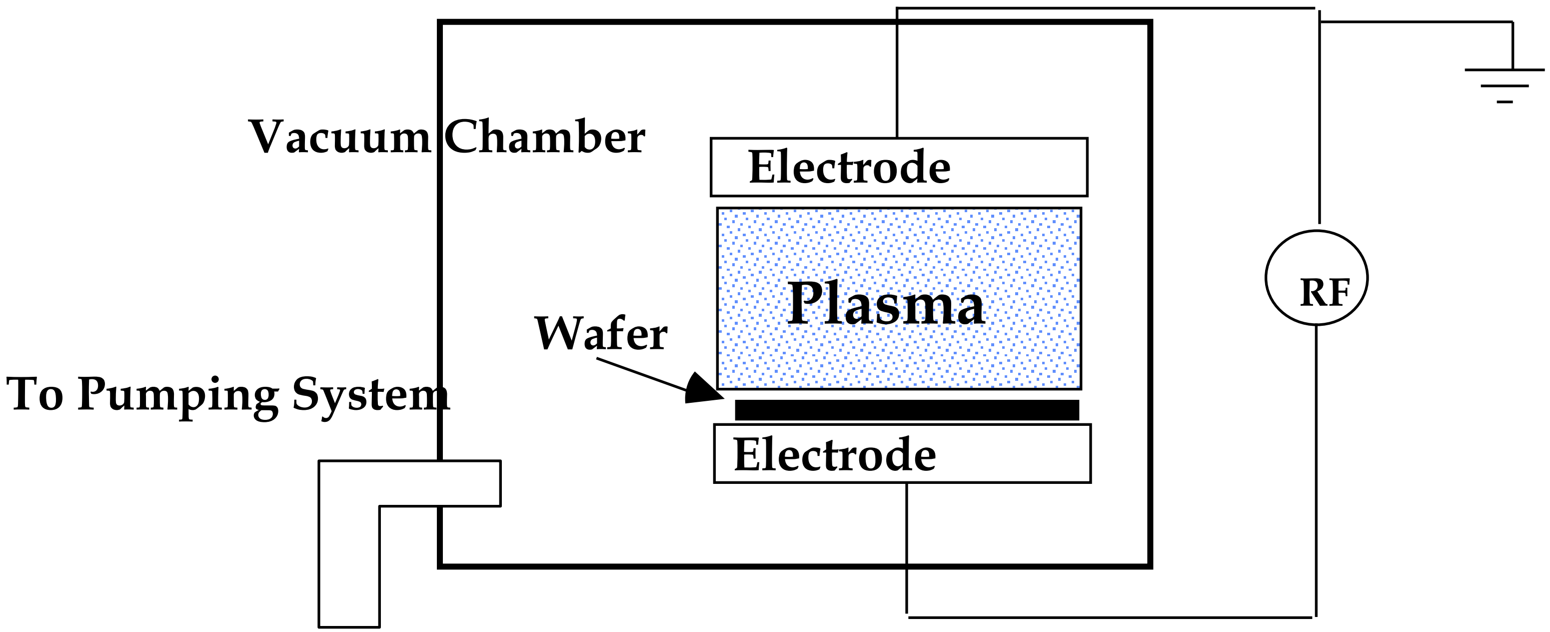
- Dry etching has become widely used for process geometries below ~ 3μm
- Dry etching combines physical and chemical removal of material
- Controlling the etch process conditions allows the isotropy of the etch to be controlled

Plasma Etch –Barrel Etchers



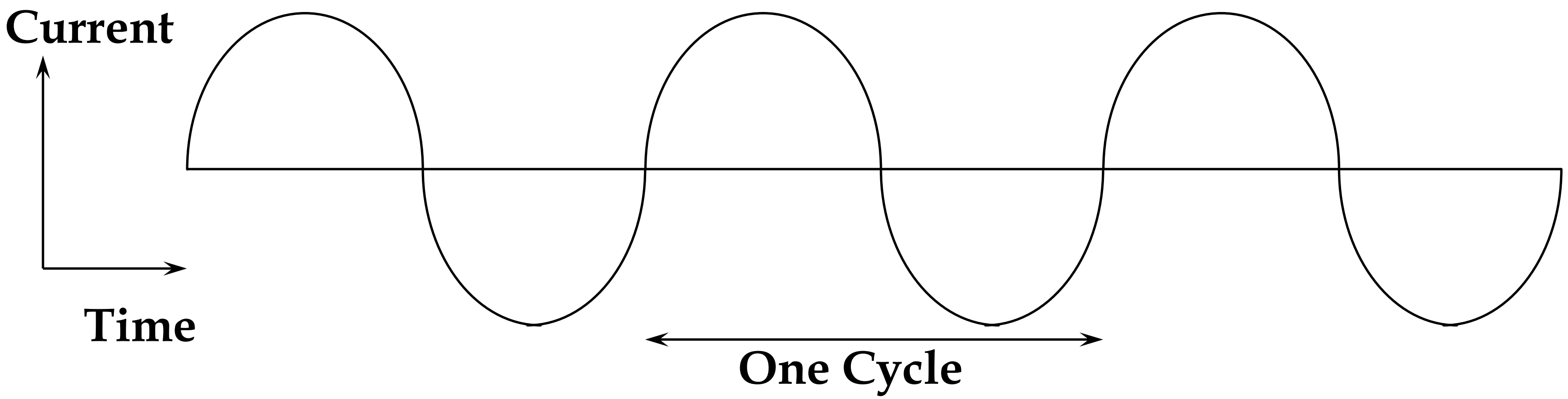


DRY ETCHING



- Dry etching is performed by exposing the wafer to a plasma or glow discharge
- Plasmas are usually created by applying an R.F. bias between two electrodes.

R.F. electrical supply



- R.F. is short for radio frequency
- R.F. is a form of alternating current i.e. current follows a sinusoidal waveform with respect to time
  - A.C. mains supply (50 Hz)
  - R.F. supply (13.5 MHz)

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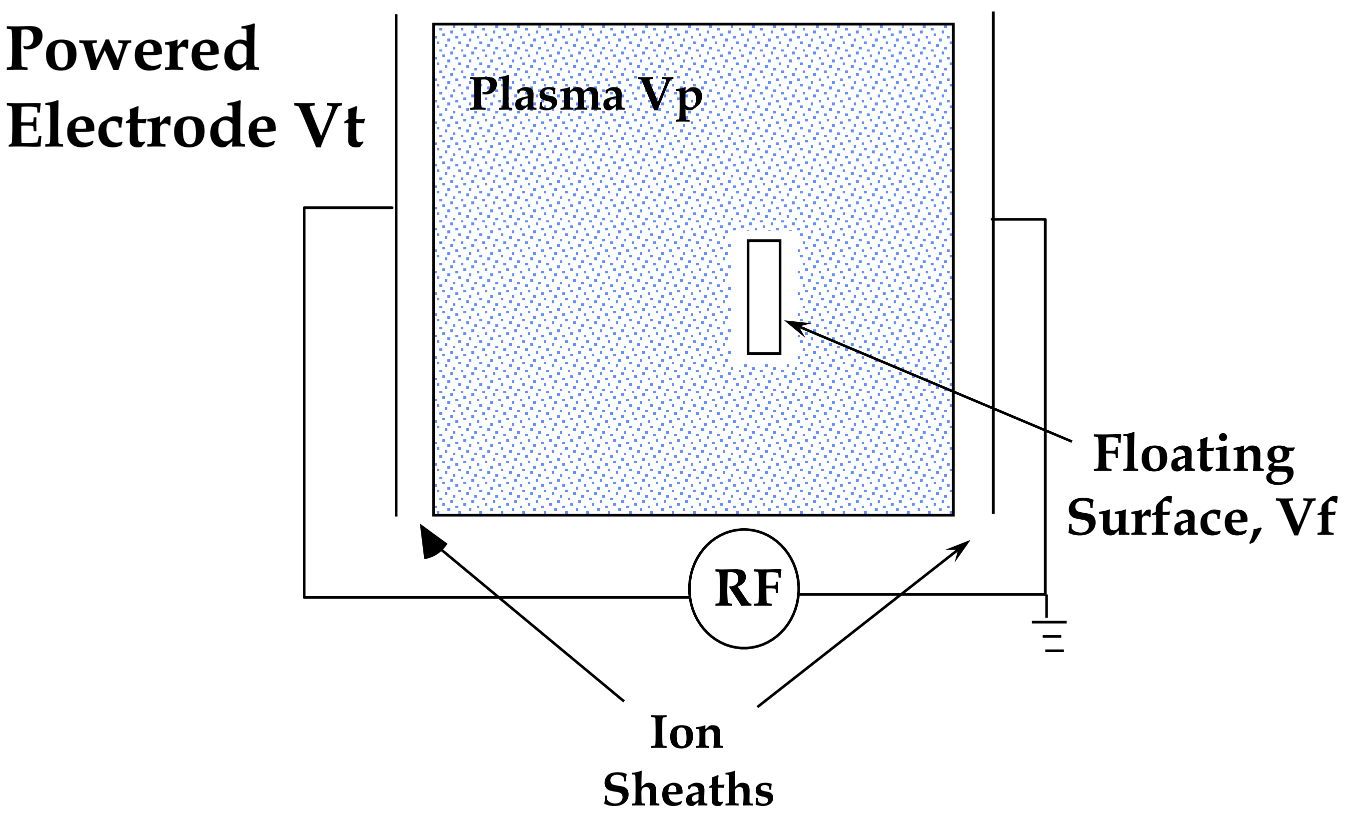
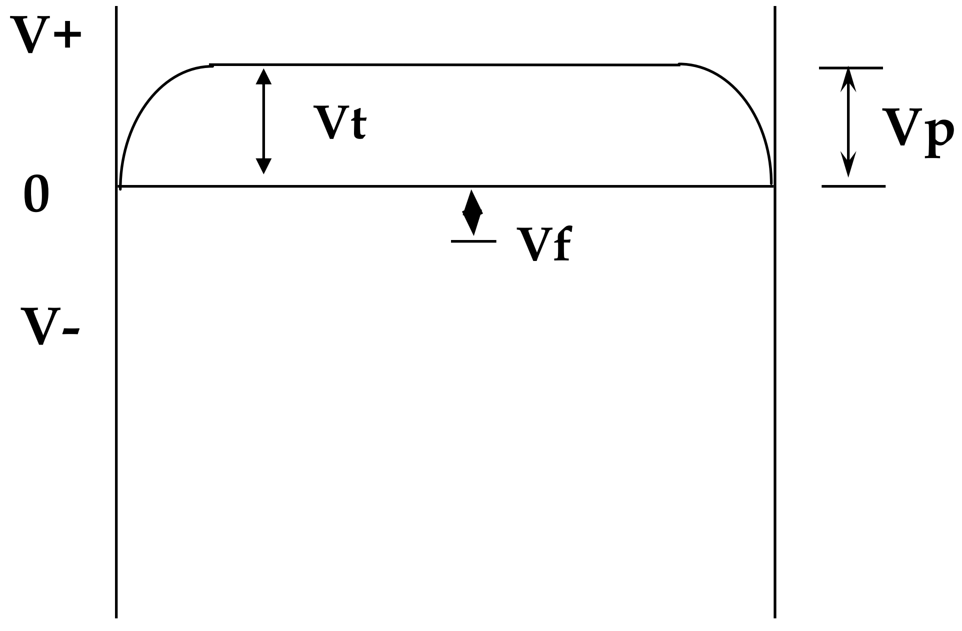
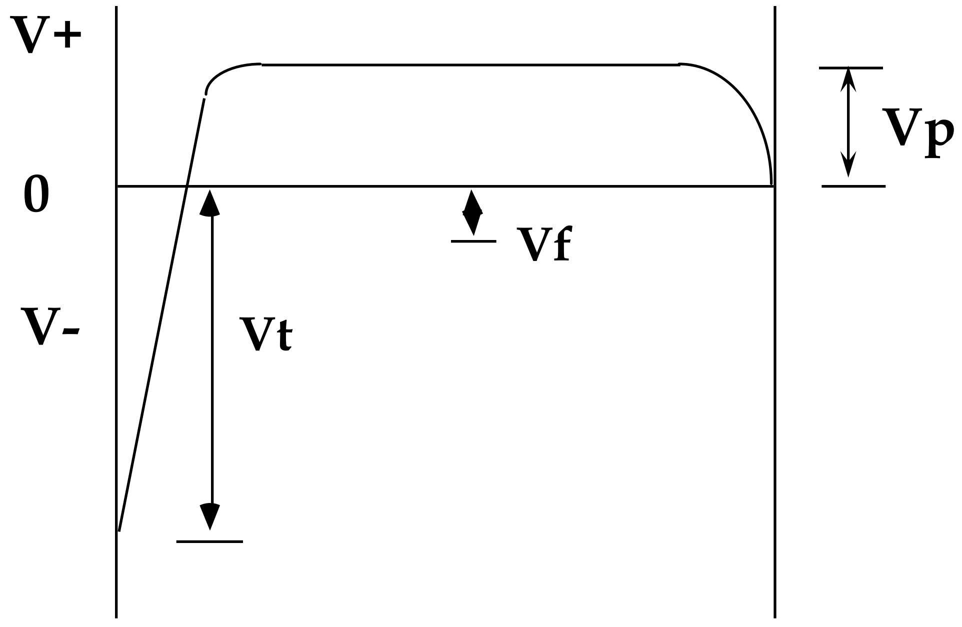
Plasma Potential



Equal Sized Electrodes



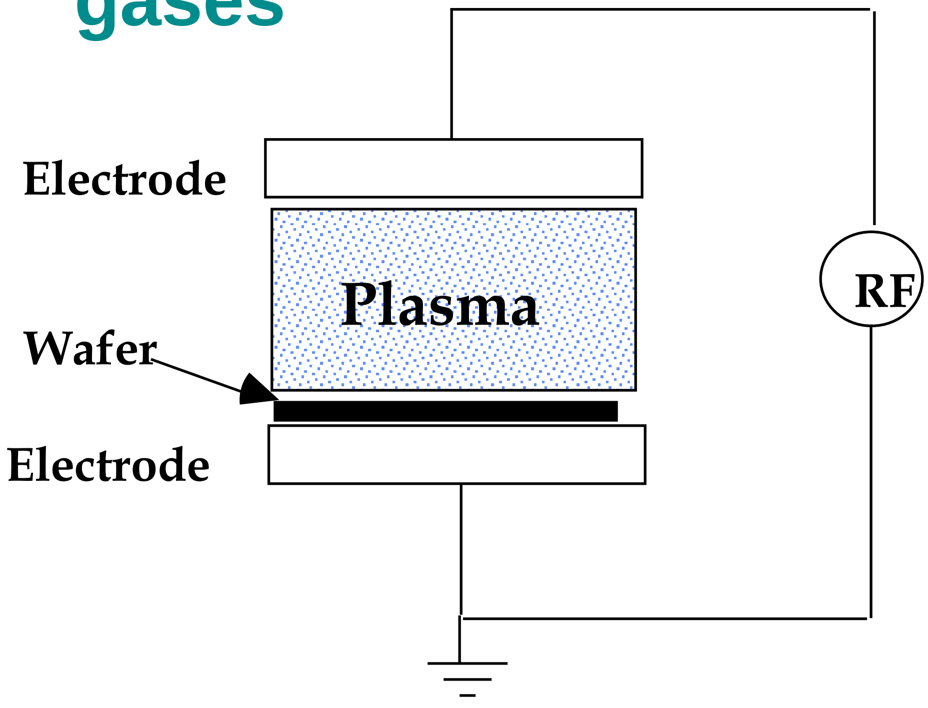
Plasma Potential Plot



Smaller Electrode

Configuration of Plasma Etching Systems

- Wafer is placed on grounded electrode
- This results in a relatively low bias at wafer
- Plasma etching uses chemically reactive gases



Typical Values
DC Voltage drops 10 - 100V

Pressure 100mT - 1Torr

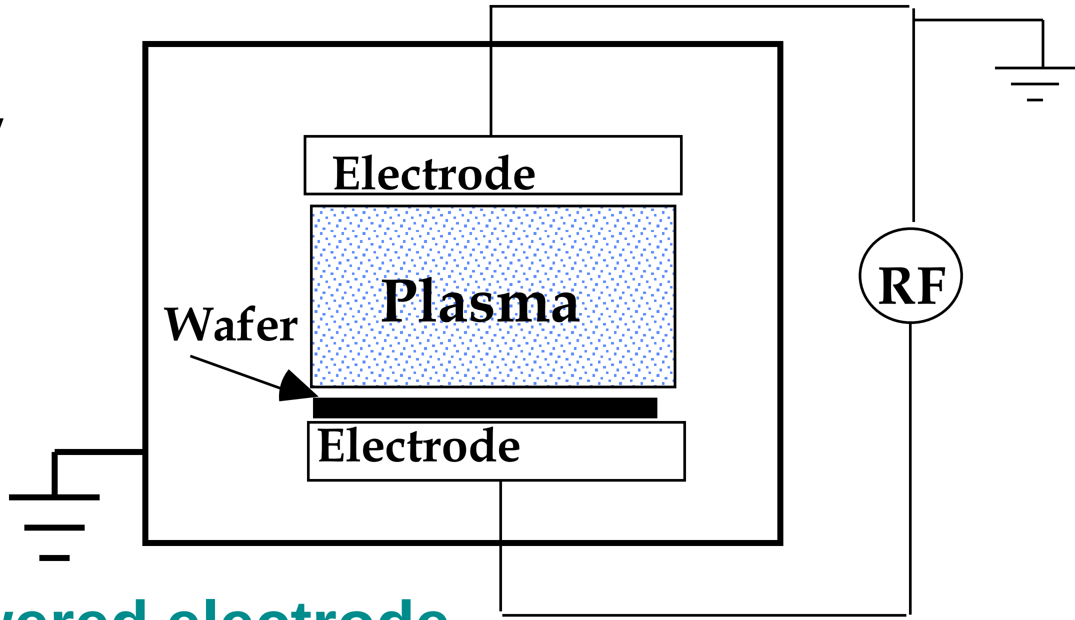
1Torr =133.322Pa
1Torr = 1.333mBar

Configuration of Reactive Ion Etching (RIE) Systems

Typical Values
DC Voltage drops 100-700V

Pressure 10 - 100mT

1Torr =133.322Pa
1Torr = 1.333mBar



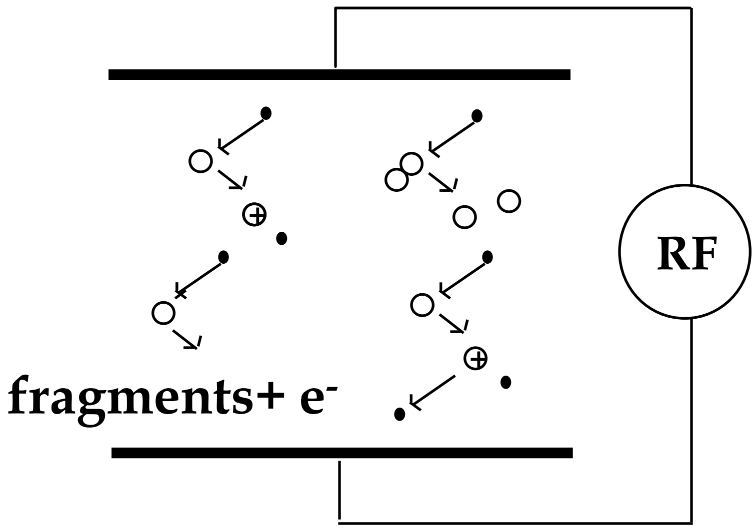
- **Wafer is placed on powered electrode**
- **This results in higher biases at the wafer surface**
- **RIE etching uses chemically reactive gases**
- **Ion milling uses the same configuration as RIE etching but uses inert gases**

Dry Etch Chemistry

Plasma etching and RIE etching use the same chemistries

- Fluorine containing gases are commonly used for etching silicon oxide and silicon nitride e.g. silicon tetrafluoride($SiCl_4$), sulphur hexafluoride(SF_6)
- Chlorine containing gases are commonly used for etching metal and polysilicon e.g. chlorine, boron trichloride

Dry Etch Chemistry



- Trifluoromethane (CHF_3) is commonly used for the etching of silicon dioxide based materials
- Radicals: CHF_3 ---> e.g. CF_3 , CF_2 , CF, F, H
- Ions: CHF_3 ---> e.g. CF_3+ , CF_2 +, CF+, F+, H+

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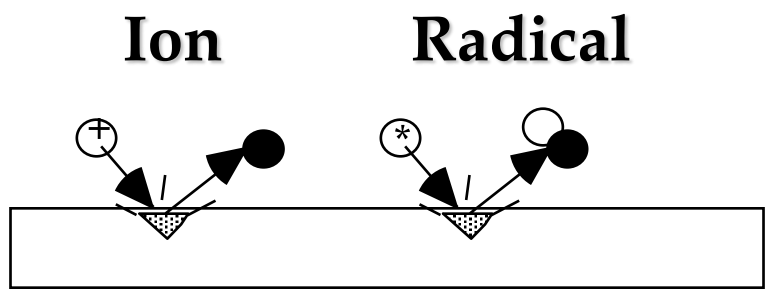
Dry Etch Chemistry

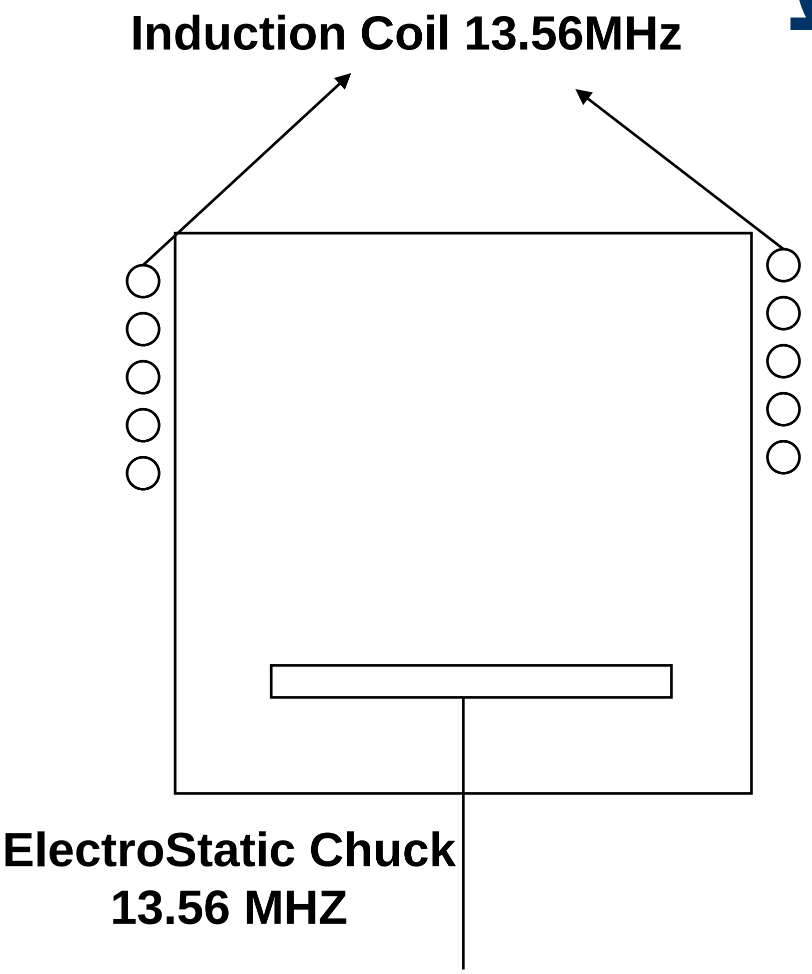


- As stated previously dry etching achieves anisotropy by introducing physical component
- Physical component of etch is supplied by attraction of positive ions to the negatively biased substrate
- Chemical component from both ion and radical interaction

High Density Plasmas (HDP)

- Relatively new systems generating higher density plasmas
  - ICP (Inductively Coupled Plasmas)
  - ECR (Electron Cyclotron Resonance)
  - M0RI (Magnetic Zero Resonant Induction)
- Plasma density {10^{11} - 10^{12} ions/cm^3}
- Allow higher etch rates at lower pressures without plasma damage
- Pressure range 1 - 10mT range

Inductively Coupled Plasma (ICP)



- Plasma is generated in the induction coil
- The wafer is held on the chuck electrostatically

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Magnetic Zero Resonant Induction M0RI

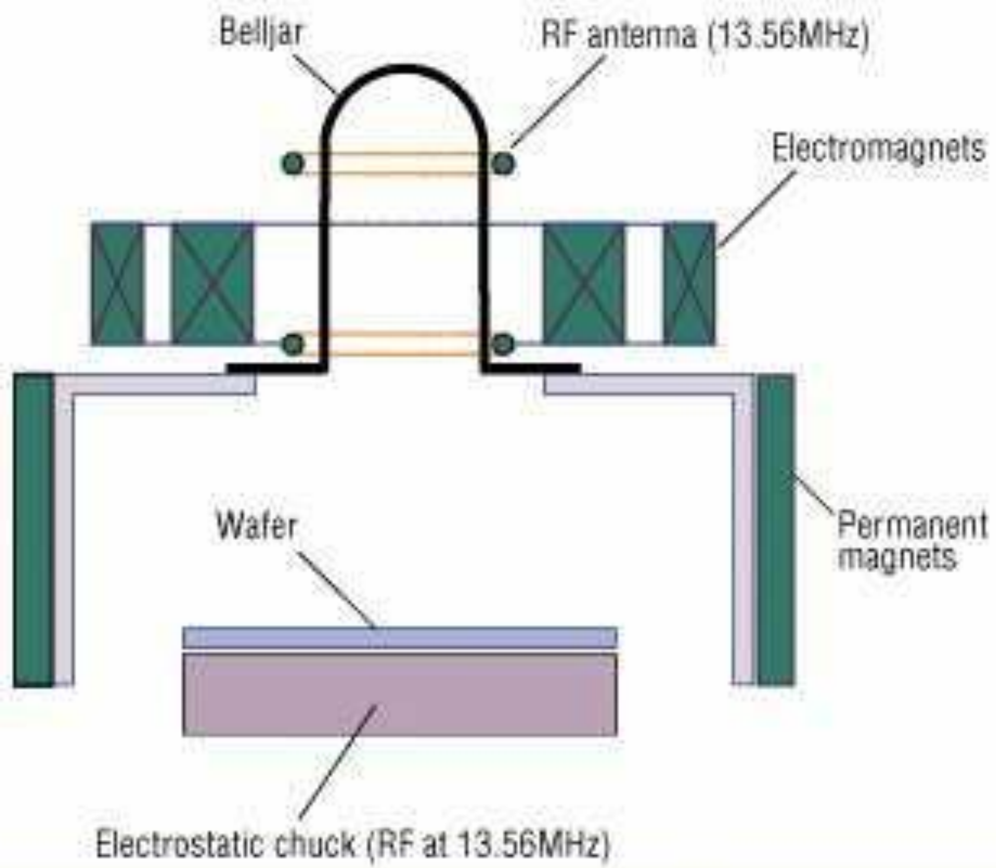

Figure 1. Schematic of a Trikon M0RI plasma etch chamber.

- **The plasma in generated by the RF antenna**
- **A helicon wave is propagated by the Electromagnets**
- **The wafer is held on an electrostatic chuck**
  - **Helicon wave - whistler wave!**

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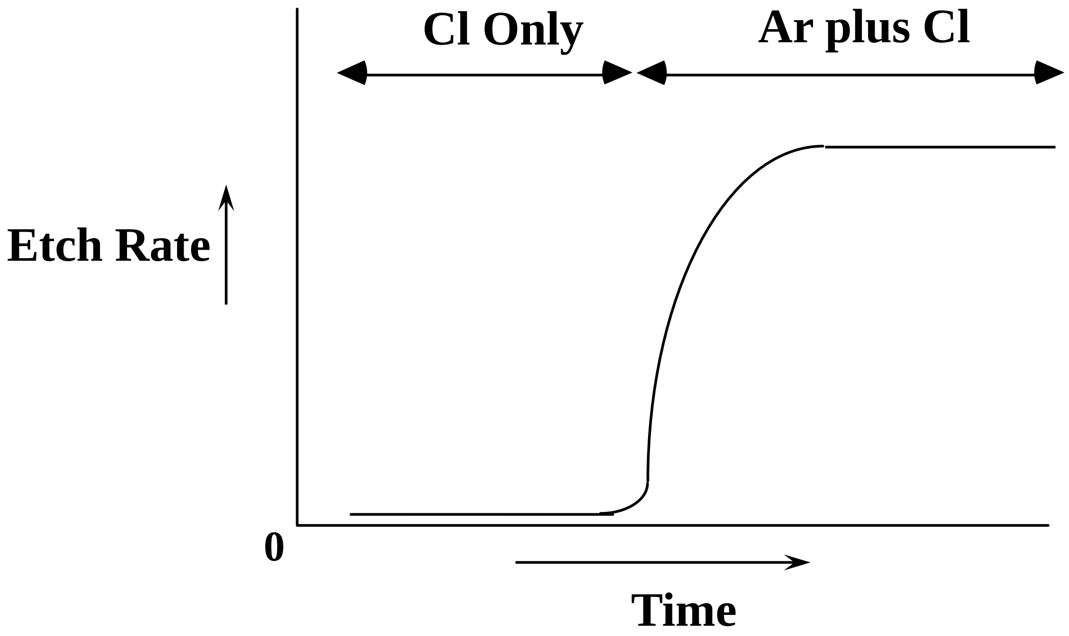
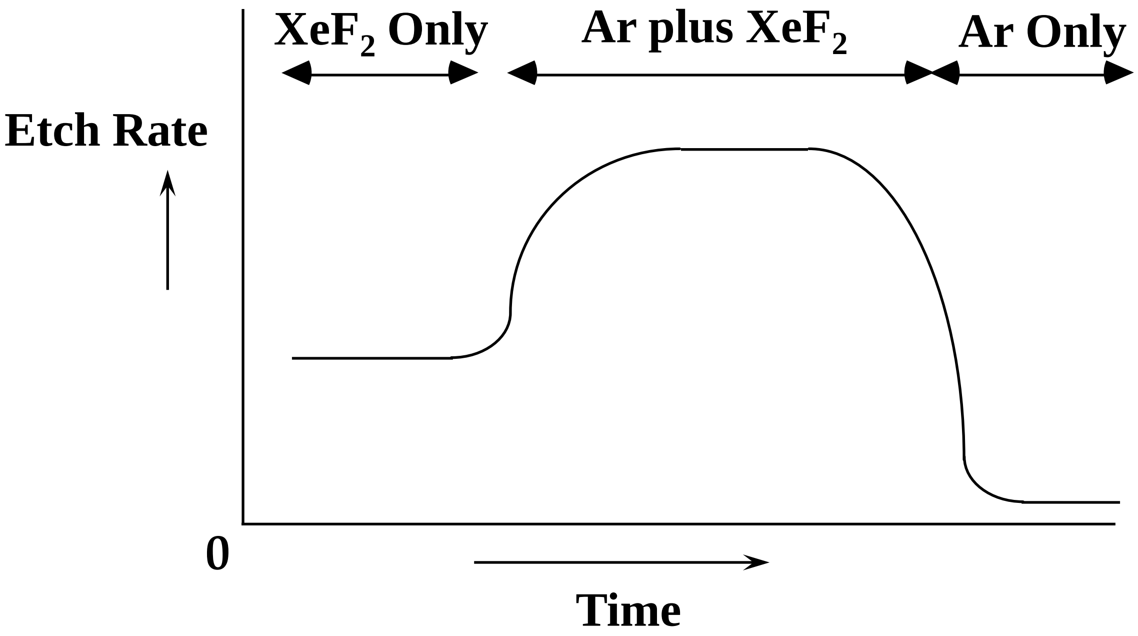
Ion induced reactions



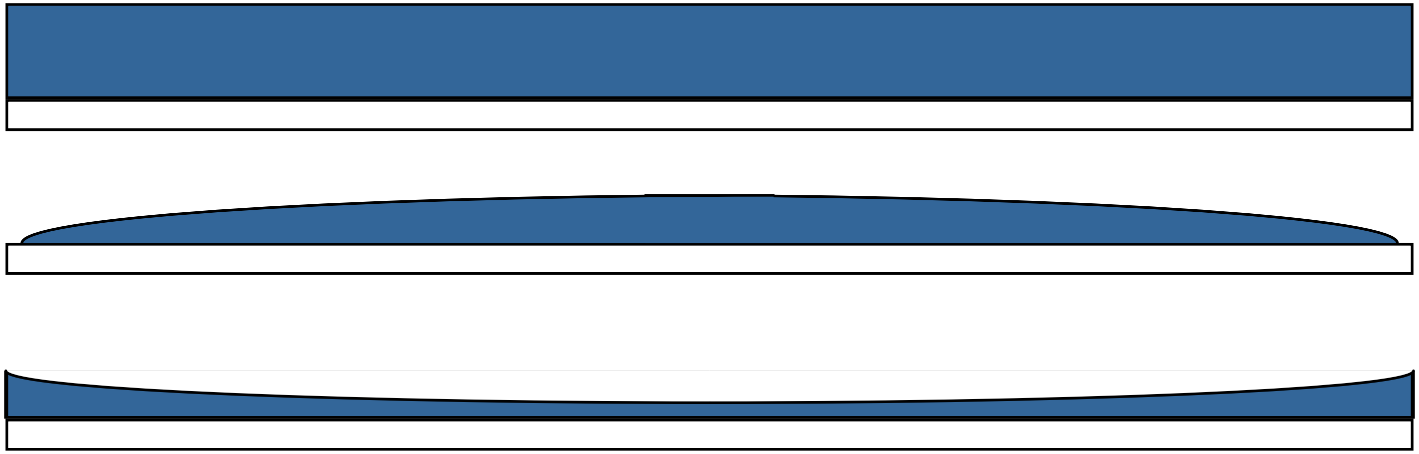
- Under certain etch conditions etch rate of silicon is negligible
- Adding Ar to gas flow increases etch rate
- Ar ion bombardment of surface damages it making chemical reaction with Cl easier

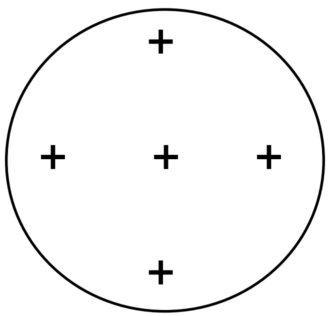
Ion enhanced reactions



- Some etching without inert gas
- Etch rate increases with inert gas
- No etching without reactive gas

Uniformity

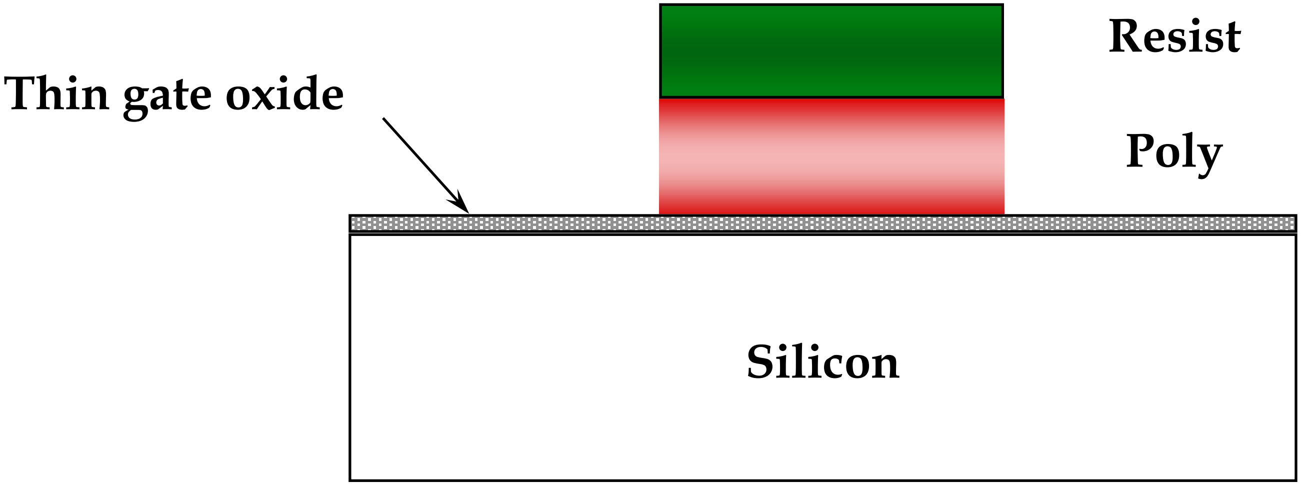




$$\text{Unif} = \frac{\text{Max} - \text{Min}}{2 \times \text{Mean}} \times 100 \ \%$$

- Uniformity is a measure of the variation in etch rate across a wafer
- For most etch processes should be < 5%

Selectivity



Selectivity

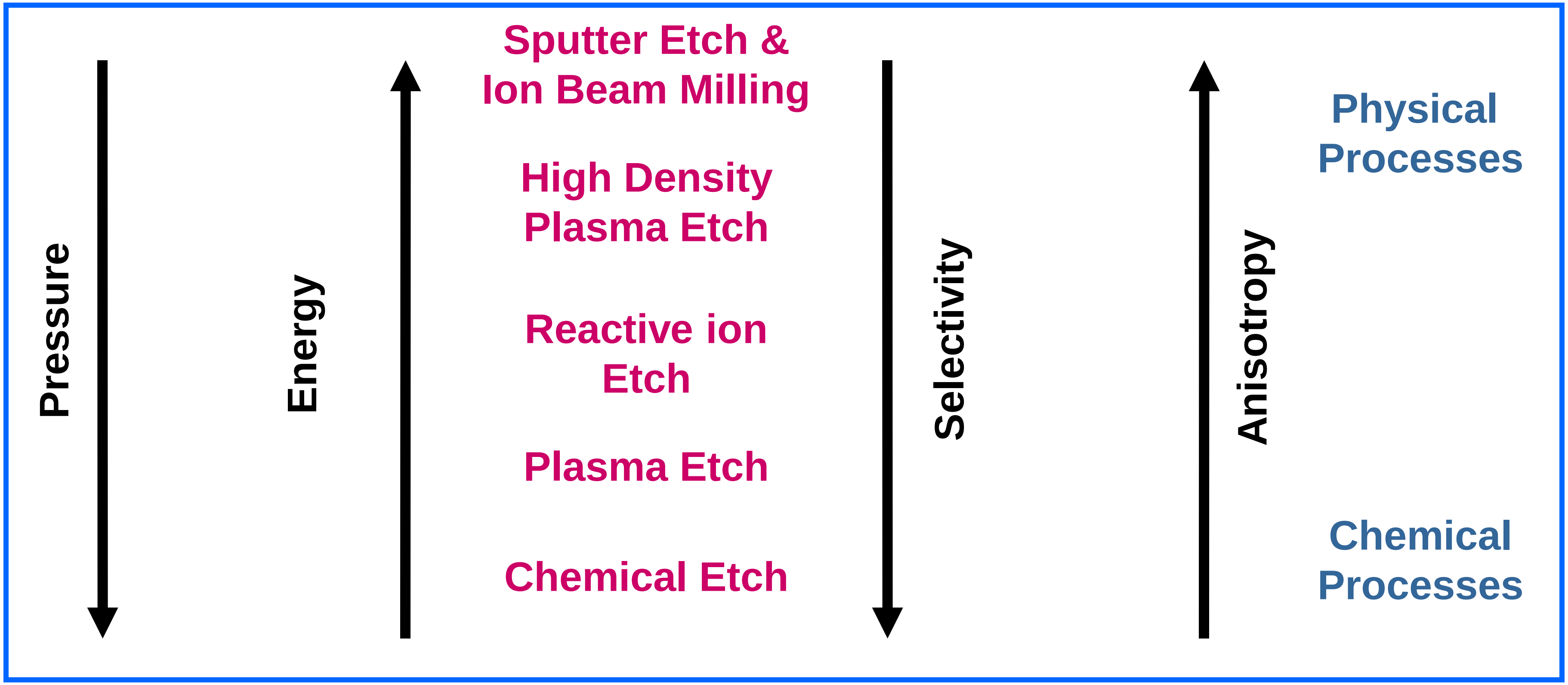
- Selectivity is the ratio of etch rates
- e.g. Poly-Oxide selectivity is:

$$\frac{\text{Etch rate poly}}{\text{Etch rate oxide}}$$

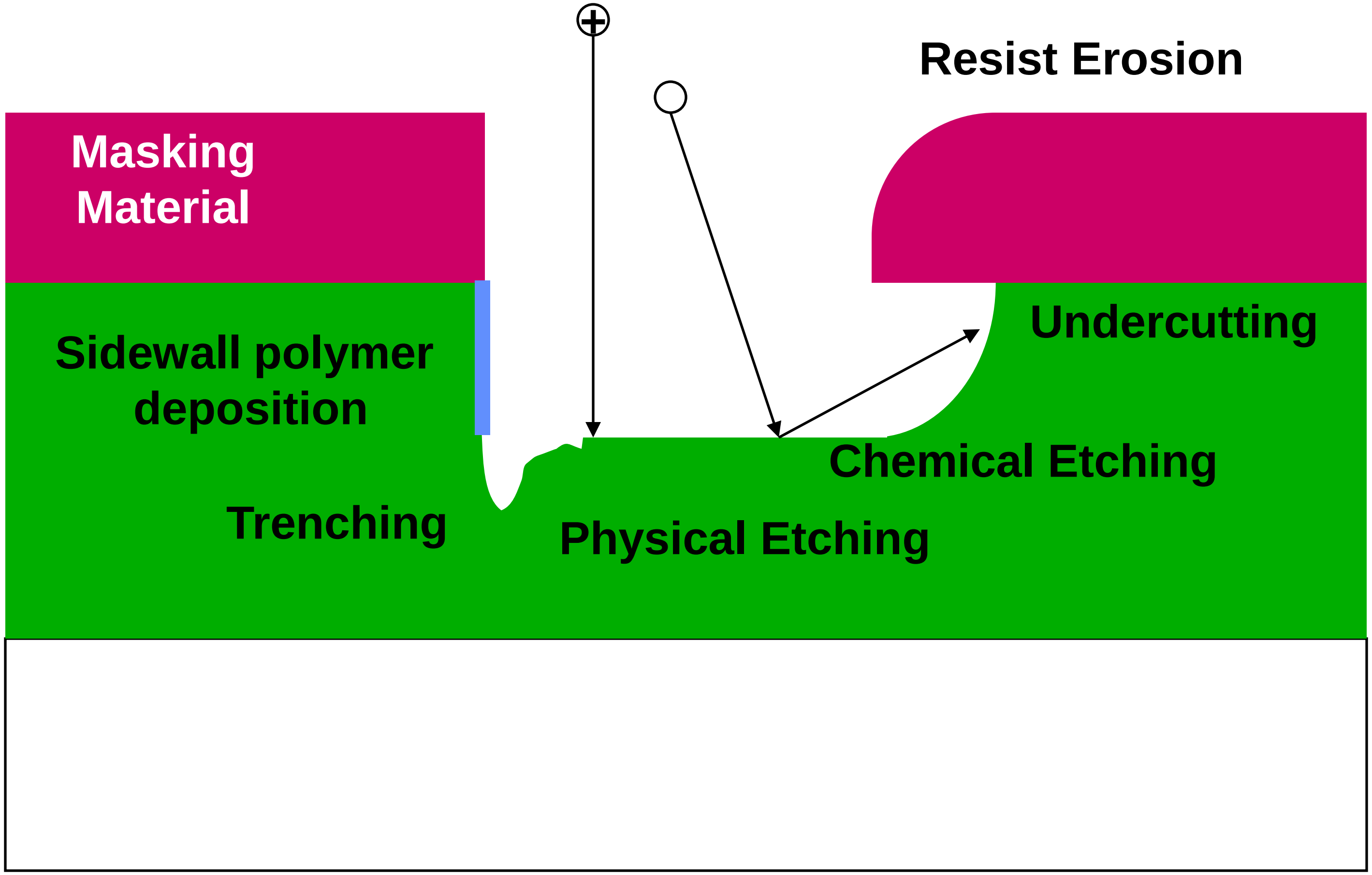
$S=r_1/r_2$

- Selectivity is an important consideration when trying to predict the amount of material removed underneath the etched pattern
- Example shown above where thin gate oxide under poly gate must be left intact

Etch System Summary Trends



Process Summary



Linear Etch Model

- Simplest model assumes that the Chemical and Ionic etch rates are linear and independent
- The net etch rate at any point is a combination of the purely chemical and ion-driven etching with each term linearly dependant on the appropriate flux

Linear Etch Model Equation

Etch Rate = **R**

$$R = \frac{\left(S_c K_f F_c + K_i F_i\right)}{N}$$

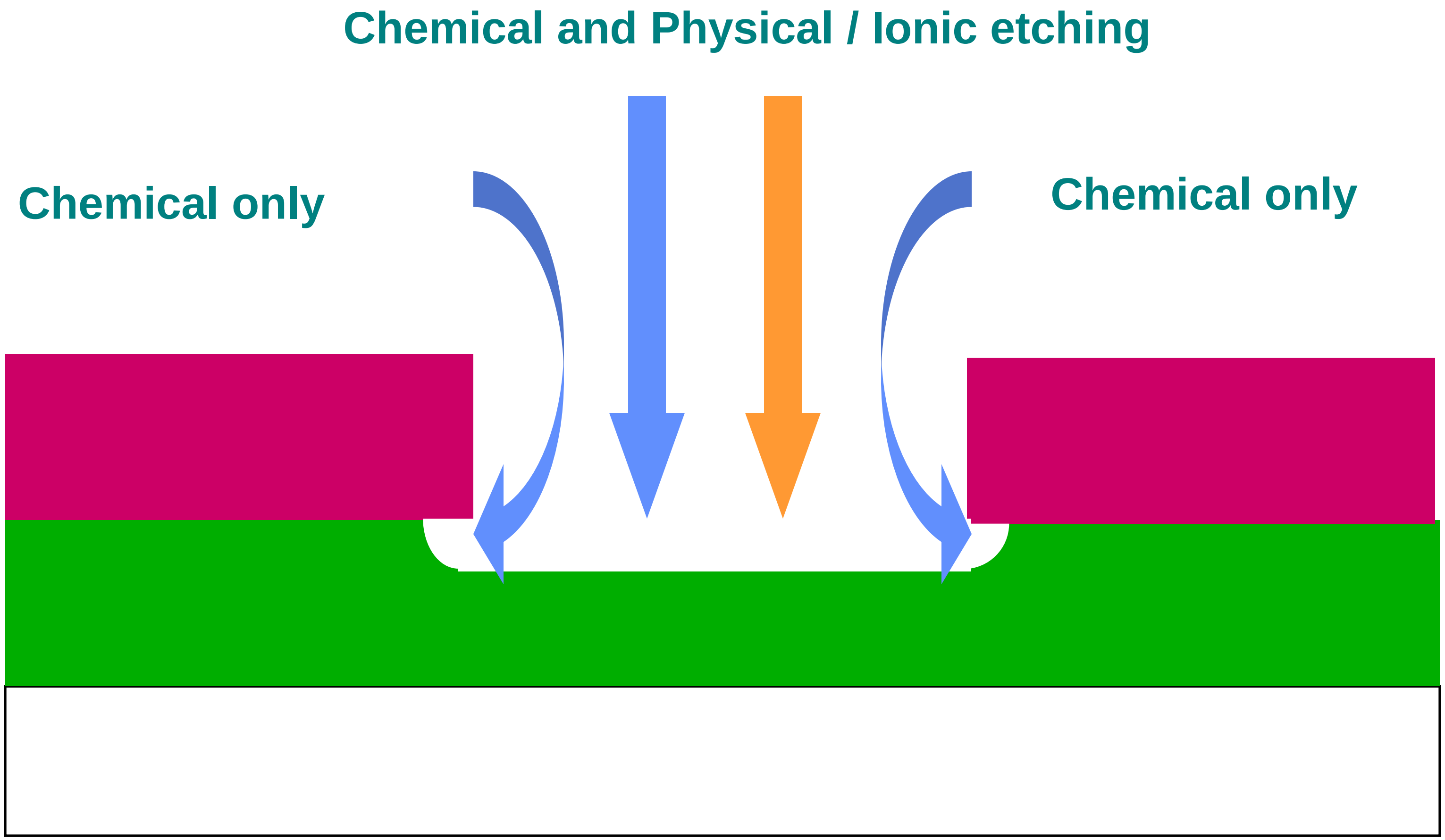
S_c = Sticking coefficient usually between 0 and 1.0

K_f and K_i are the relative rate constants for the two processes

F_c and F_i are the chemical and ion fluxes

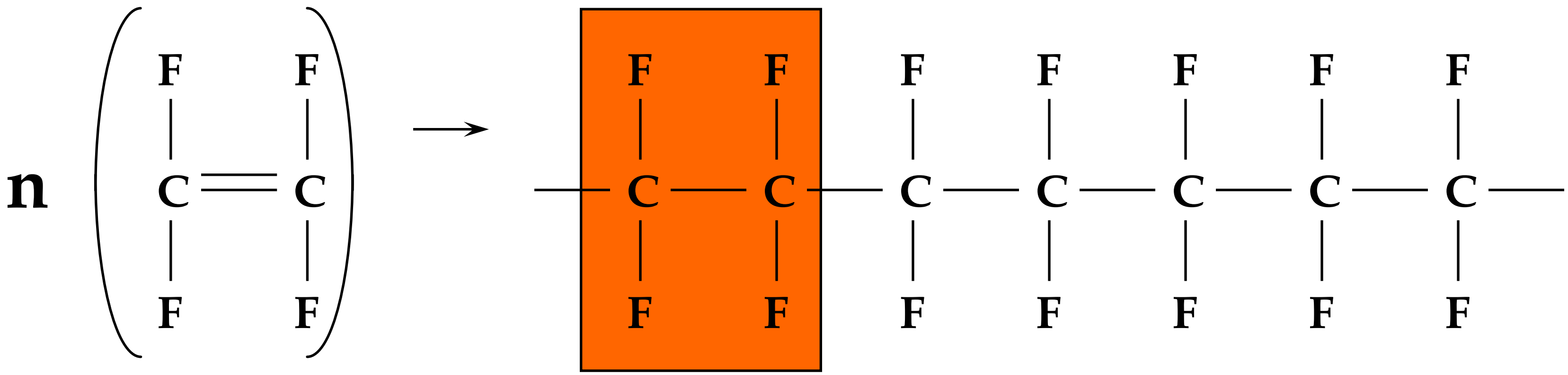
N is the density (atoms/cm^3)

Etch Model Example



Polymerisation

Teflon



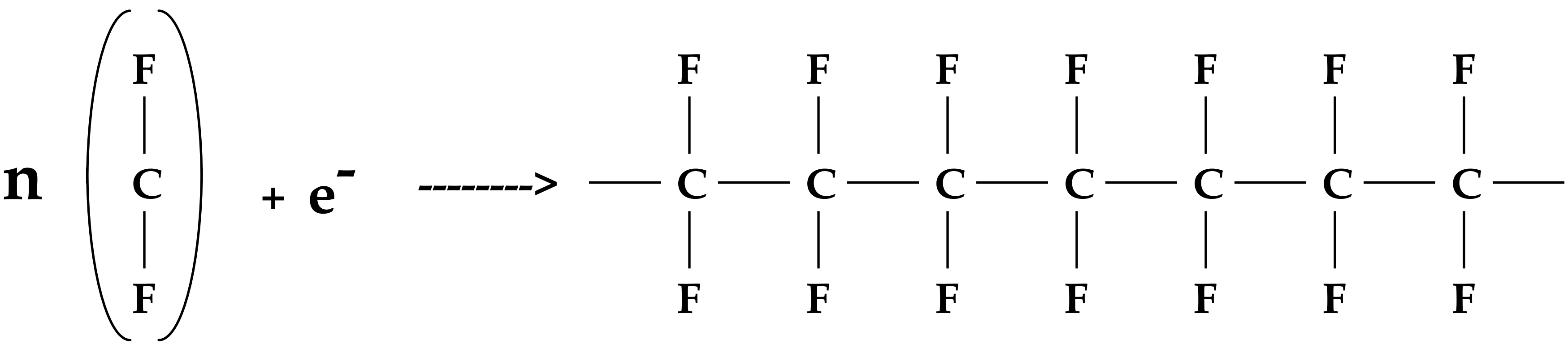
Monomer Polymer

- Polymers are formed by chain linking monomers
- Above reaction is typical of a polymerisation process
- The number of monomer units in the polymer can be 10,000s

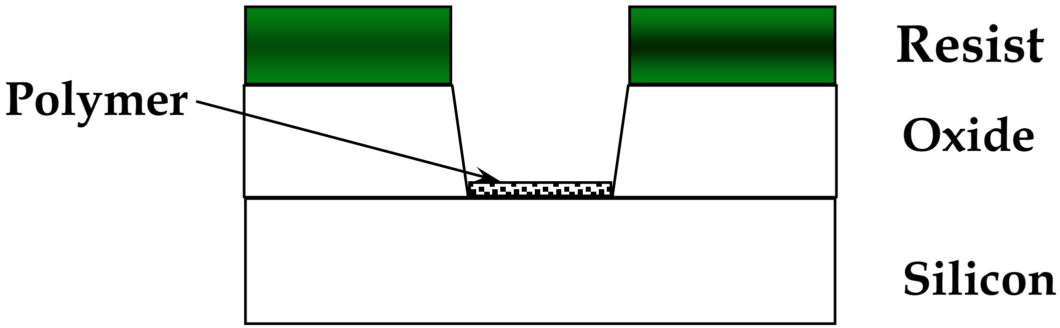
Polymer formation in a plasma

Example:

- CHF_3 is commonly used for oxide etching
- CF_2 is produced by the reaction
  CHF_3 ---> $CF_2 + H + F$
- CF_2 can then polymerise to form a teflon like polymer



Polymer inhibiting reaction



- This reaction is used when etching oxides to improve selectivity to underlying material
- The polymer deposits more quickly on silicon than on silicon dioxide thus slowing the etch when the oxide has been removed

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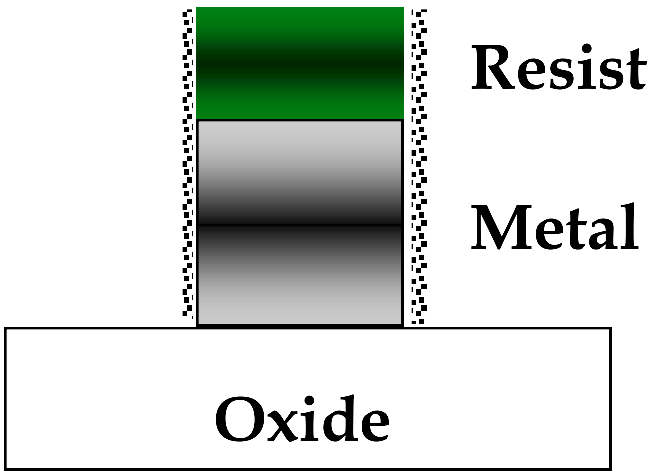
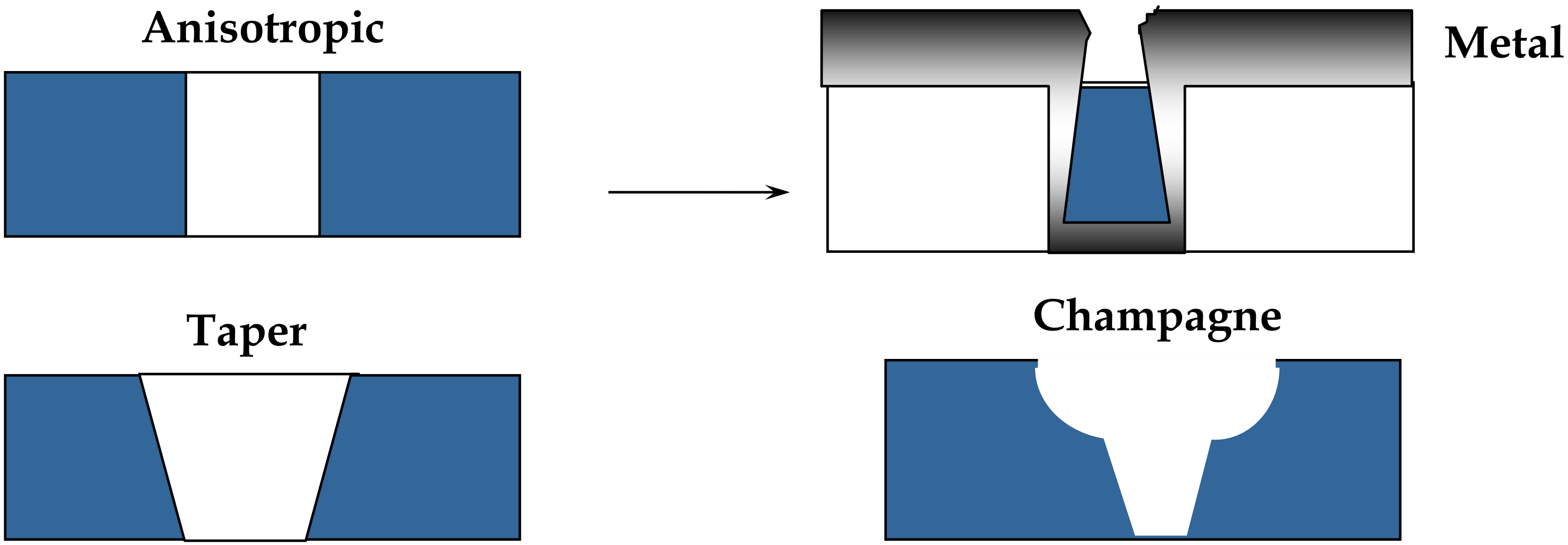
Polymer enhancing anisotropy



- Metal anisotropy is maintained by the deposition of polymer on sidewall of metal
- The polymer consists of etch by-products and resist erosion products
- The polymer is also deposited on horizontal surfaces but ion bombardment causes desorption

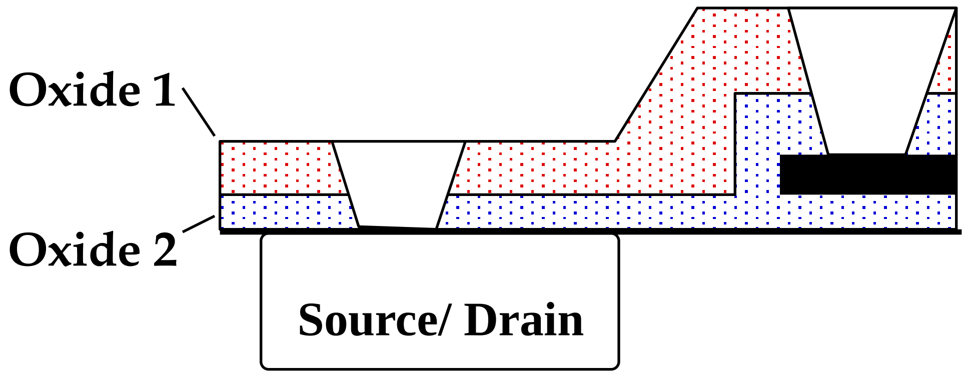
Contact etching



Contact Etching

- For contacts 1.5μm and below metal step coverage can be a problem i.e. too thin in contact hole
- This can be improved by taper or champagne etch
- Alternatively selective tungsten plug metallisation is used which completely fills anisotropically etched contact

Contact etching

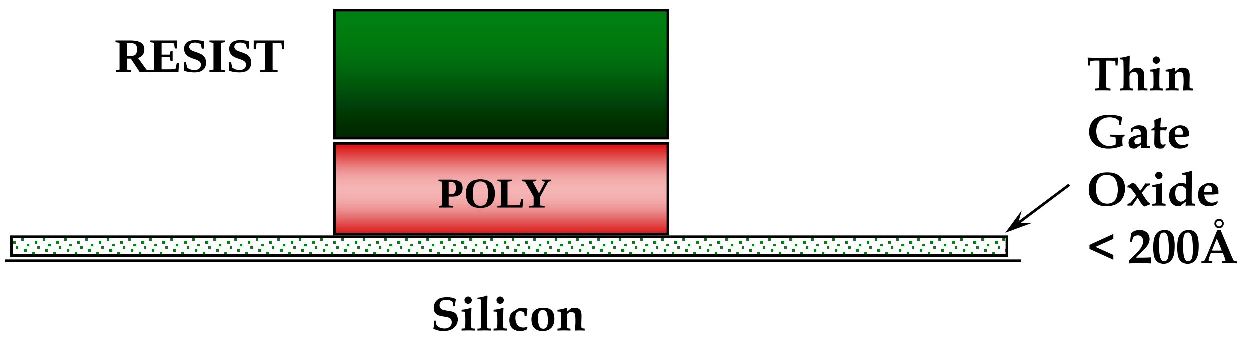


- Due to uneven topography it is sometimes necessary to etch through different oxide thicknesses
- Also different oxides can have different etch rates e.g. thermal/deposited, doped/undoped

Tyndall Contact Etch Recipe

- **Step 1 C2F6 0 sccm Power 250 W**
  - CHF3 65 sccm Pressure 1000 mT
  - O2 35 sccm Time 15 sec.
  - The oxygen erodes the resist CHF3 etches oxide
- **Step 2 C2F6 23 sccm Power 275 W**
  - CHF3 143 sccm Pressure 155 mT
  - O2 0 sccm Time Endpoint
  - This is the bulk etch and etches most of the BPSG
  - Endpoint is indicated by changes in plasma colour
  - 40% overetch to clear all contacts
- **Step 3 C2F6 120 sccm Power 70 W**
  - CHF3 0 sccm Pressure 180 mT
  - O2 14 sccm Time 15 sec.
  - Low power step to remove damaged silicon and polymer.

Poly etching

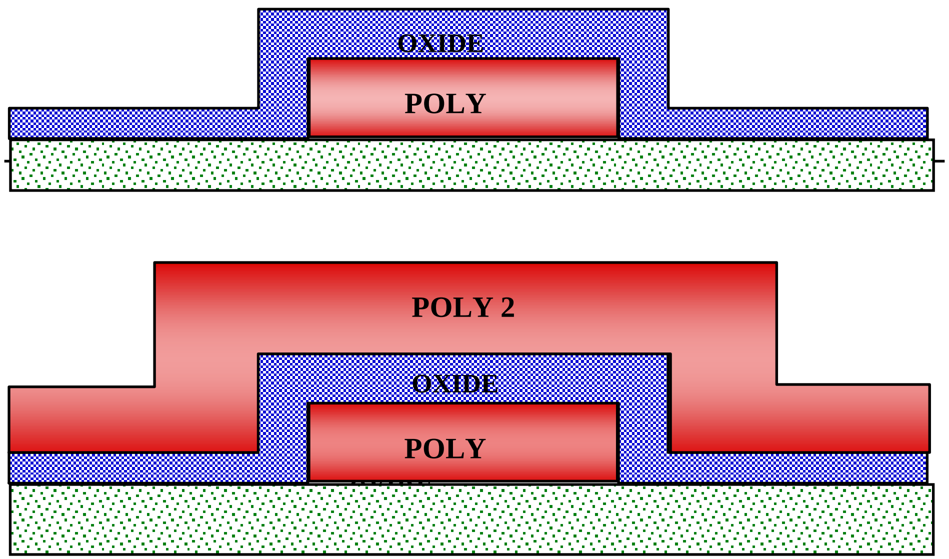


- As device dimensions shrink gate oxides become thinner
- Acceptable gate oxide loss =/< 50Å
- High selectivity between poly and gate oxide required

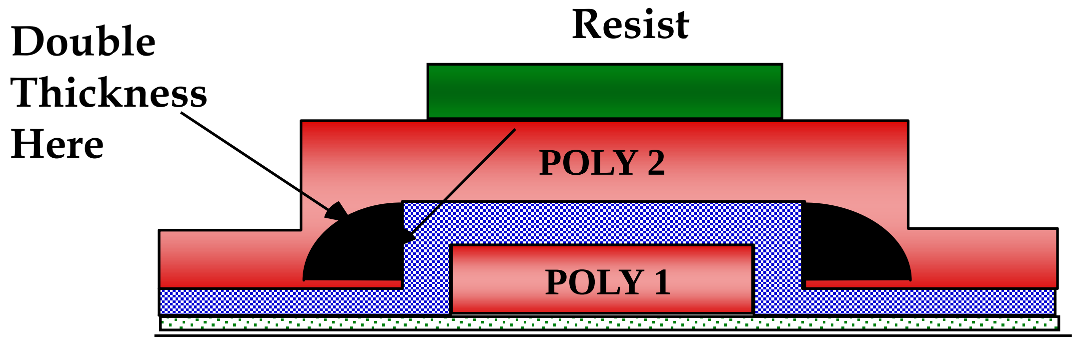
Poly Etch Recipe

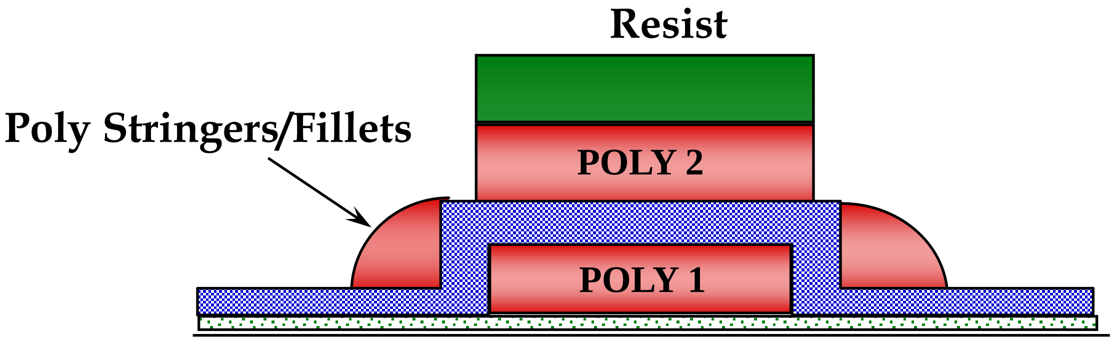
Step no. Name	Bth	Polyblk	Gas.st	Ov_etch
He Back pressure – Torr	15 ± 5	15 ± 5	15 ± 5	15 ± 5
Pressure – mTorr	6 ± 10	6 ± 10	10 ± 10	10 ± 10
Cl_2 – sccm	20 ± 10	25 ± 10	---------	---------
O_2 – sccm	---------	---------	3 ± 10	3 ± 20
HBr – sccm	---------	25 ± 10	40 ± 10	40 ± 20
RF Power – Watts	40 ± 10	25 ± 10	---------	20 ± 10
MORI Power – Watts	1500 ± 10	1500 ± 10	---------	2000 ± 20
MORI Inner – Amps	60 ± 10	60 ± 10	20 ± 20	20 ± 20
MORI Outer – Amps	60 ± 10	60 ± 10	60 ± 20	60 ± 20
Step time (4500 Å Poly)	00:10	00:50	00:10	00:30
Poly Etch rate (Å/min)	2100	4250	---------	2650
SiO_2 Etch Rate (Å/min)	800	350	---------	20
$S_{\text{Poly : SiO2}}$	---------	12 : 1	---------	120 : 1
$S_{\text{Poly : Photoresist}}$	---------	1.7 : 1	---------	2.1 : 1

Double Poly Etch I



Double Poly Etch II





- Because poly is thicker at step poly 2 needs to be overetched
- Overetching can cause problems with polyoxide loss or undercut on poly 2

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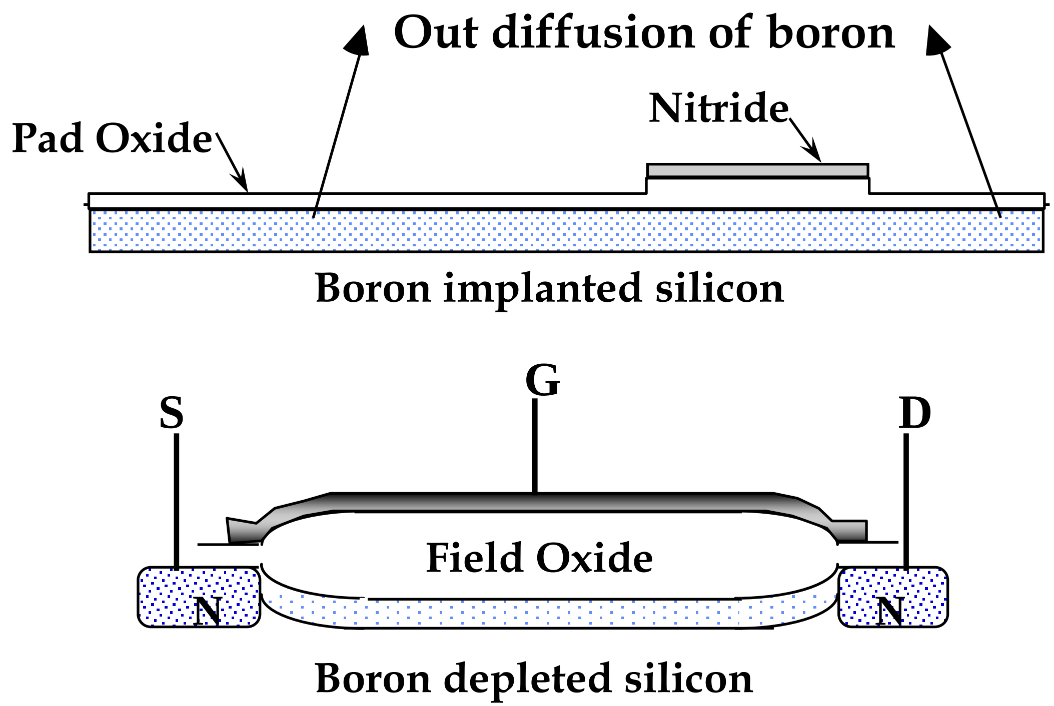
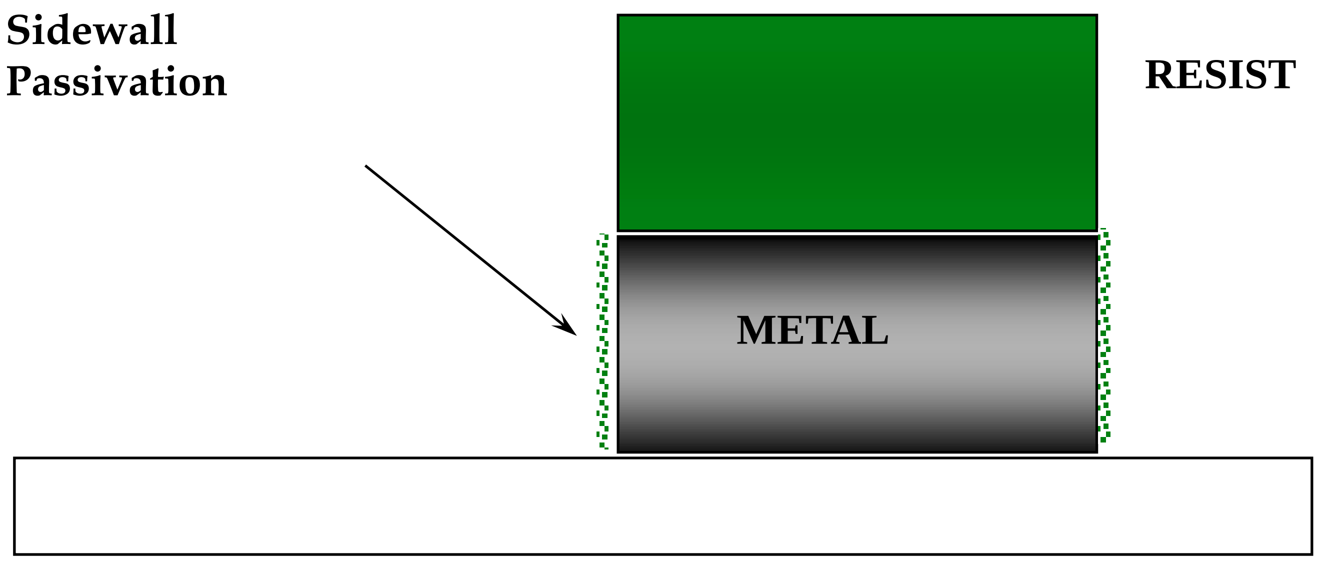
NITRIDE ETCHING

<u>Process sequence</u>
Nitride photo
Nitride etch
Resist strip
Field implant
Field oxide



- If the pad ox is excessively thin, dopant implanted in field can be lost during field oxide growth
- Therefore pad oxide loss should be kept to a minimum during nitride etch

Metal etching



Metal Etching

- Atomic chlorine produced in plasma will readily etch aluminium
- To prevent lateral etching of the metal the sidewalls of the metal are passivated by etch residues
- A high resist erosion rate is required for this passivation
- This passivation contains chlorine and can react with moisture when exposed to air causing corrosion problems
- Therefore resist must be ashed soon after etch

Tyndall Metal Etch Recipe

Step no. Name	BRKTHRU	stab1	BULK	stab2	OE
He BP - Torr	9.5 ± 10 %	9.5 ± 10 %	9.5 ± 10 %	9.5 ± 10 %	9.5 ± 10 %
Pressure – mTorr	5 ± 20 %	5 ± 99 %	5 ± 20 %	5 ± 99 %	5 ± 20 %
Cl_2 – sccm	40 ± 10 %	25 ± 99 %	25 ± 10 %	15 ± 99 %	15 ± 10 %
Ar – sccm	20 ± 10 %	---------	---------	---------	---------
BCl_3 – sccm	---------	6 ± 99 %	6 ± 15 %	---------	---------
N_2 – sccm	---------	---------	---------	5 ± 99 %	5 ± 99 %
Bias RF Power – Watts	50 ± 30 %	30 ± 99 %	30 ± 30 %	0 ± 99 %	25 ± 30 %
ICP Power – Watts	500 ± 20 %	900 ± 99 %	900 ± 15 %	0 ± 99 %	900 ± 15 %
Step time	00:20	00:10	Endpoint Max 1:30	00:10	50 % of bulk time
Endpoint	Disabled	Disabled	Falling Delay: 0:30 25% drop	Disabled	Disabled

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