Dry etching

Hyuk Jae Jang
School of Electrical Engineering and Computer Science
Gwangju Institute of Science and Technology

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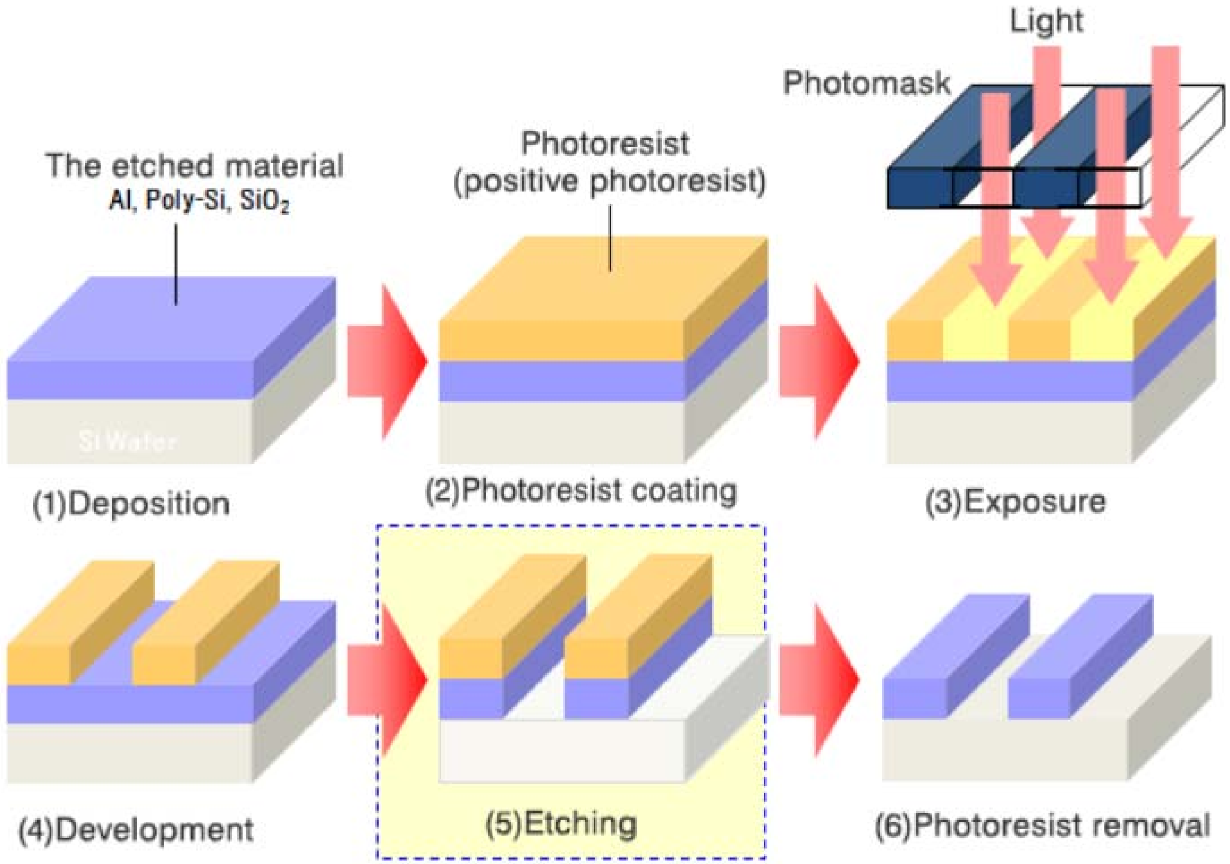
Introduction

Etching is the process that removes the material to create a design



Introduction

The terminology related to etching

- Etch rate
- Selectivity
- Etch profile
- Uniformity

Introduction

- Etch rate

how fast material is removed in the etch process

$$\boldsymbol{Etch\,rate} = \frac{\boldsymbol{Thickness\,before\,etch\ - Thickness\,after\,etch}}{\boldsymbol{etch\,time}}$$

Depends on

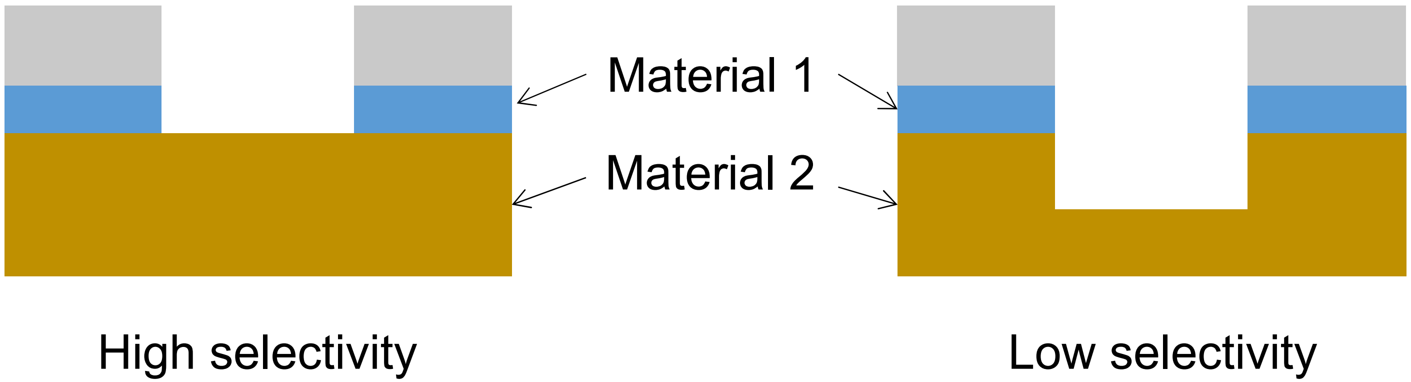
- Pressure
- Source power
- Bias voltage
- Wafer temperature

Introduction

- Selectivity

Ratio of the etch rates between the different materials

$$Selectivity = \frac{Etch\ rates\ of\ material\ 1}{Etch\ rates\ of\ material\ 2}$$



Introduction

- Etch profile

Ratio of the etch rates between the horizontal and vertical wall

$$\boldsymbol{R_L} = \frac{\textit{Horizontal Etch rate}}{\textit{Vertical Etch rate}}$$

Isotropy
$R_L = 1$

Anisotropy
$0 < R_L < 1$

Completely Anisotropy
$R_L = 0$

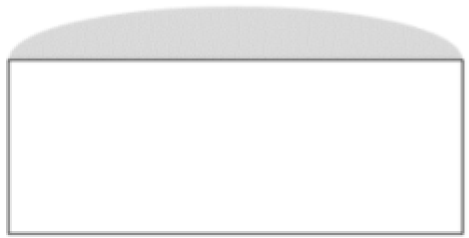
Introduction

- Uniformity

Measuring wafer thickness before and after the etch process

$$\textbf{Uniformity} = \frac{\boldsymbol{Max\,Etch\,rate - Min\,Etch\,rate}}{\boldsymbol{Max\,Etch\,rate + Min\,Etch\,rate}} * \mathbf{100}\,\%$$

Good uniformity



Bad uniformity

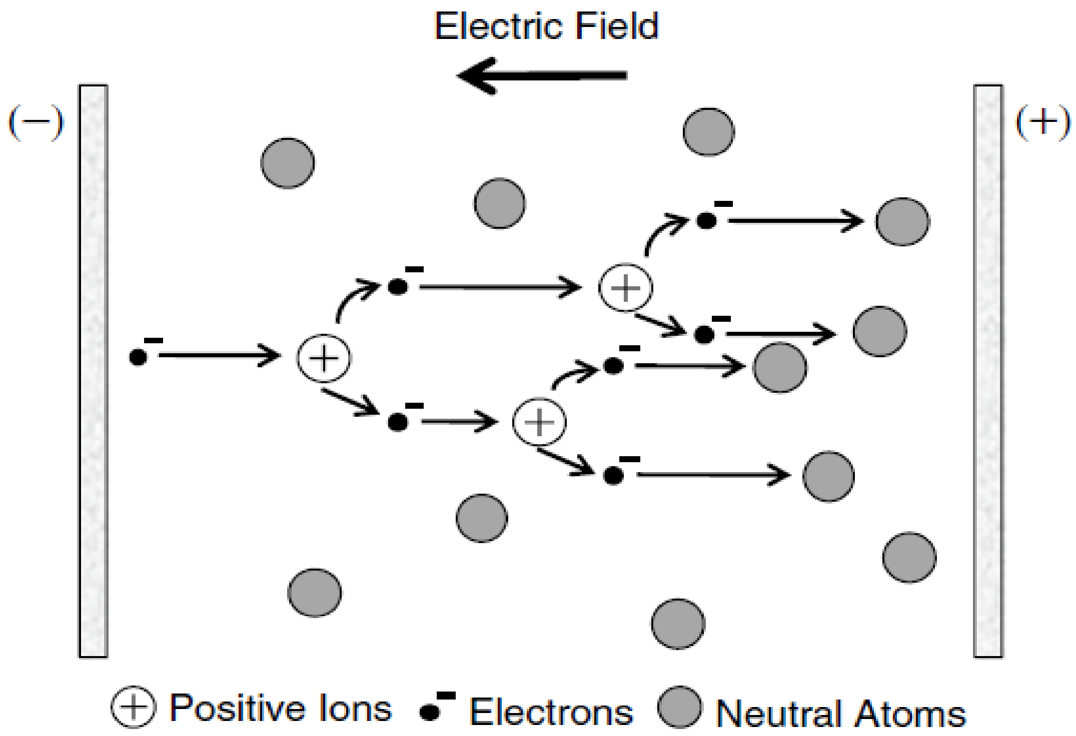
Wet vs Dry etching

- Dry etching
  - Gas phase etchants in a plasma
  - Chemical and physical (sputtering) process
  - High resolution
  - Both isotropic and anisotropic process
- Wet etching
  - Liquid etchant
  - Only chemical process
  - Hard to control critical feature dimension

Wet vs Dry etching

Parameter	Dry etching	Wet etching
Directionality	**Highly with most materials**	Almost poor
Typical Etch rate	Slow (0.1um/min)	Fast(1um/min)
Control of etch rate	**Good**	Difficult
Materials that can be etched	Only certain material	**All**
Equipment cost	Expensive	**Inexpensive**
Radiation damage	Can be severe	**None**
Production-line automation	**Good**	Poor
Environmental impact	**Low**	High
Cost chemicals	**Low**	High
CD control	**Good**	Poor

Plasma



If the kinetic energy of an electrons is greater than the ionization energy, and making more electron in chamber, **that create plasma**.

Dry etching techniques

- Types of dry etching processes

  - Ion beam etching (IBE)

    Physical etching

  - Plasma etching (PE)

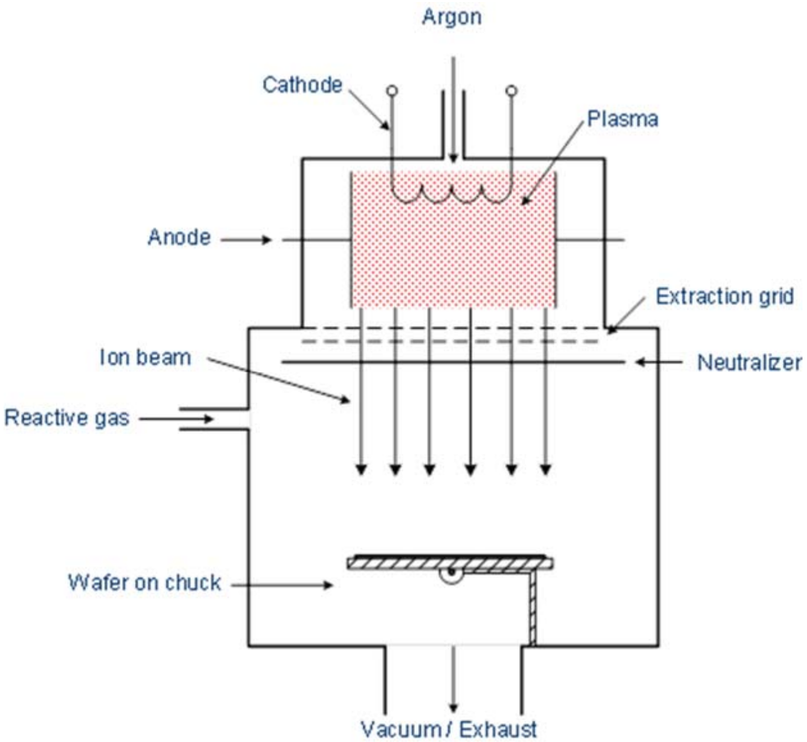
    Chemical etching

  - Reactive ion etching (RIE)

    Physical and Chemical etching

Dry etching techniques

- **Ion Beam Etching (IBE): '**Physical' dry etching process



Properties of IBE

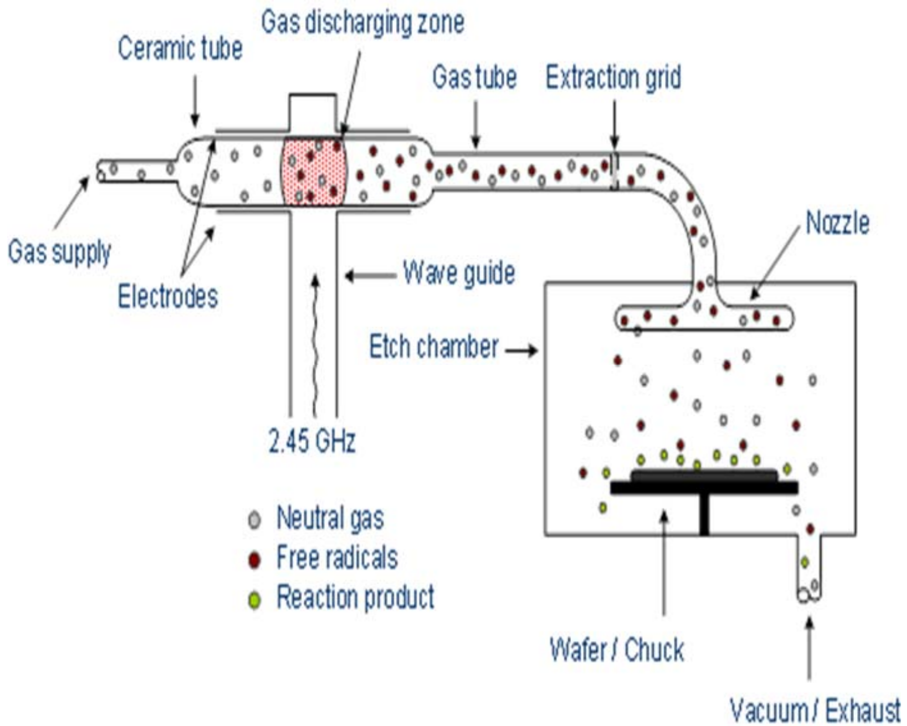
- Ion beam energy: 1 – 3 keV
- Cathode: **emitting** electrons
- Grid: **accelerate ions** that pass through the grid to form the ion beam
- Neutralizer filament: introduce electrons to **balance the positively** charged ions.
- Operating pressure: 10^{-6} - 10^{-4} Torr

Dry etching techniques

- **Plasma etching (PE):** 'Chemical' dry etching process

$$2CF_4 + O_2 \rightarrow 2COF_2 + 2F_2$$, Neutral gas CF_4

$$4F(g) + Si \rightarrow SiF_4(g)$$, **CF_4** can etch **Si**



Properties of PE

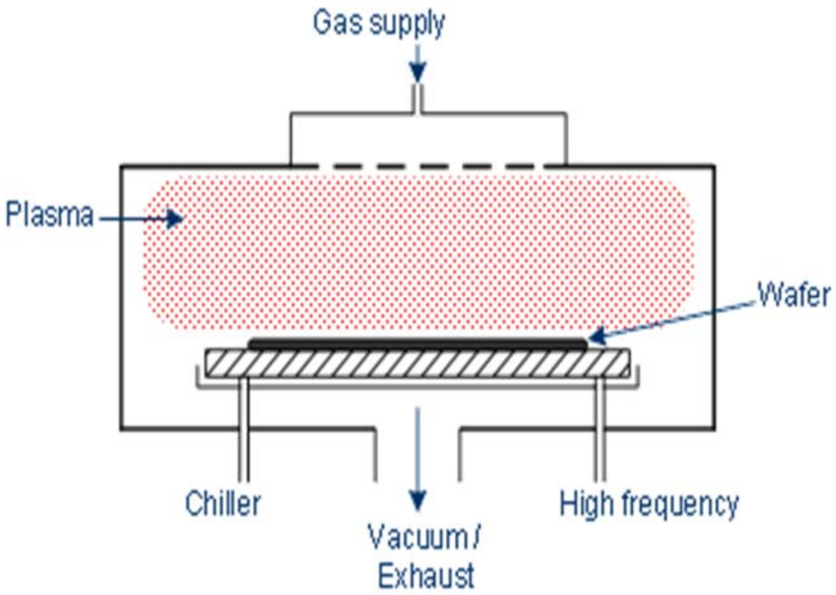
- Isotropic etching
- No damage by accelerated ions
- Operating pressure: 0.1-10mTorr

Dry etching techniques

- **Reactive ion etching (RIE):** 'Chemical' and 'Physical' dry etching process

$$SF_6 + Si \rightarrow SiF_4$$

$$Cl_2 + Si \rightarrow SiCl_4$$



Properties of RIE

- Isotropic and Anisotropic
- 13.56 MHz RF generator
- Operating pressure : 0.01 ~ 0.1 Torr

Thank you

Q&A

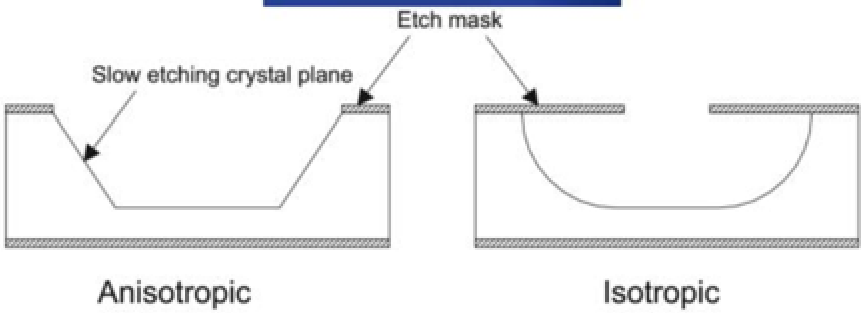
Appendix (Wet vs dry etching)

1. **Wet Etch**
   - Liquid Etchant
   - Chemical process Only
   - Advantage:
     - Low Cost and easy to implement
     - High etching rate
     - Good selectivity for most material.
   - Disadvantage:
     - Very hard to control critical feature Dimension
     - Eliminates Toxic fumes.
2. **Dry etch**
   - Gas Phase etchants in a plasma
   - Chemical and physical (sputtering) process
   - Advantage:
     - Both isotropic and anisotropic process can be done.
     - High resolution and cleanliness
     - Better process control
     - Ease of automation.

Appendix (Dry chemical etching)

Dry chemical etching mechanisms : purely 'chemical'

- XeF_2 Gas Phase Etching (high pressure, chemical only)
  - no plasma (just pump)
  - 10 µm/min
  - no damage
  - isotropic
  - very selective (Si over Al, photoresist, oxide and nitride)
  - CMOS compatible

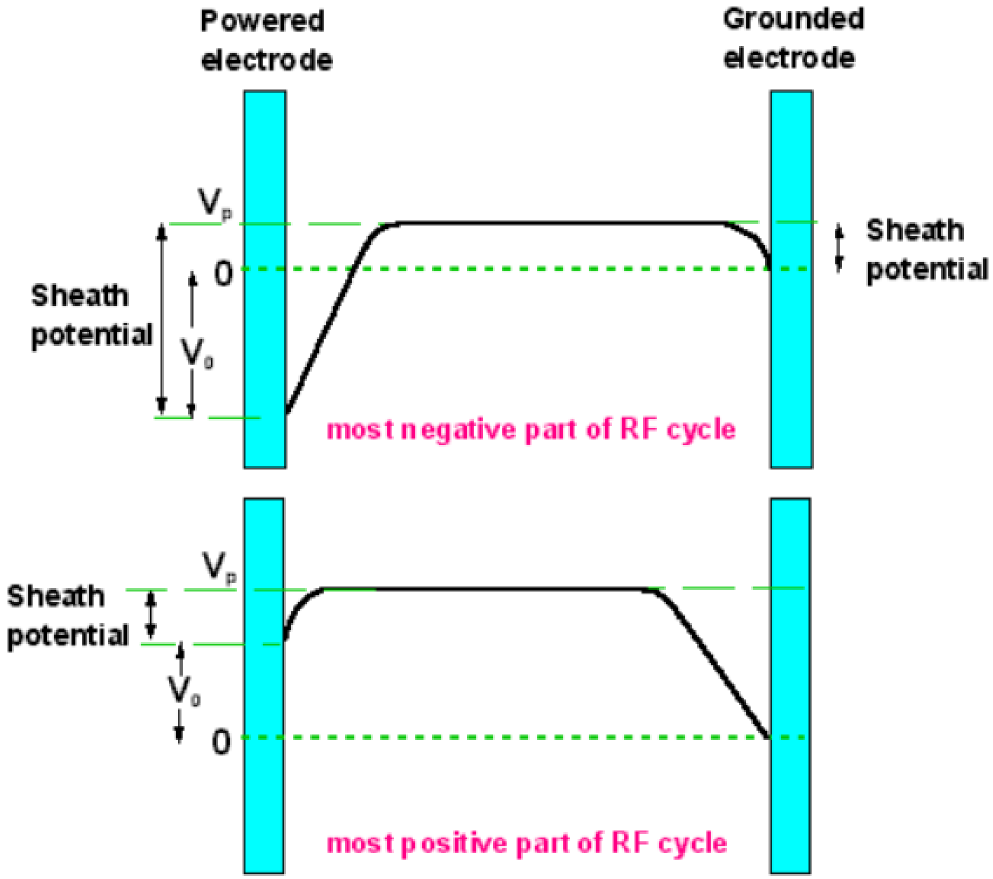


Appendix (Plasma)

- At the start of a sustained gas breakdown a current starts flowing and the voltage drops to about 150 V.
- To sustain a plasma, a mechanism must exist to generate additional free electrons after the plasma generating ones have been captured at the anode.
- The additional electrons are formed by ions of sufficient energy striking the cathode (emitting secondary Auger electrons).
- This continuous generation provides a steady supply of electrons and a stable plasma.
- Plates too close: no ionizing collisions (not enough energy), too far too many inelastic collisons in which ions loose energy.

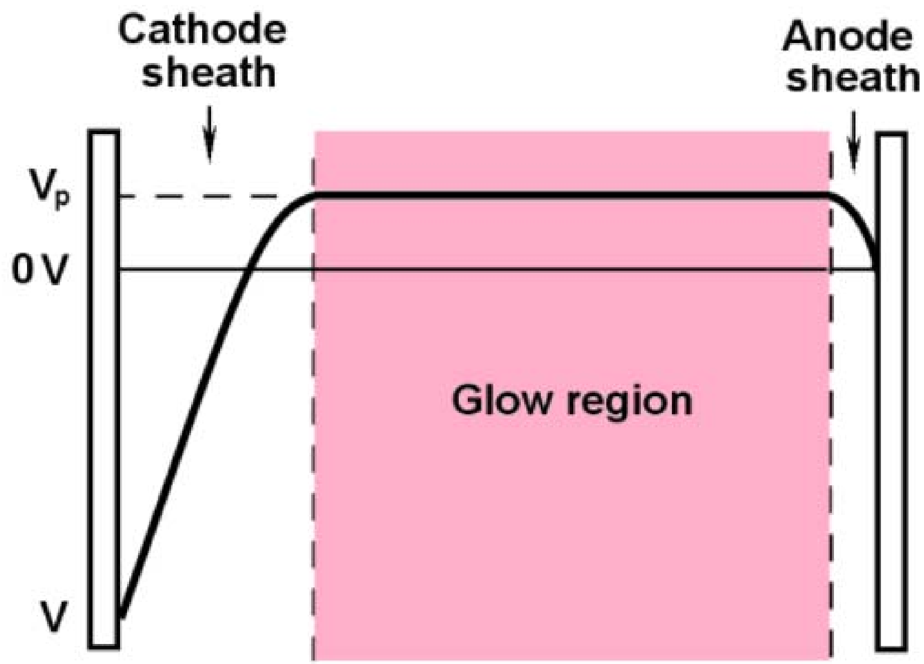
Appendix (Plasma)

the relationship between the applied RF voltage, V_0, the plasma potential, V_p, and the sheath voltages developed at either electrode.



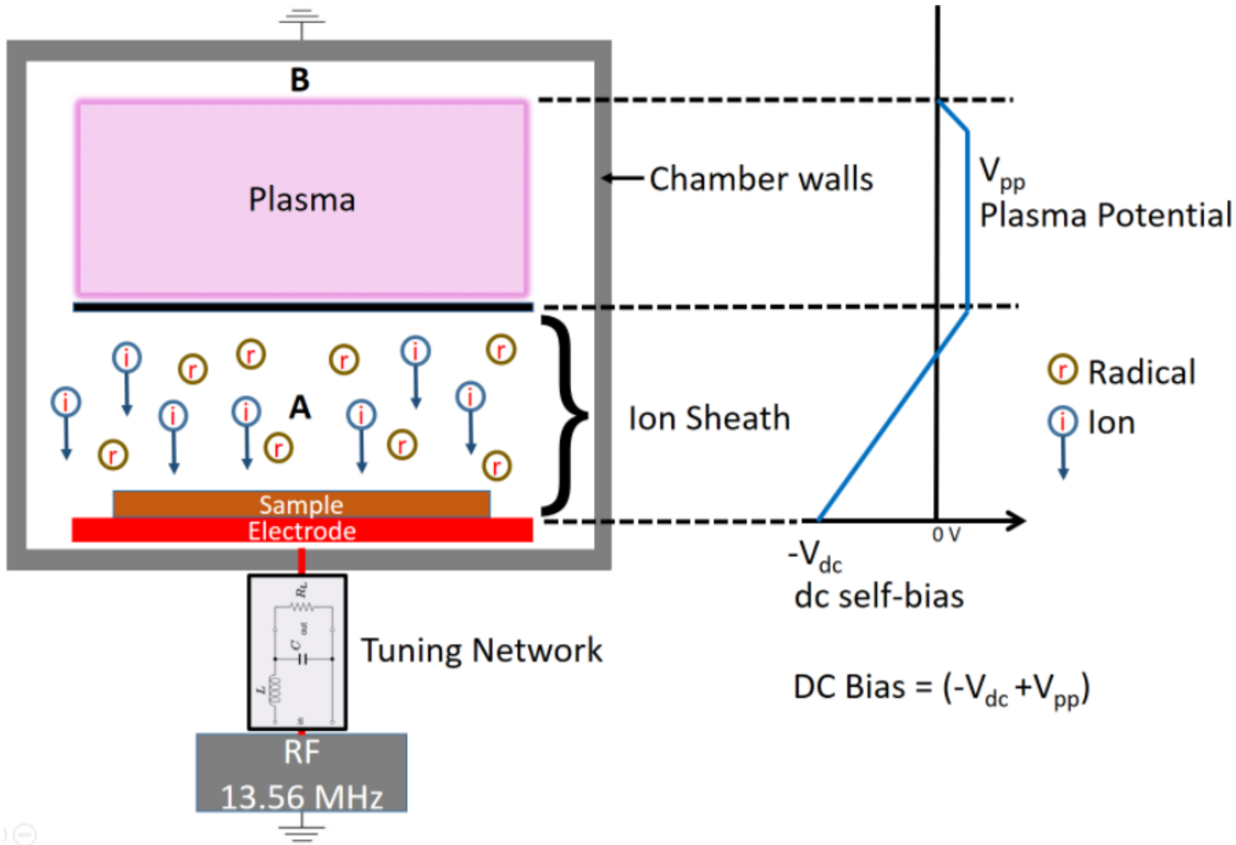
Appendix (Plasma)

Typical potential distribution on a DC glow discharge, also known as DC plasma

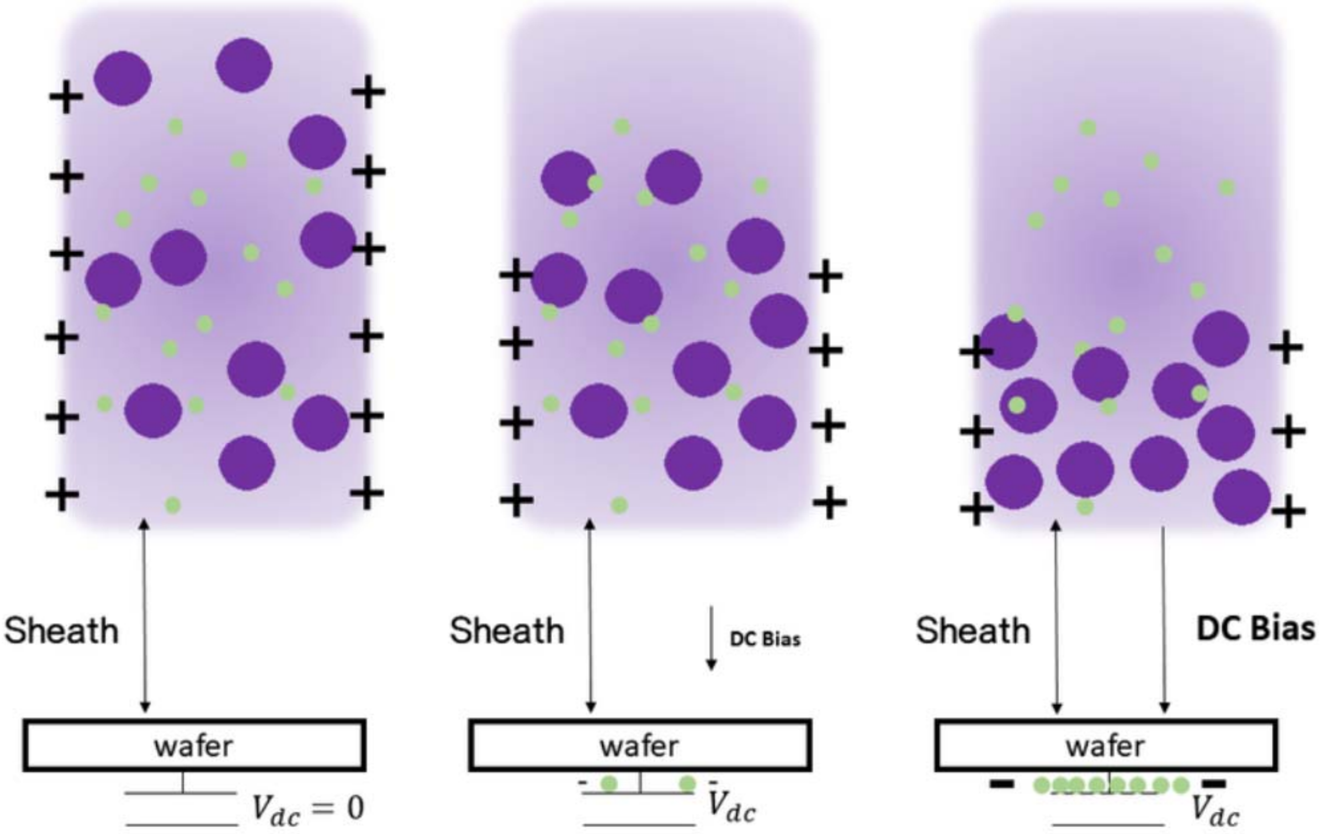


Appendix (Plasma)

Plasma distribution (grounded chamber) and electrical potential(electrode) in a reactive ion etching process



Appendix (blocking capacitor)



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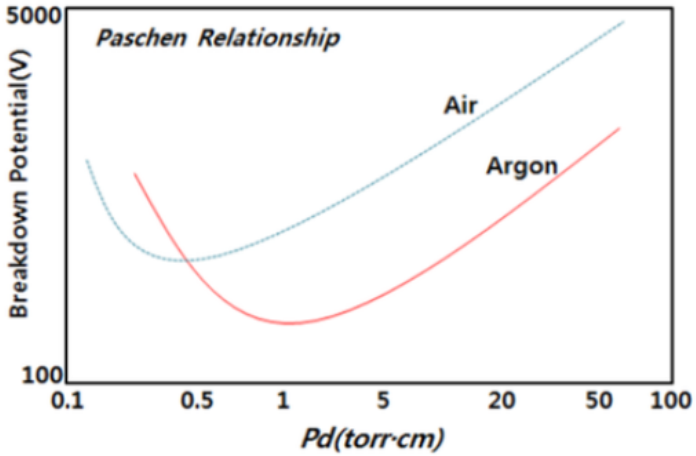


파셴 곡선 (Paschen's Curve)

$$V_b = \frac{B \cdot pd}{A + \ln(pd)}$$

$$A, B = \text{constants}$$

거리(d) 일정한 상황

-압력(P) 감소-

가속된 전자가 기체와 충돌 할 수 있는 확률이 작아 이온화가 어렵다.

-압력(P) 증가-

평균자유행로가 짧아져서 충돌에너지가 낮게 때문에 이온화가 어렵다.

압력(P) 일정한 상황

-가까운 거리(d)-

기체와 충돌 확률이 낮다.

-먼 거리(d)-

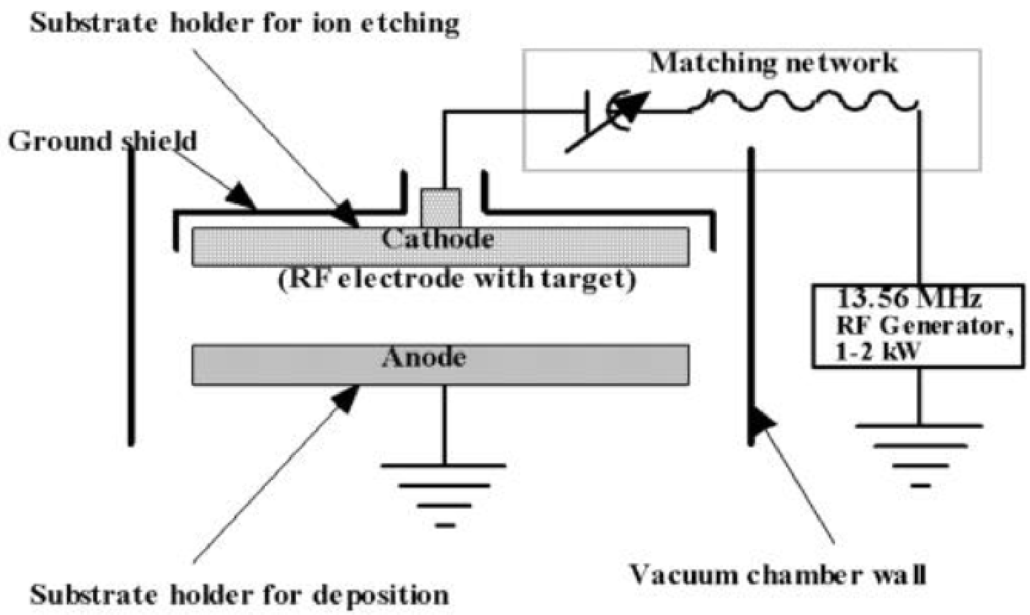
전기장의 세기가 약해지므로 전자나 이온을 가속 시킬 수 있는 힘이 줄어들어 이온화되어도 이온들이 전극에 들어오는 확률이 낮아진다. 그래서 더 높은 전압 필요

파센곡선은 플라즈마를 생성할때 필요한 **Breakdown potential**을 나타냅니다.

압력과 **거리**에 따라서 필요한 에너지의 값이 달라지는 것을 볼 수 있습니다.

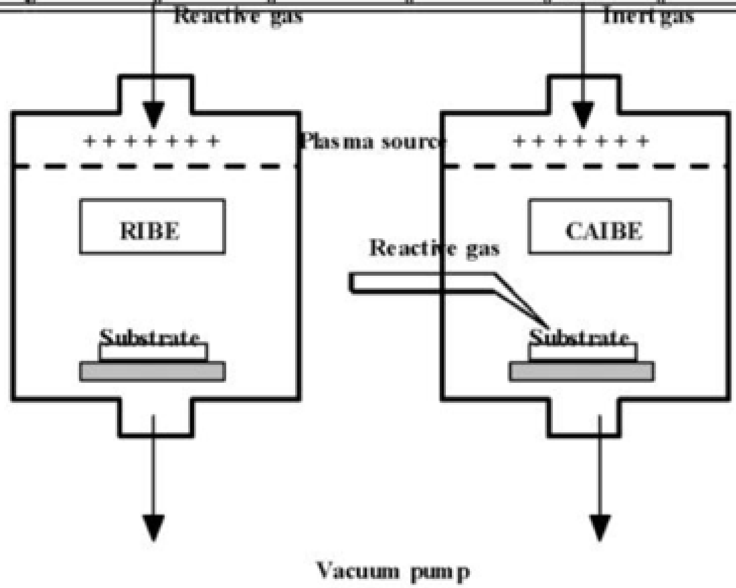
Appendix (Plasma)

Plasma in PECVD



Appendix (Dry etching techniques)

	CAIBE	RIBE	IBE	MIE	MERIE	RIE	Barrel Etching	PE
Pressure (Torr)	$\sim 10^{-4}$	$\sim 10^{-4}$	$\sim 10^{-4}$	10^{-3}-10^{-2}	10^{-3}-10^{-2}	10^{-3}-10^{-1}	10^{-1}-10^{0}	10^{-1}-10^{1}
Etch Mechanism	chem/ phys	chem/ phys	phys	phys	chem/ phys	chem/ phys	chem	chem
Selectivity	good	good	poor	poor	good	good	excellent	good
Profile	anis or iso	anis	anis	anis	anis	iso or anis	iso	iso or anis



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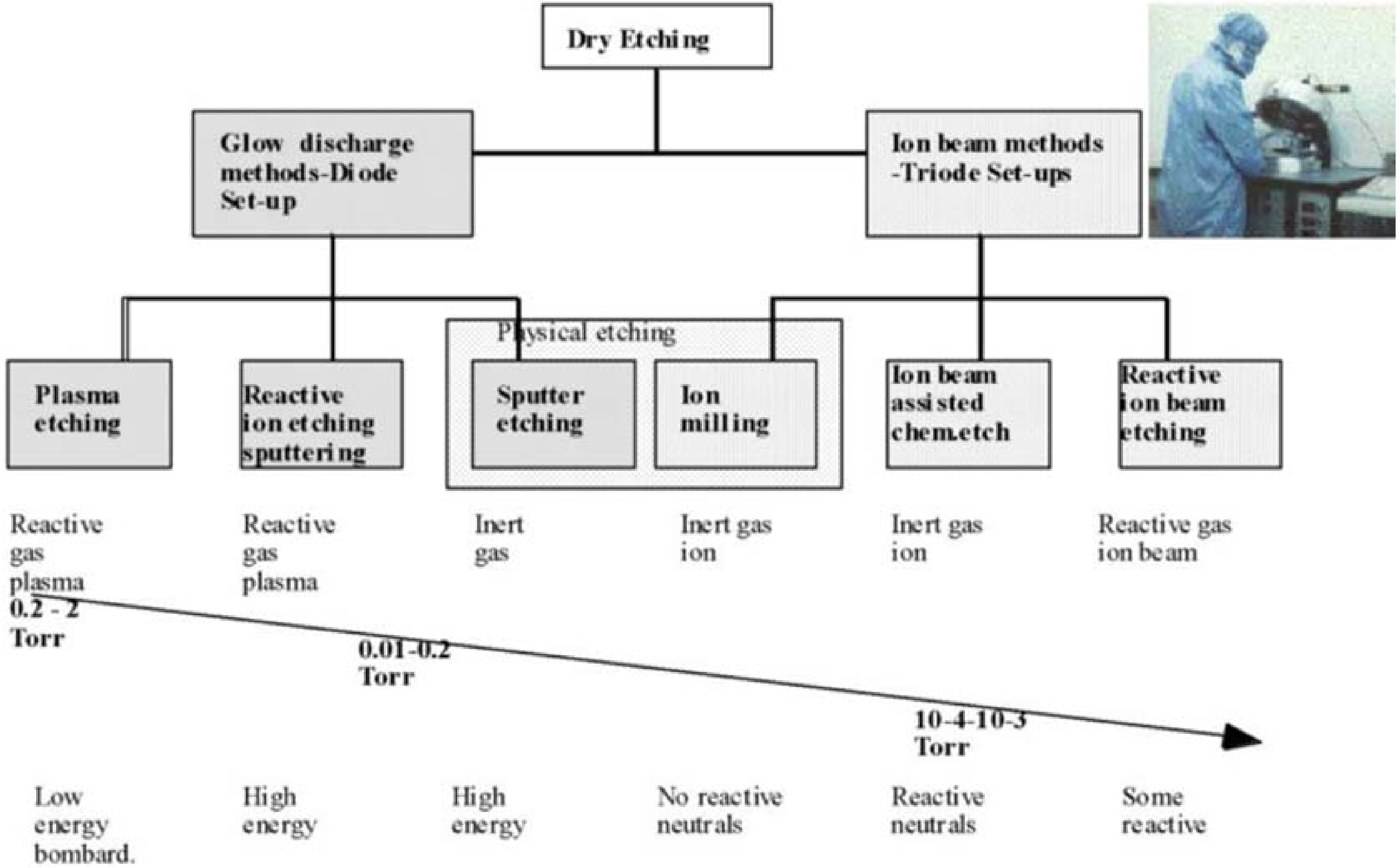
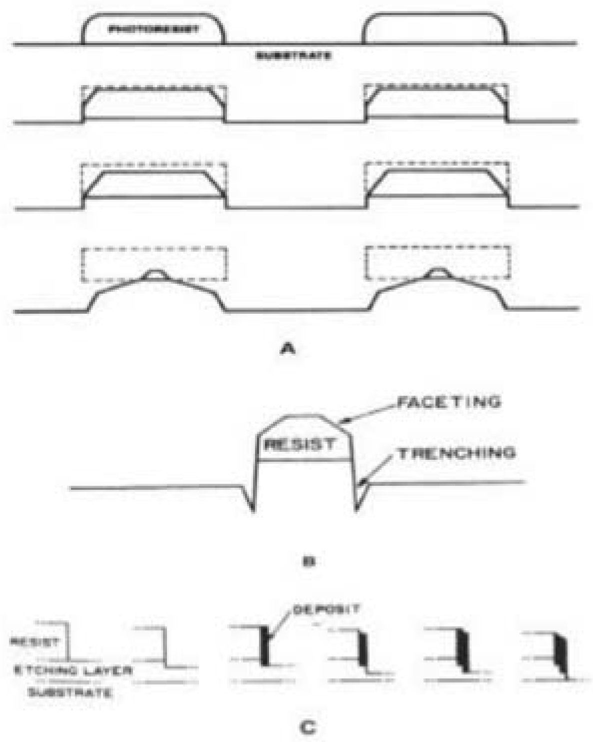

Dry Etching
Glow discharge methods-Diode Set-up
Ion beam methods -Triode Set-ups
Physical etching
Plasma etching
Reactive ion etching sputtering
Sputter etching
Ion milling
Ion beam assisted chem.etch
Reactive ion beam etching
Reactive gas plasma
Reactive gas plasma
Inert gas
Inert gas ion
Inert gas ion
Reactive gas ion beam
0.2 - 2 Torr
0.01-0.2 Torr
10-4-10-3 Torr
Low energy bombard.
High energy
High energy
No reactive neutrals
Reactive neutrals
Some reactive

Appendix (Physical etching : profiles)

Etching profiles in physical etching

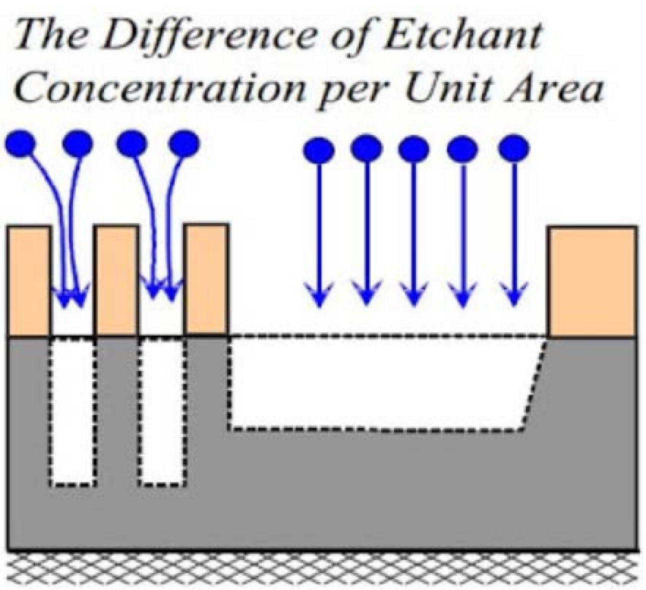
- Faceting: angle of preferential etching
- Ditching (trenching): sometimes caused by faceting
- Redeposition: rotational stage might reduce this effect.



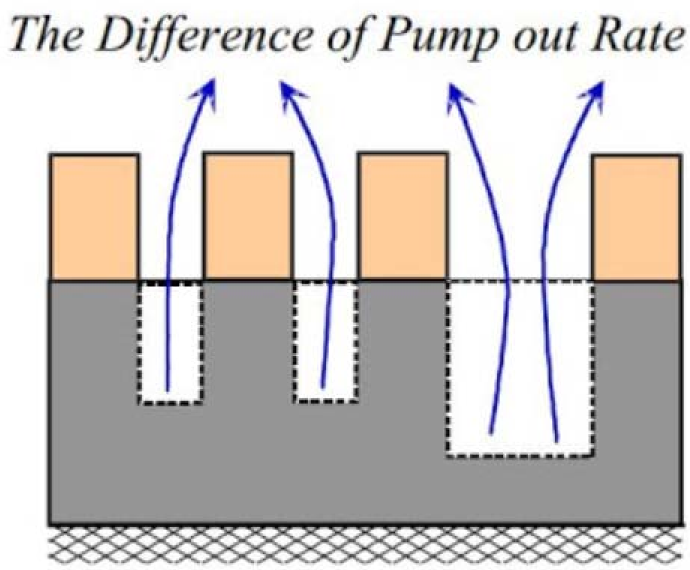
Appendix (Loading effects)

Loading effect

When the etch rate is dependent upon the amount of etchable surface **exposed** to the etchant



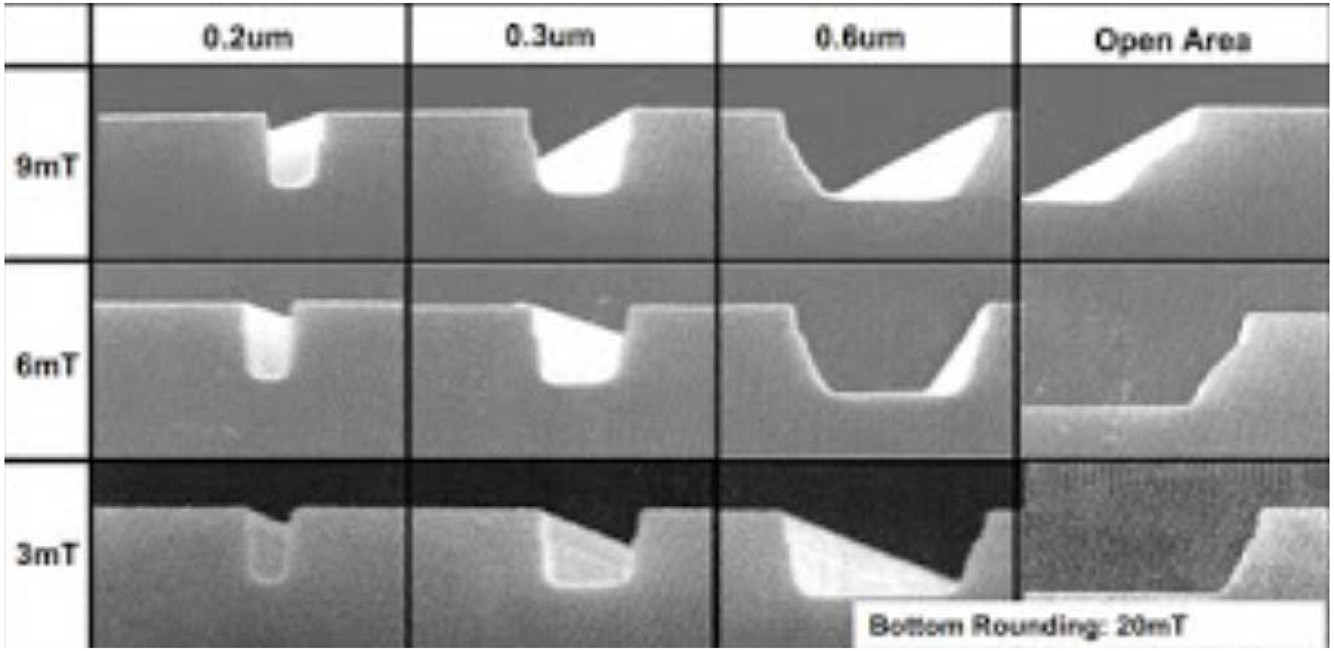
Macro Loading effect



Micro Loading effect

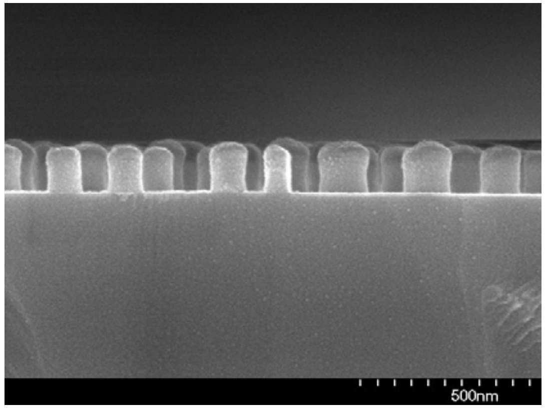
Appendix (Loading effects)

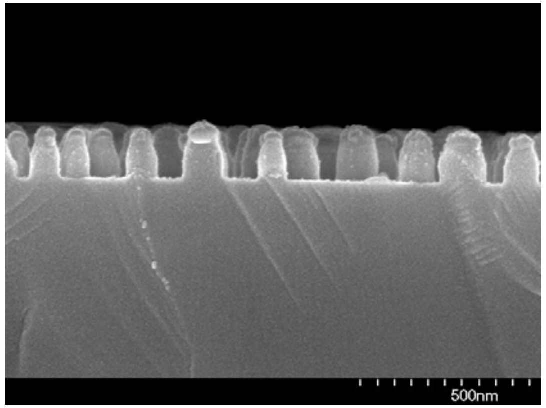
Loading effect profiles

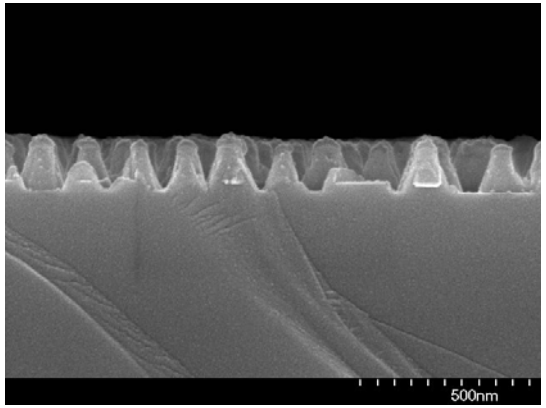


Appendix (Over etching)

Reactive ion etching for SiO_2

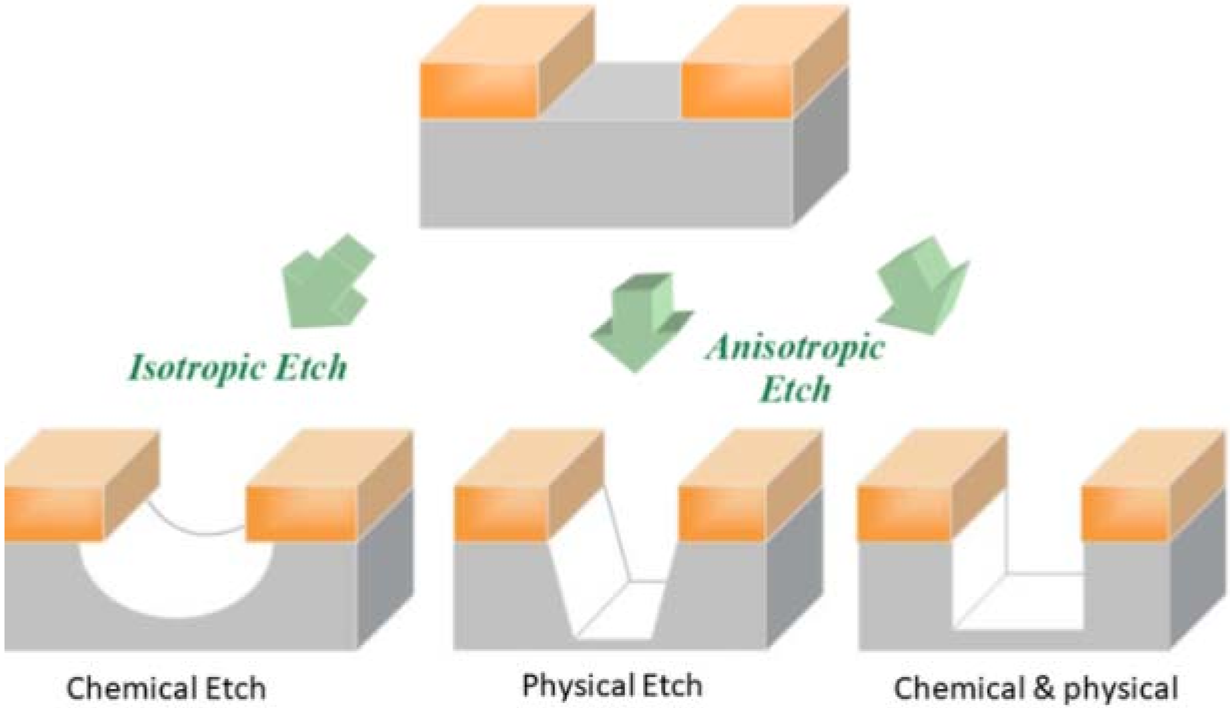




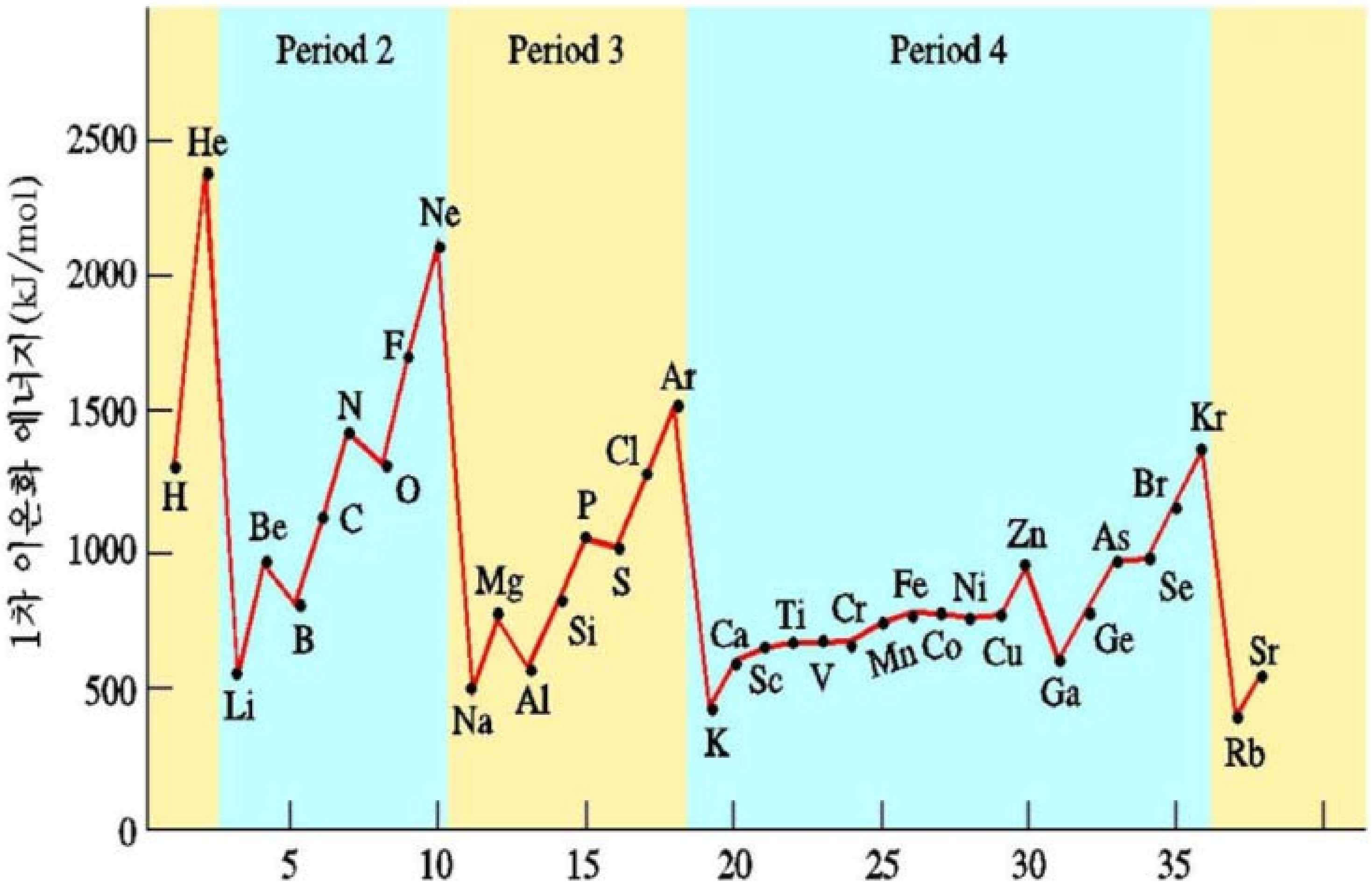


Appendix (etching profiles)

‘Chemical’ & ‘Physical’ etching



Appendix (Ionization energy)



Appendix

플라즈마 내의 충돌 종류

electrons	
$e + A \rightarrow A^+ + 2e$	Ionization
$e + A \rightarrow A^* \rightarrow e + A + h\nu$	Excitation
$e + A^* \rightarrow A^+ + 2e$	Penning ionization
$e + A \rightarrow A + e$	Elastic scattering
$e + AB \rightarrow e + A + B$	Dissociation
$e + AB \rightarrow 2e + A^+ + B$	Dissociation ionization
$e + AB \rightarrow A^- + B$	Dissociation attachment
$e + A^+ + B \rightarrow A + B$	Recombination
ions	
$A^+ + B \rightarrow A + B^+$	Charge exchange
$A^+ + B \rightarrow A^+ + B$	Elastic scattering
$A^+ + B \rightarrow A^+ + B^+ + e$	Ionization
$A^+ + B \rightarrow A^+ + B^* \rightarrow A^+ + B + h\nu$	Excitation
$A^+ + e + B \rightarrow A + B$	Recombination
$A^+ + BC \rightarrow A^+ + B + C$	Dissociation
$A + BC \rightarrow C + AB$	Chemical reaction

Appendix

Typical RIE Gases

Material	Gas	Etching Rate (A/min)	Mask	Selectivity
Si (a-Si)	1) CF4 2) SF6 3) BCl2 + Cl2	~ 500	Resist Metal (Cr, Ni, Al)	~ 20:1 ~ 40:1
SiO_2	1) CHF3 + O2 2) CF4 + H2	~ 200	Resist Metal (Cr, Ni, Al)	~ 10:1 ~ 30:1
SI_3N_4	1) CF4 + O2 (H2) 2) CHF3	~ 100	Resist Metal (Cr, Ni, Al)	~ 10:1 ~ 20:1
GaAs	1) Cl2 2) Cl2 + BCl3	~ 200	SI_3N_4 Metal (Cr, Ni)	~ 10:1 ~ 20:1
InP	1) CH4/H2	~ 200	SI_3N_4 Metal (Cr, Ni, Al)	~ 40:1
Al	1) Cl2 2) BCl3 + Cl2	~ 300	Resist SI_3N_4	~ 10:1
Resist / Polymer	1) O2	~ 500	SI_3N_4 Metal (Cr, Ni)	~ 50:1