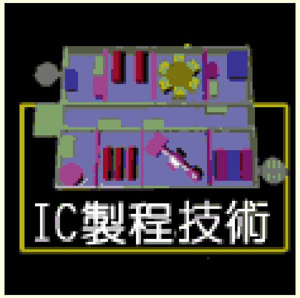
半導製程原理與概論 **Lecture 8**

蝕刻技術

(Etching)



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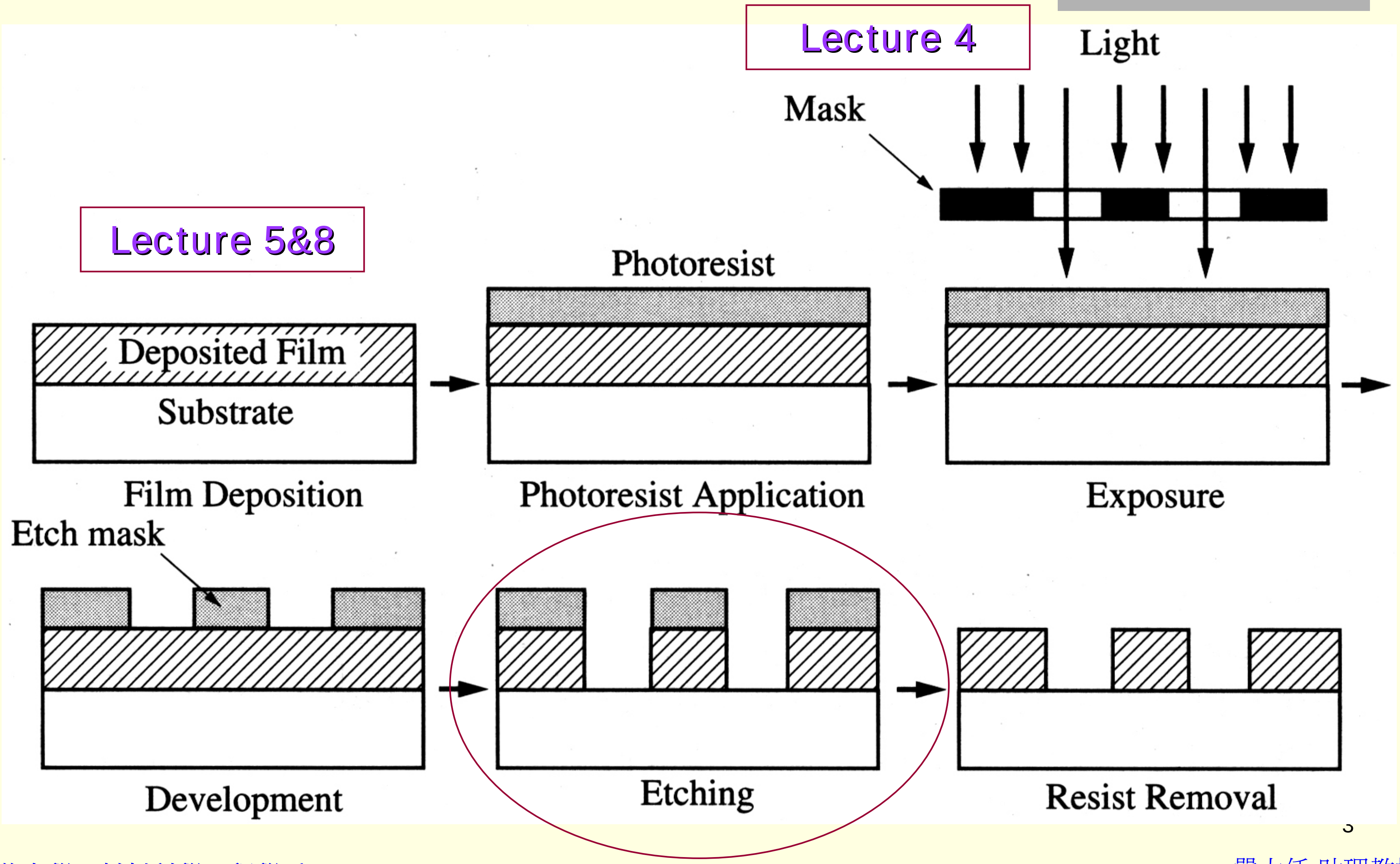
Outline

- Introduction
- How to Control Etching Process?
- Isotropic Wet Etching
- Anisotropic Wet Etching
- Dry Etching

蝕刻技術簡介

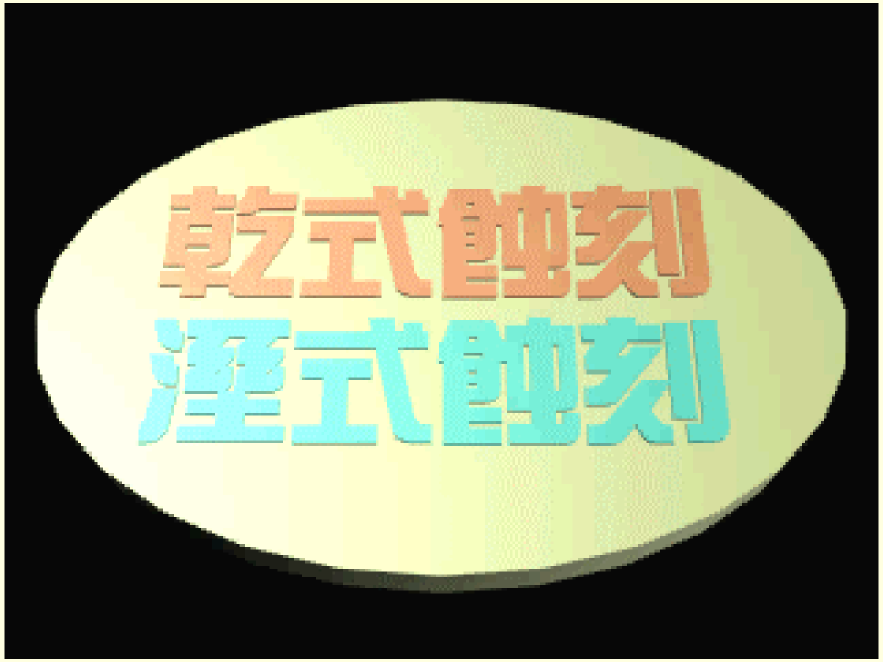


Lecture 4

Lecture 5&8

蝕刻技術分類

- 蝕刻製程乃是將經過微影製程在表面定義出IC電路圖案的晶圓， 以化學腐蝕反應的方式，或物理撞擊的方式，或上述兩種方式的合成效果，去除部份材質，留下IC電路結構。
- 蝕刻技術主要分成兩大類：濕式蝕刻法與乾式蝕刻法。



Types of Etching Processes

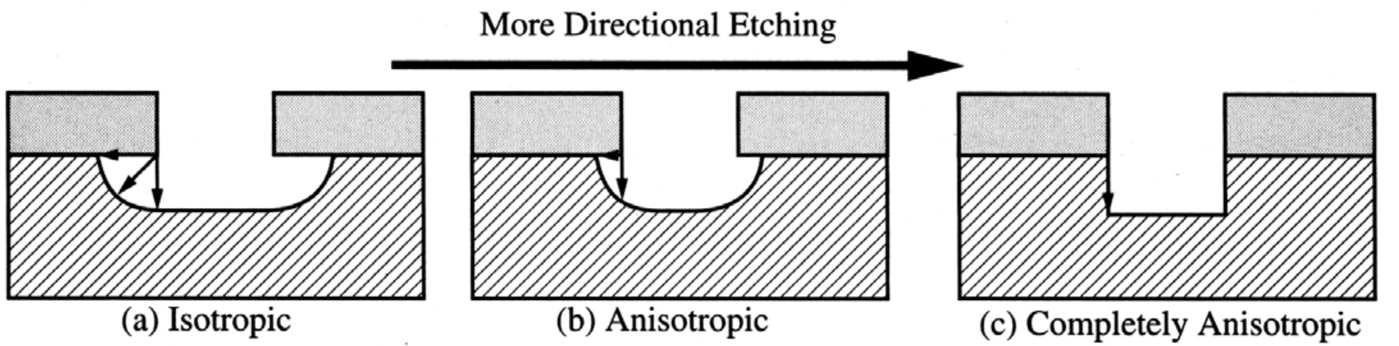


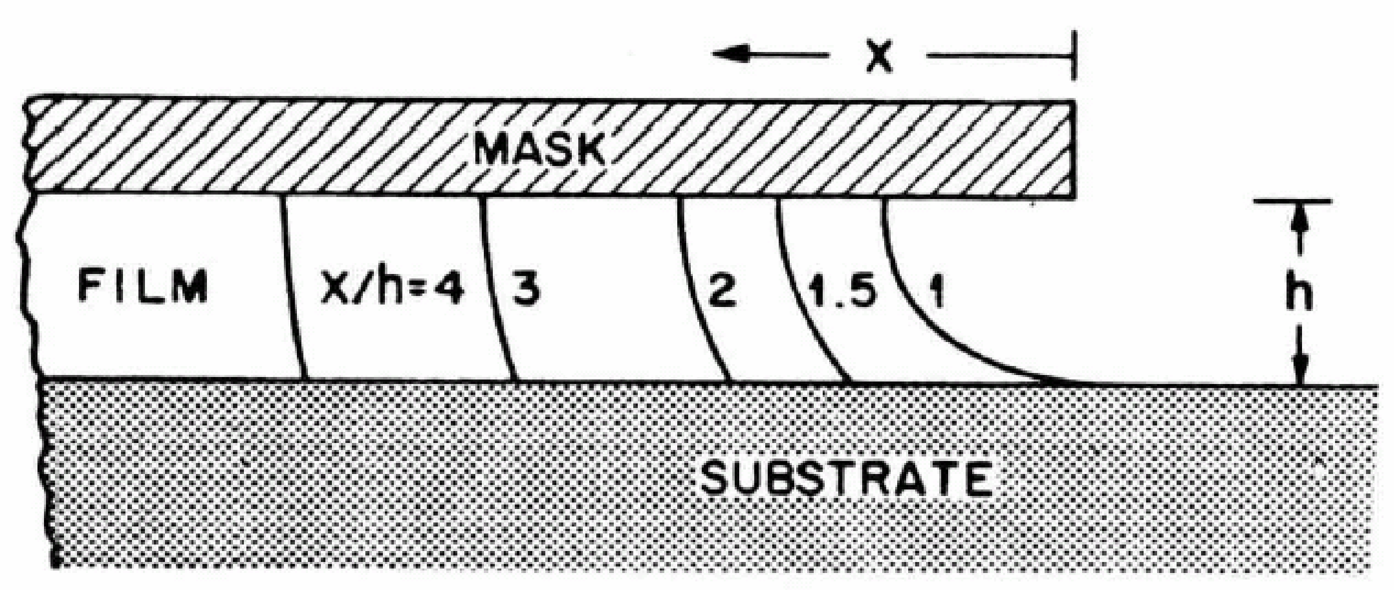
Figure 10–3 Etch profiles for different degrees of anisotropic, or directional, etching: (a) purely isotropic etching; (b) anisotropic etching; (c) completely anisotropic etching.

- Isotropic (等向性):
  - Best to use with large geometries, when sidewall slope does not matter, and to undercut the mask
  - Quick, easy, and cheap
- Anisotropic (非等向性):
  - Best for making small gaps and vertical sidewalls
  - Typically more costly

Etch Parameters

- Etch Rate (蝕刻速率, r):
    - Rate of material removal (μm/min)
    - Function of concentration, mixing, temperature, …
- Etch Selectivity (蝕刻選擇比, $S=r_1/r_2$):
    - Relative (ratio) of the etch rate of the film to the mask, substrate, or another film
    - Trade off etch rate and selectivity
- Etch Geometry (蝕刻幾何形狀):
    - Sidewall slope

Undercutting: Isotropic



- Near vertical sidewalls can be obtained with isotropic etching
- Caveat: long over-etch is required
  (i.e., it is difficult to make small gaps in thick films)

Undercutting: Isotropic

Etch bias (along x-axis) **Overetching** (along y-axis)

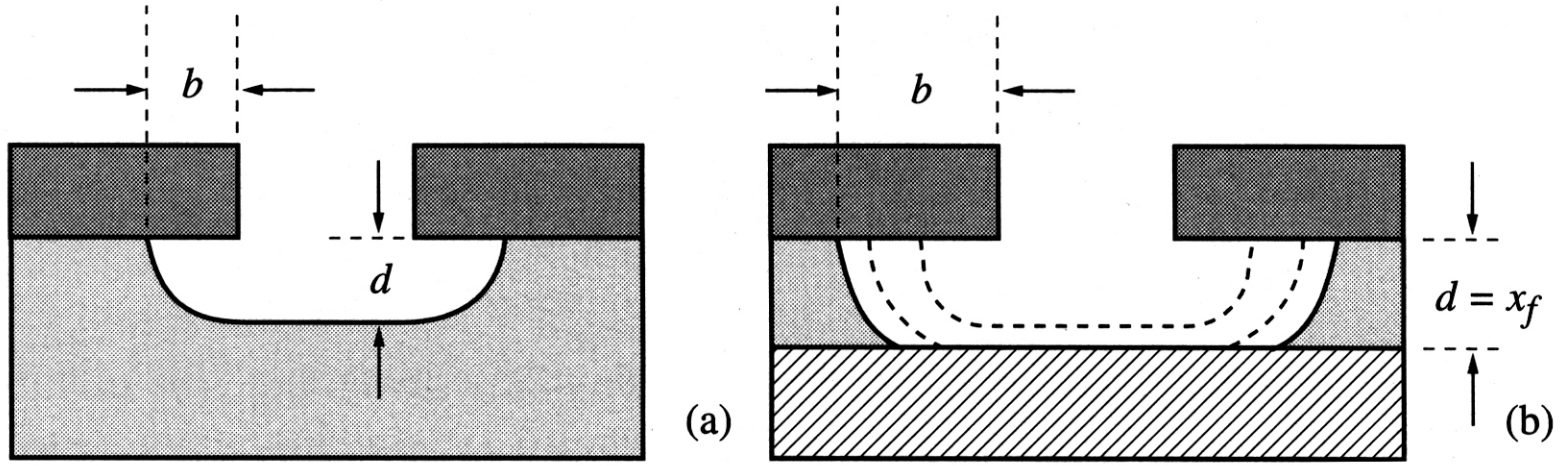


Figure 10–4 Illustration of etch bias and overetch. In (a) the etch bias, *b*, is shown for a given etch depth, *d*. In (b), overetching is illustrated where etching is continued even after the etch depth, *d*, equals the film thickness, x_f, with the result that the etch bias increases.

Example 1: Selectivity

矽基板表面上有1μm的SiO_2要蝕刻, 氧化膜的蝕刻速率是0.40μm/min, 氧化膜對矽的蝕刻選擇比爲25比1, 如果三分鐘後停止蝕刻, 試問會有多少下層的Si被蝕刻掉?

$$S = \frac{r_{SiO_2}}{r_{Si}} \Rightarrow 25 = \frac{0.4\mu m/\min}{r_{Si}}$$

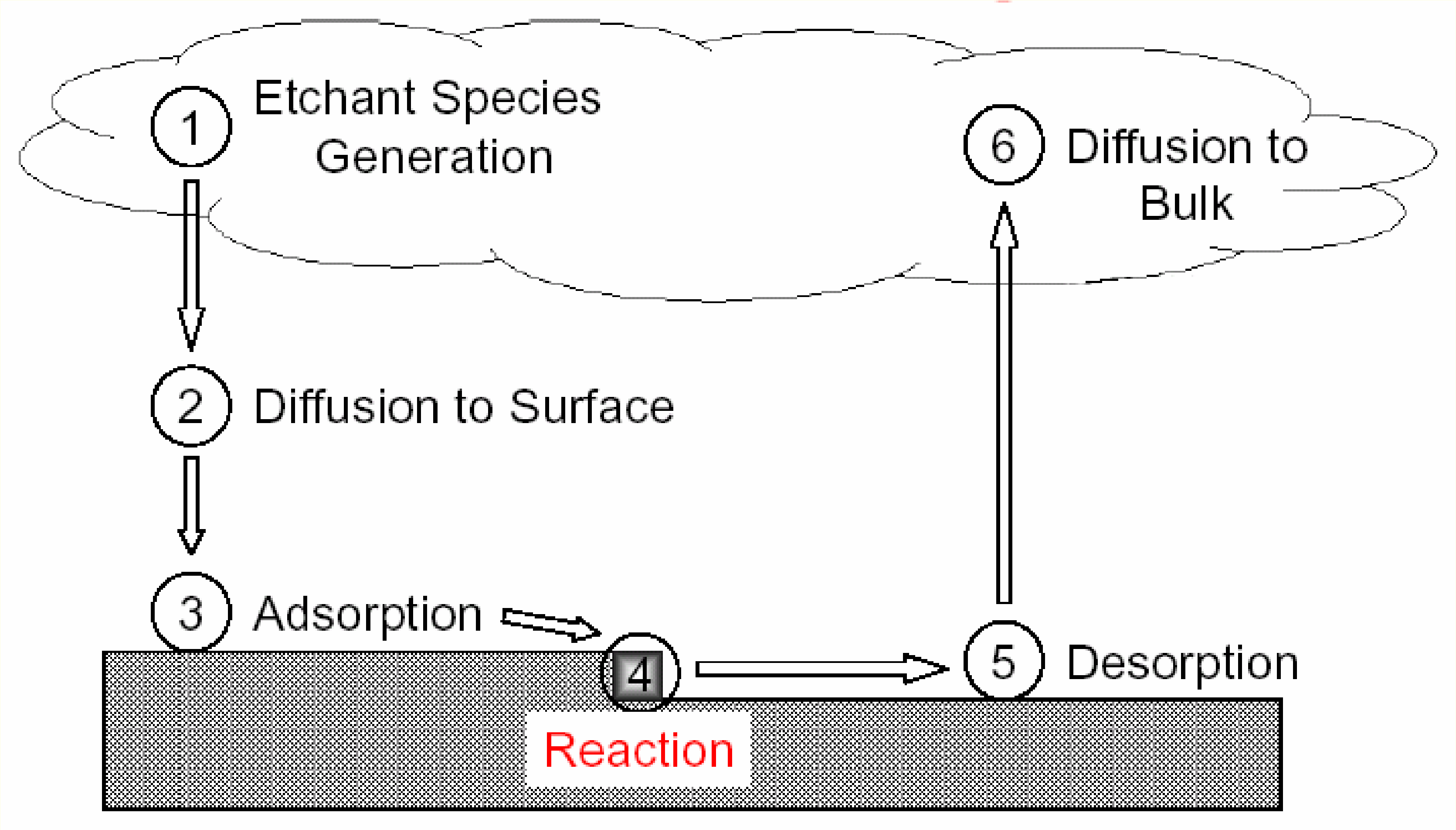
Etching rate of Si $\Rightarrow r_{Si} = 0.016\mu m/\min$

Etching 1μm of SiO_2 $\Rightarrow t_{SiO_2} = 1\mu m/(0.40\mu m/\min) = 2.5\min$

Over etching of Si $\Rightarrow thickness_{Si} = (0.016\mu m/\min)\times 0.5\min = \boxed{8nm}$

Etch process & Etch Rate

Mechanism of the Etching Process


① Etchant Species Generation

② Diffusion to Surface

③ Adsorption

④

Reaction

⑤ Desorption

⑥ Diffusion to Bulk

SLOWEST Dominates!!!

Slowest Step Dominates (What if each is slowest?)

- Etchant Species Generation
  - Etch rate will be slow
- Diffusion to Surface
  - Etch rate will be highly dependent on mixing but not temperature
  - Also dependent on layout and geometry
- Reaction
  - Etch will be highly dependent on temperature but not on mixing or layout and geometry
- Diffusion to Bulk
  - Etch rate will be highly dependent on mixing but not temperature
  - Also dependent on layout and geometry

Etch Rate Variation

Function of :

- Setup
- Material being etched
- Layout and structure

1. Etch Rate Variation (Due to Setup)

- Temperature
- Loss of reactive species
- Loss of liquids to evaporation
- Mixing
- Etch-product blocking of chemical flow
- Applied potential
- Illumination
- Contamination

2. Etch Rate Variation (Due to Material Being Etched)

- Impurities in or on the materials
- Microstructure
- Film Stress

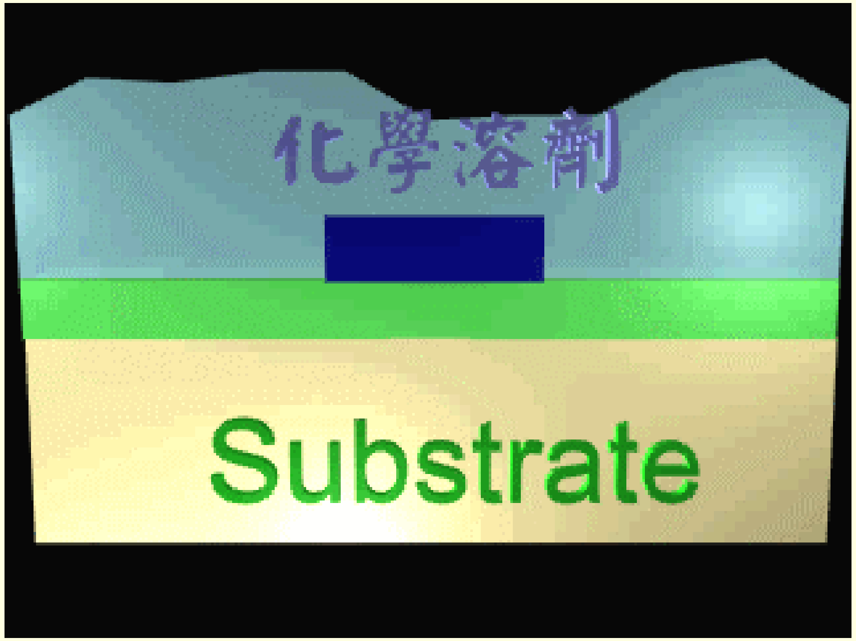
3. Etch Rate Variation (Due to Layout or Structure)

- Distribution and fraction of surface area of the exposed target layout (loading effect)
- Structure geometry

Wet Etching
(濕式蝕刻)

濕式蝕刻法(Wet Etching)

濕式蝕刻法利用化學溶液腐蝕晶圓上擬去除的材料，並在完成蝕刻反應後，由溶液帶走腐蝕物。這種完全利用化學反應的方法來進行蝕刻的技術有其先天上的缺點，也就是其蝕刻結構的形狀是各方向均勻的，這樣會造成嚴重的側向腐蝕現象，顯著地限制了元件尺寸向微細化的發展。



Wet Etching (濕式蝕刻)

- Mixtures of acids, bases, and water
  - HF, HPO_3, H_2SO_4, KOH, H_2O_2, HCL, ..
  - 10:1, 5:1, or maximum (solubility limit)
- Can be used to etch many materials
  - Si, SiO_2, Si_3N_4, PR, Al, Au, Cu, ….
- Etch Rate:
  - Wide range
- Etch Selectivity:
  - Typically quite high
  - Sensitive to contamination
- Etch Geometry:
  - Typically isotropic
  - Some special cases are anisotropic

Isotropic Etching

- Etch at equal rates in all directions
  - Rounds sharp edges or corners
  - Removes roughness and damaged surfaces
- Amorphous and polycrystalline Films
  - Always
- Single Crystal Materials
  - Possible

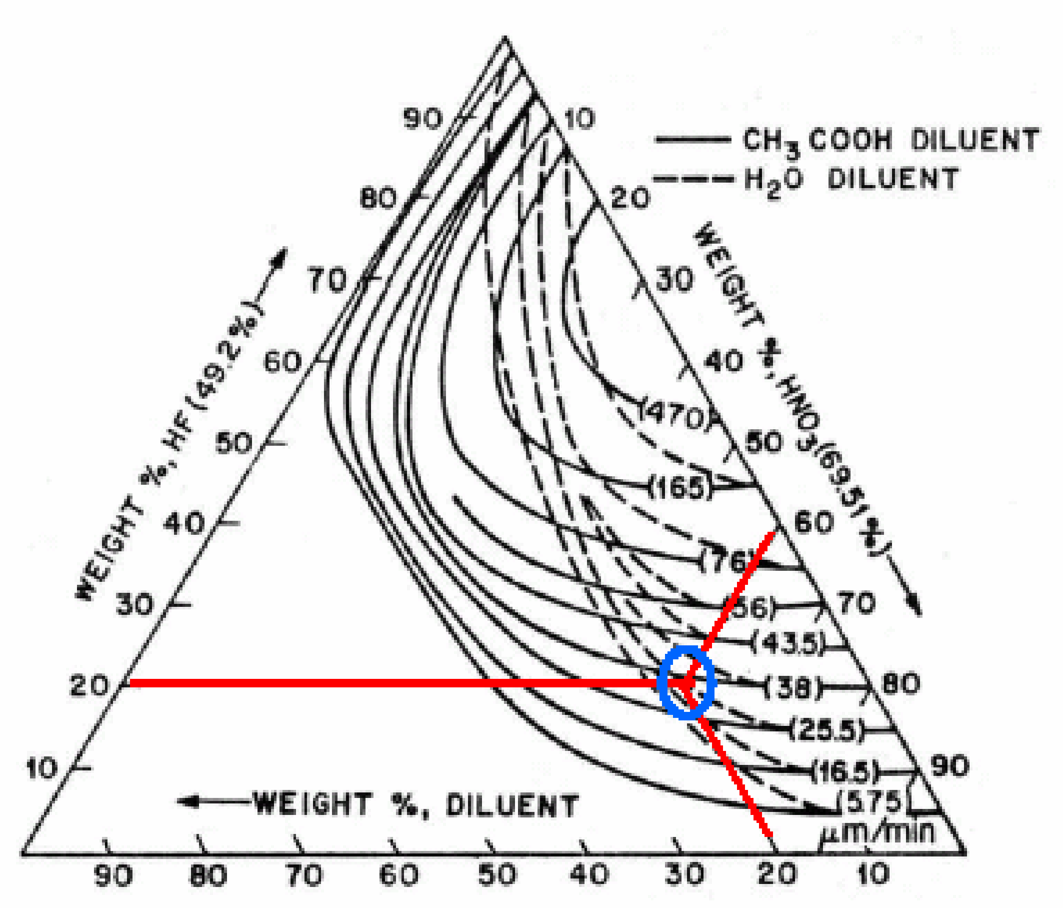
Isotropic Wet Etching – HF for SiO_2 Etch

- Selective (room temperature)
  - Etches SiO_2, but not Si
  - Also attack Al, Si_3N_4
- Rate depends strongly on concentration
  - Maximum: 40% HF ~ <u>2μm/min</u>
  - Controlled: 5 to 50:1 ~ <0.1μm/min (Note: different with BOE)
- Dangerous
  - Not a strong acid, but penetrates skin
  - Will target bones, and attacks slowly
- Etch Geometry:
  - Completely isotropic

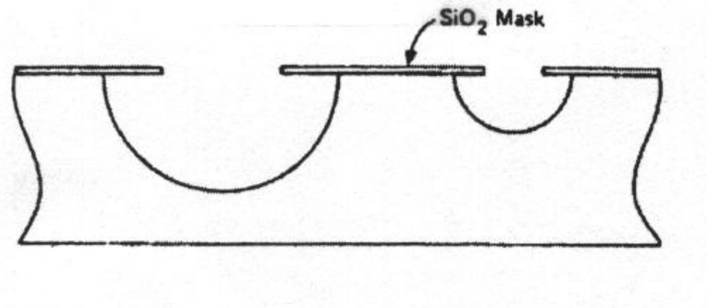
Isotropic Wet Etching – HNA for Si Etch

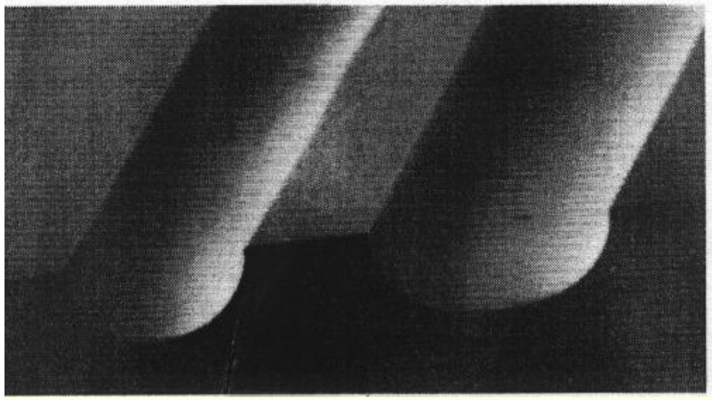
- Mixture of nitric (HNO_3) and hydrofluoric (HF) acids
- Si etch rate can be up to 50 μm/min
- HNO_3 oxidizes Si, removes SiO_2, repeat…
- High HF, but Low HNO_3 : etching limit by oxide formation => rough surface
- Low HF, but High HNO_3 : etching limit by oxide removal => smooth surface
- Dilute with water or acetic acid (CH_3COOH)
  - Acetic acid is preferred because it prevents HNO_3 disassociation

Isotropic Wet Etching – HNA for Si Etch



CH$_3$COOH or H$_2$O





Isotropic Wet Etching – Phosphoric Acid for Si_3N_4 Etch

- Selective (room temperature)
    - Etches Si_3N_4, but not Si or SiO_2
    - Also attack Al
- Rate is slow
    - H_3PO_4 at 160°C ~ 0.005μm/min
- Tough masking material needed
    - PR will not survive
    - Oxide is typically used
- Etch Geometry:
    - Completely isotropic

Isotropic Wet Etching – Masking materials

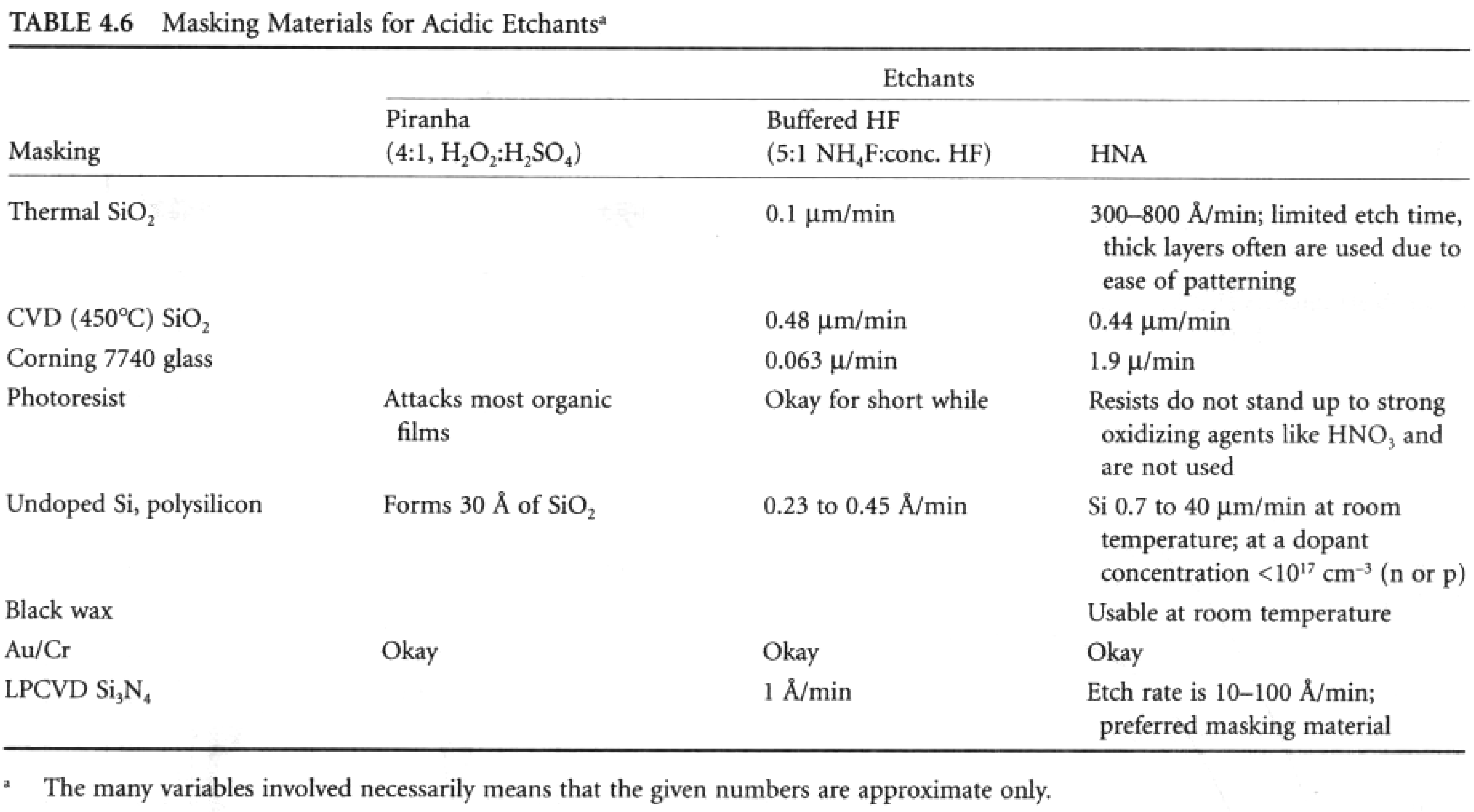


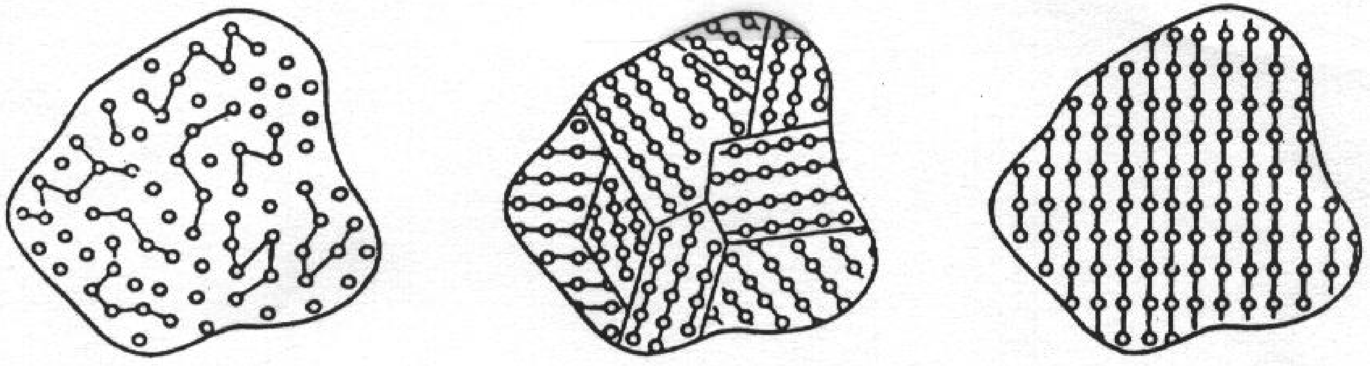
TABLE 4.6 Masking Materials for Acidic Etchants[a]

	Etchants		
Masking	Piranha (4:1, H_2O_2:H_2SO_4)	Buffered HF (5:1 NH_4F:conc. HF)	HNA
Thermal SiO_2		0.1 µm/min	300–800 Å/min; limited etch time, thick layers often are used due to ease of patterning
CVD (450°C) SiO_2		0.48 µm/min	0.44 µm/min
Corning 7740 glass		0.063 µ/min	1.9 µ/min
Photoresist	Attacks most organic films	Okay for short while	Resists do not stand up to strong oxidizing agents like HNO_3 and are not used
Undoped Si, polysilicon	Forms 30 Å of SiO_2	0.23 to 0.45 Å/min	Si 0.7 to 40 µm/min at room temperature; at a dopant concentration $<10^{17}$ cm^{-3} (n or p)
Black wax			Usable at room temperature
Au/Cr	Okay	Okay	Okay
LPCVD Si_3N_4		1 Å/min	Etch rate is 10–100 Å/min; preferred masking material

[a] The many variables involved necessarily means that the given numbers are approximate only.

Anisotropic Etching

Silicon Crystal Orientation



(a) Amorphous

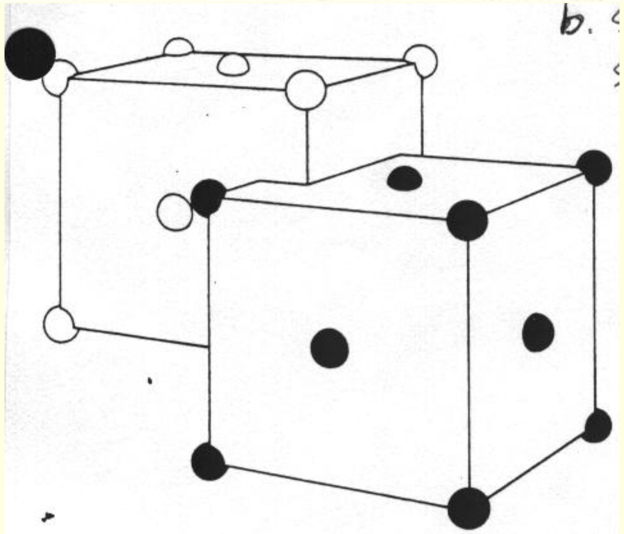
No recognizable long-range order

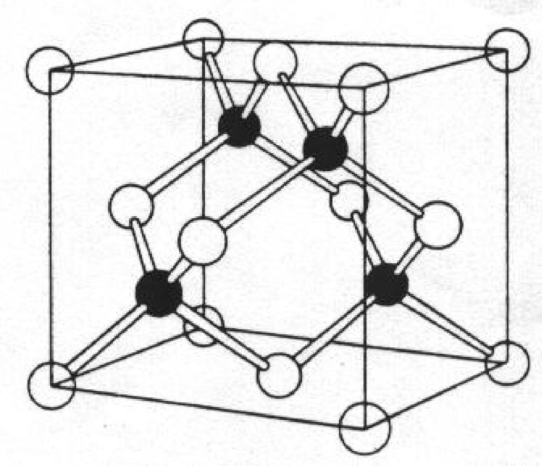
(b) Polycrystalline

Completely ordered in segments

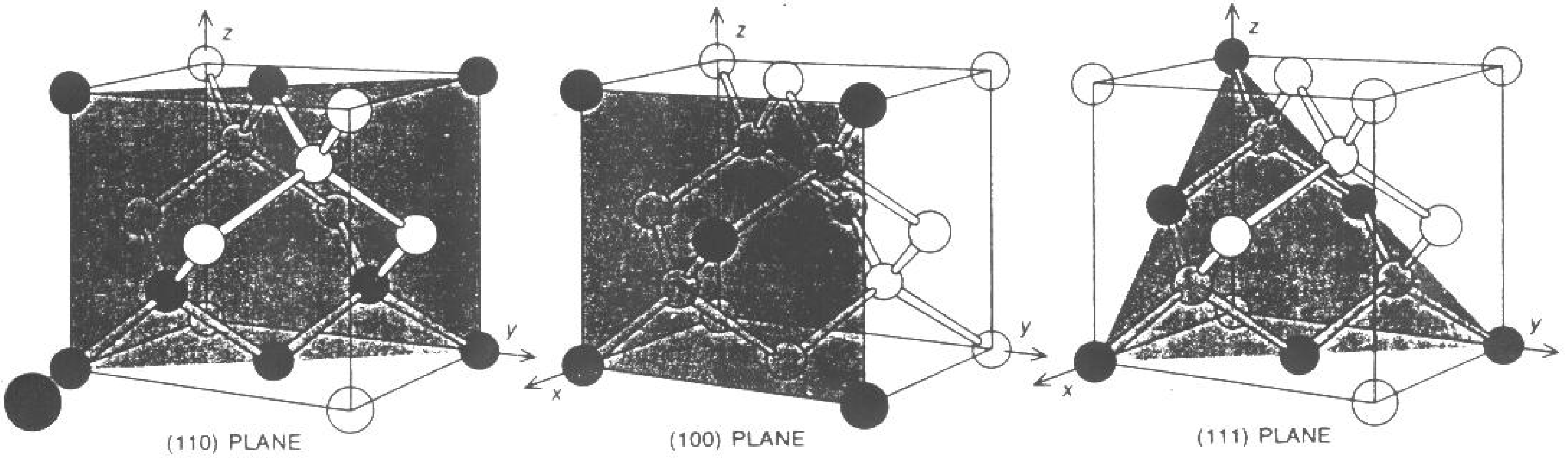
(c) Crystalline

Entire solid is made up of atoms in an orderly array



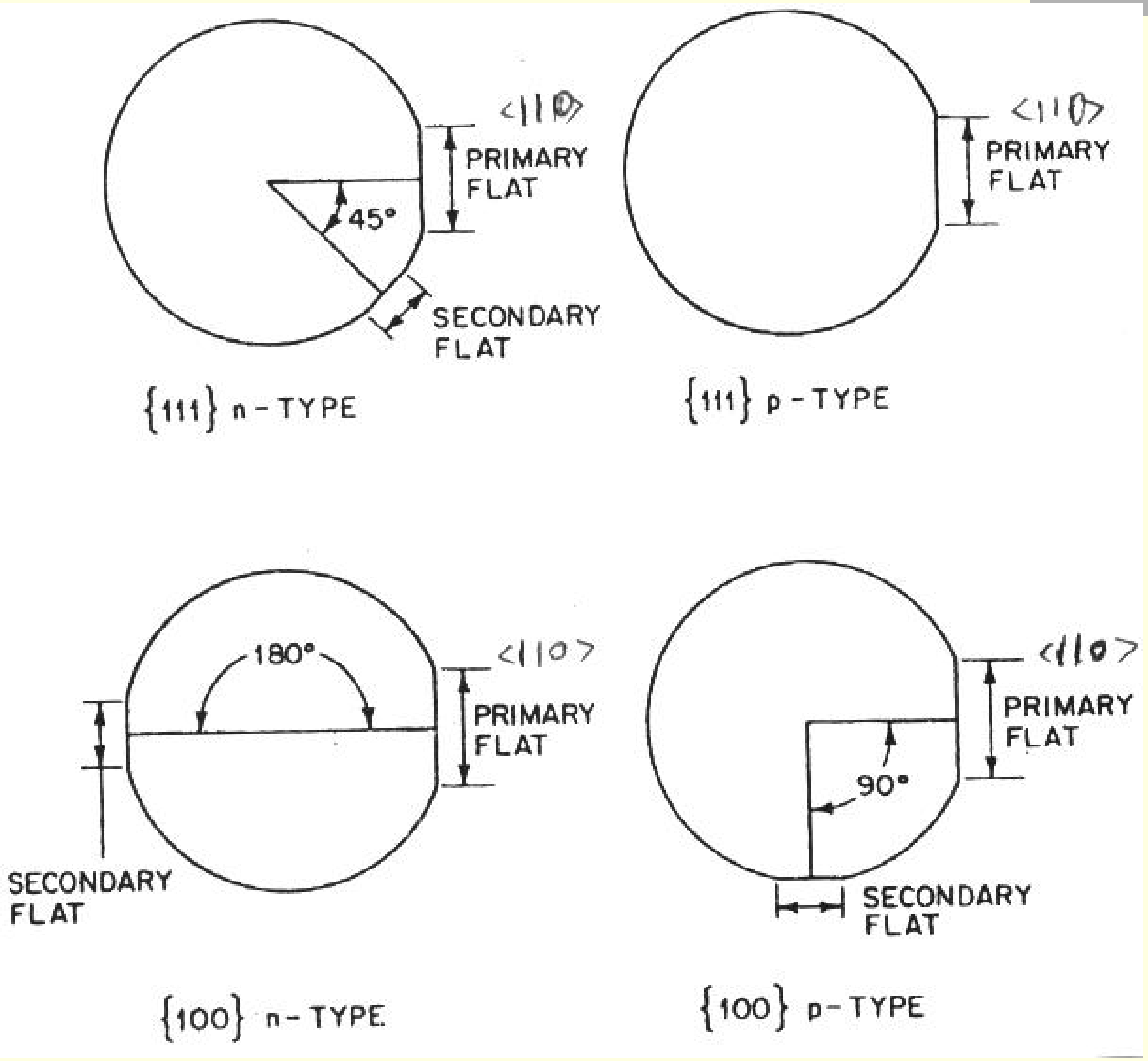


Miller Index



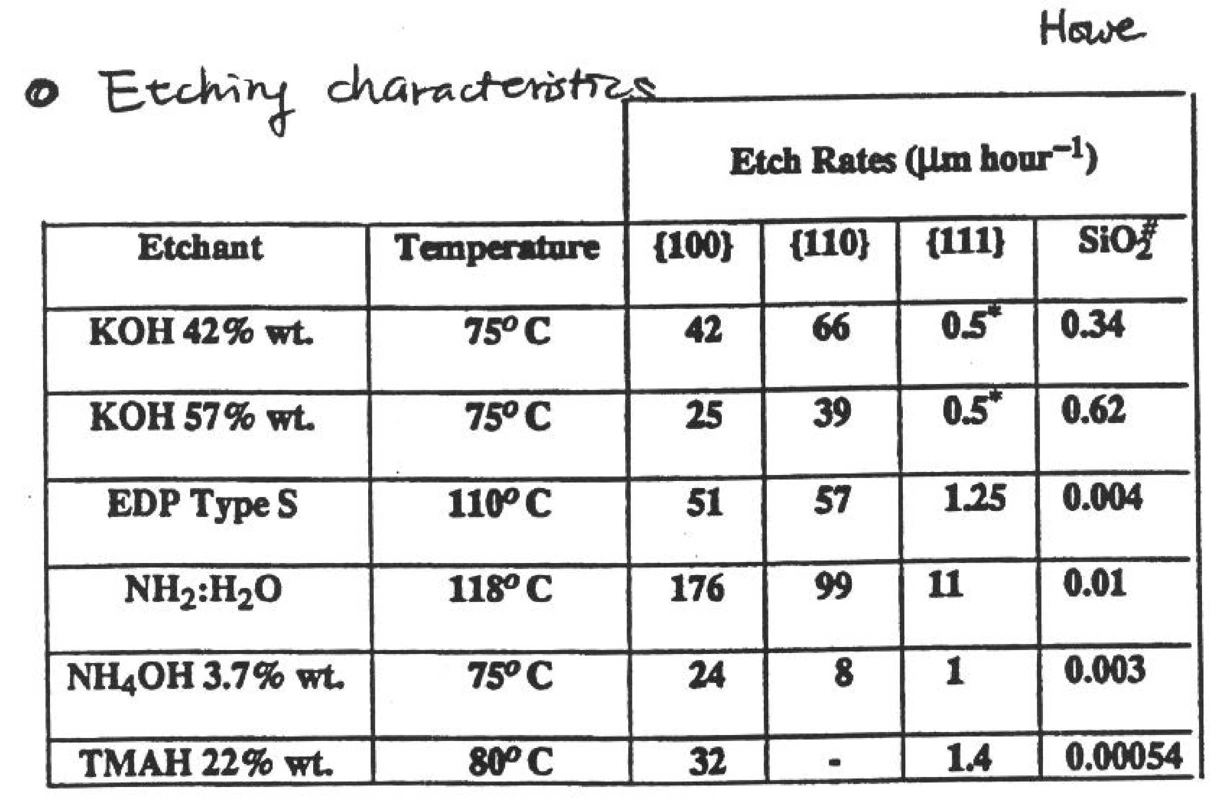
- Indices determined by
  - 1 / intercept of the vector from origin
    - Within unit cell
    - Direction [1/x, 1/y, 1/z]
    - Normal to plane ( ), { }

Wafer Flat



<110>
PRIMARY FLAT
45°
SECONDARY FLAT
{111} n-TYPE
<110>
PRIMARY FLAT
{111} p-TYPE
180°
<110>
PRIMARY FLAT
SECONDARY FLAT
{100} n-TYPE
<110>
PRIMARY FLAT
90°
SECONDARY FLAT
{100} p-TYPE

Anisotropic Wet Etching (on <100> wafer)



Howe

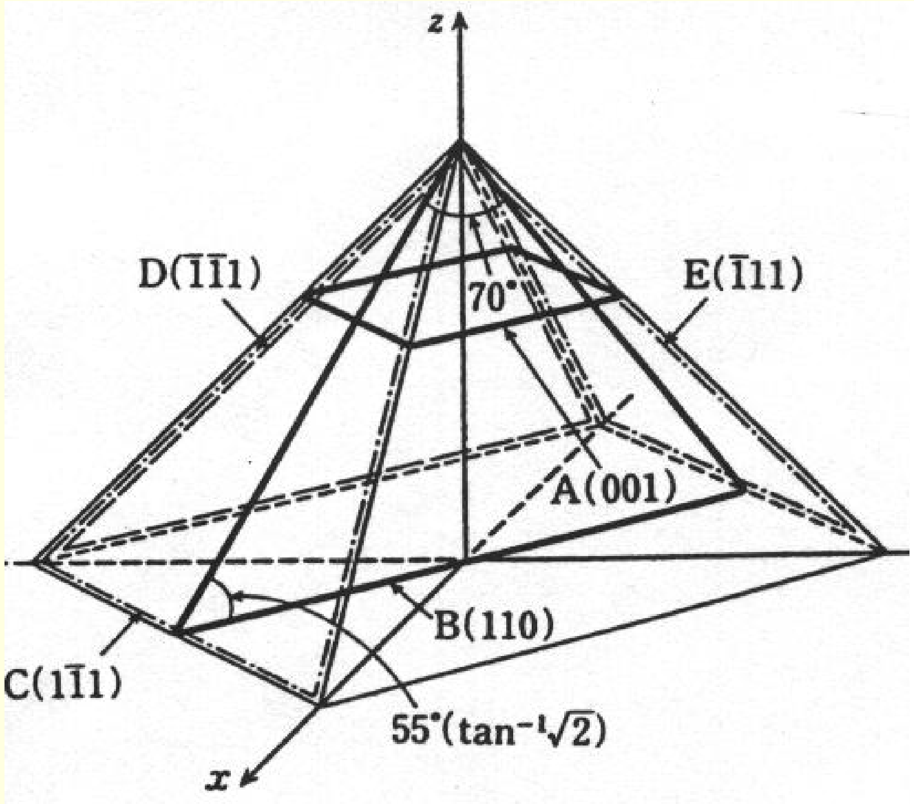
- Etching characteristics

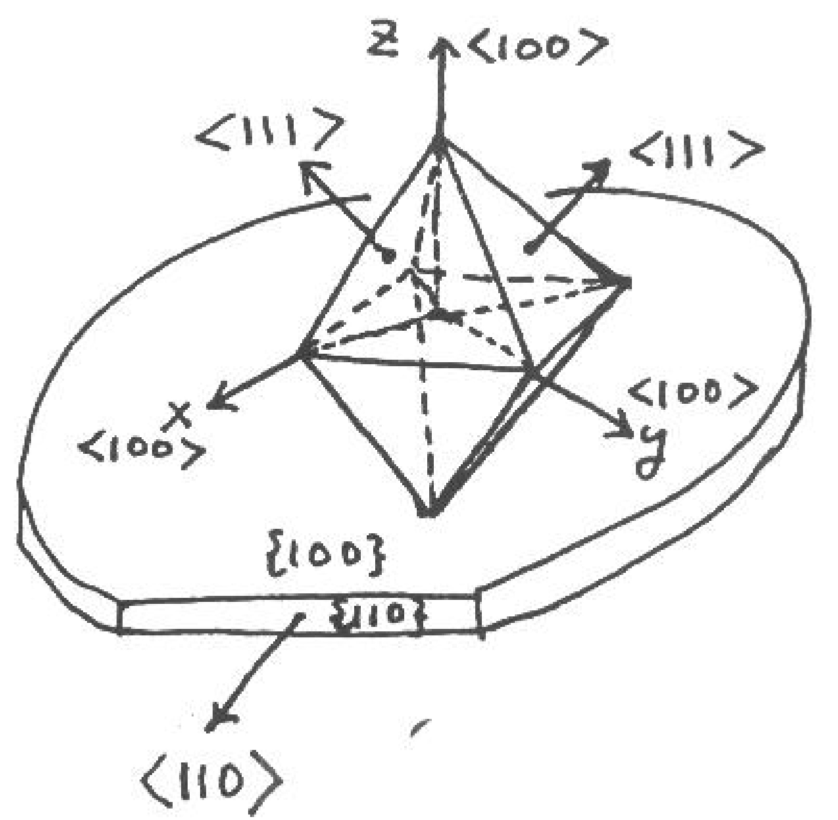
Etchant	Temperature	Etch Rates ($\mu m\ hour^{-1}$)			
		{100}	{110}	{111}	$SiO_2^{\#}$
KOH 42% wt.	75° C	42	66	0.5*	0.34
KOH 57% wt.	75° C	25	39	0.5*	0.62
EDP Type S	110° C	51	57	1.25	0.004
$NH_2:H_2O$	118° C	176	99	11	0.01
NH_4OH 3.7% wt.	75° C	24	8	1	0.003
TMAH 22% wt.	80° C	32	-	1.4	0.00054

Concentration ↑ : etching rate ↓ selectivity ↑ surface roughness ↓

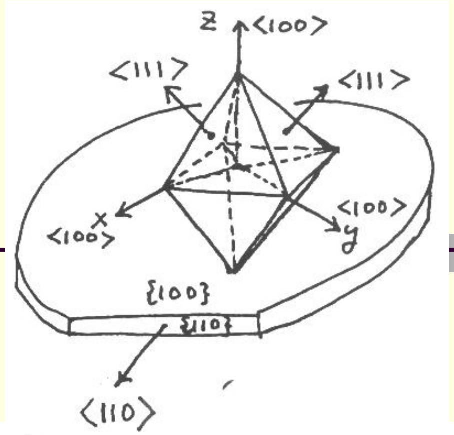
Temperature ↑ : etching rate ↑ selectivity ↓ surface roughness ↑

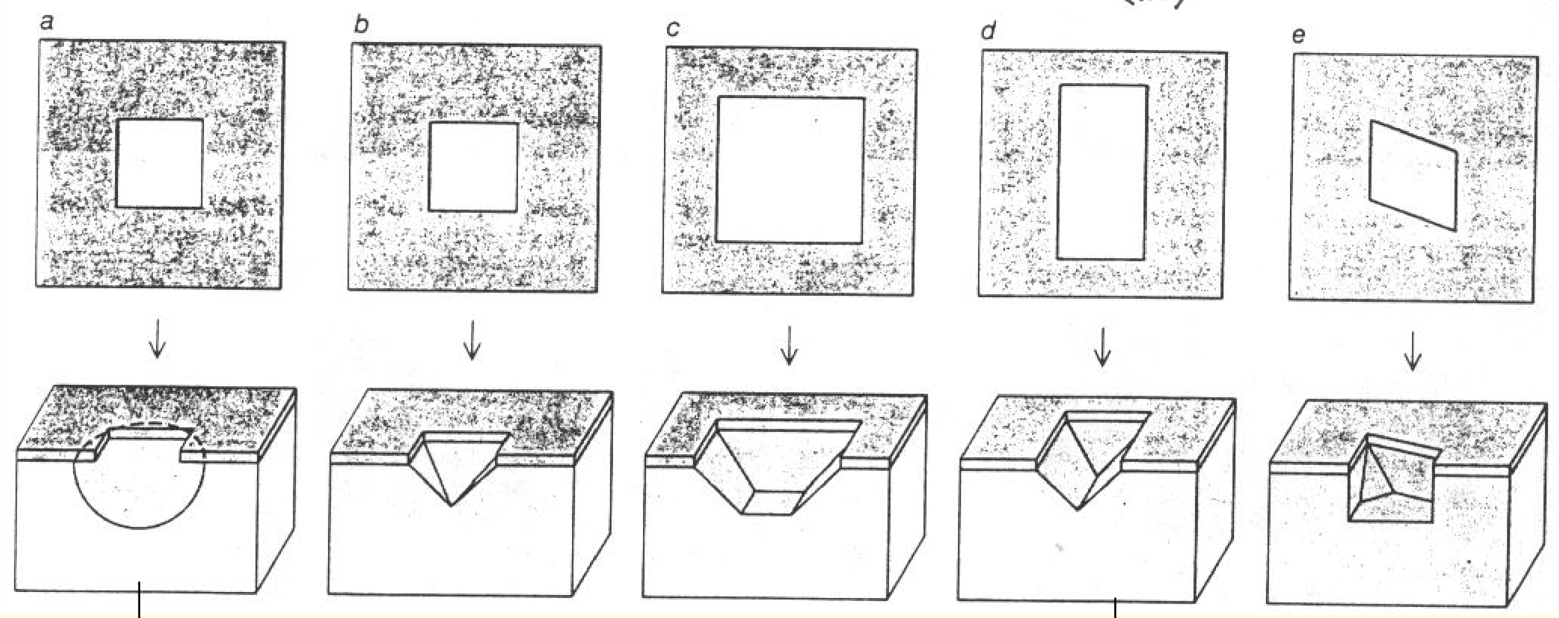
Anisotropic wet etching (on <100> wafer)





Comparison





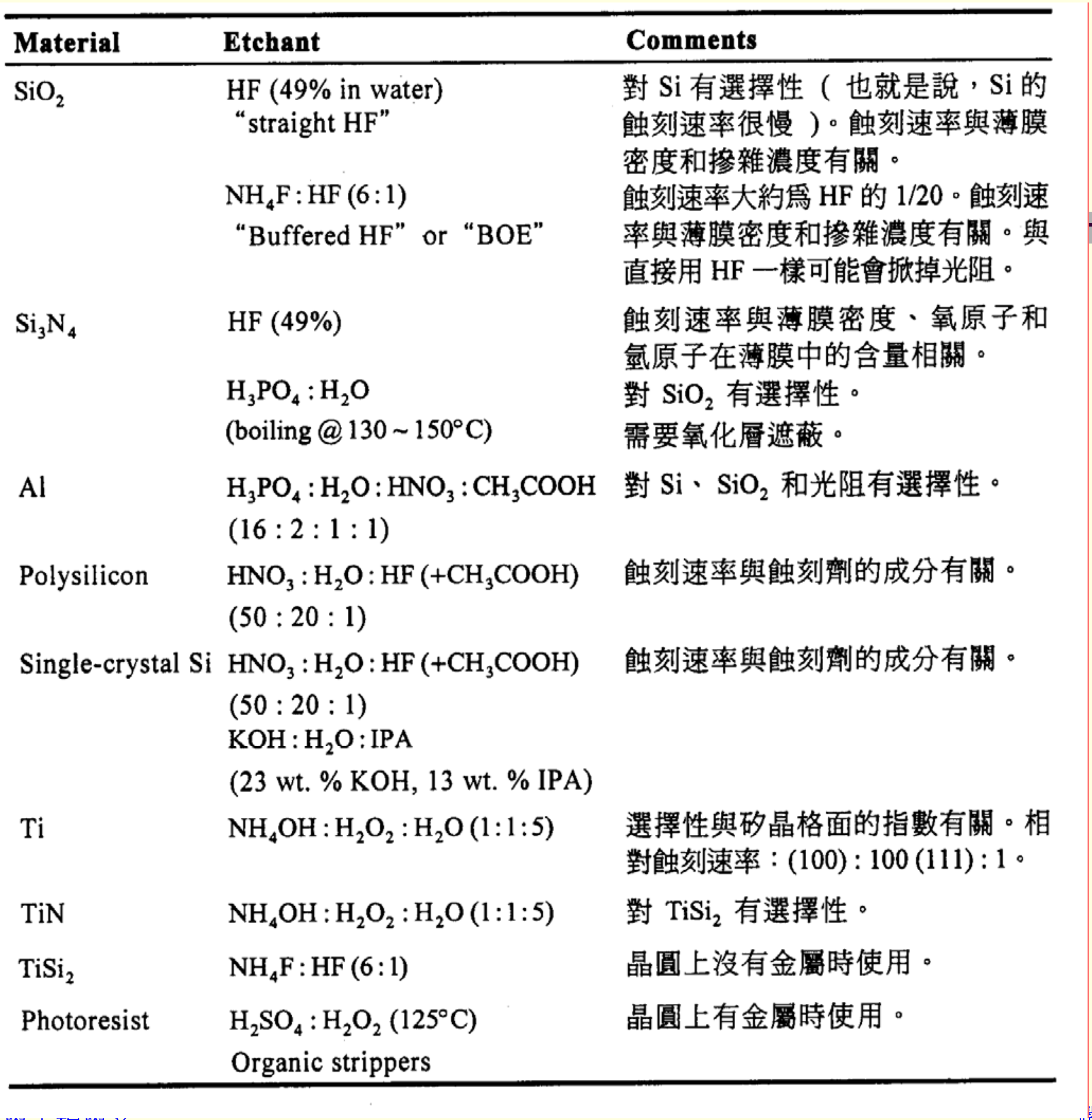
(100) wafer

(100) wafer
<110> direction

<110>

濕式蝕刻工作台(Wet Bench)

- 儀器功能：
  - 晶片（矽或III-V）之RCA清洗（含每個清洗步驟，如煮酸、蝕刻、沖水等項）
- 重要規格：
  - 有機清洗1台
  - 無機清洗1台
  - 石英管清洗1台
  - 晶片旋乾機（3"、4"）各1台
  - 注水鵝頸龍頭、DI水槍、氮氣槍、煮酸加墊板

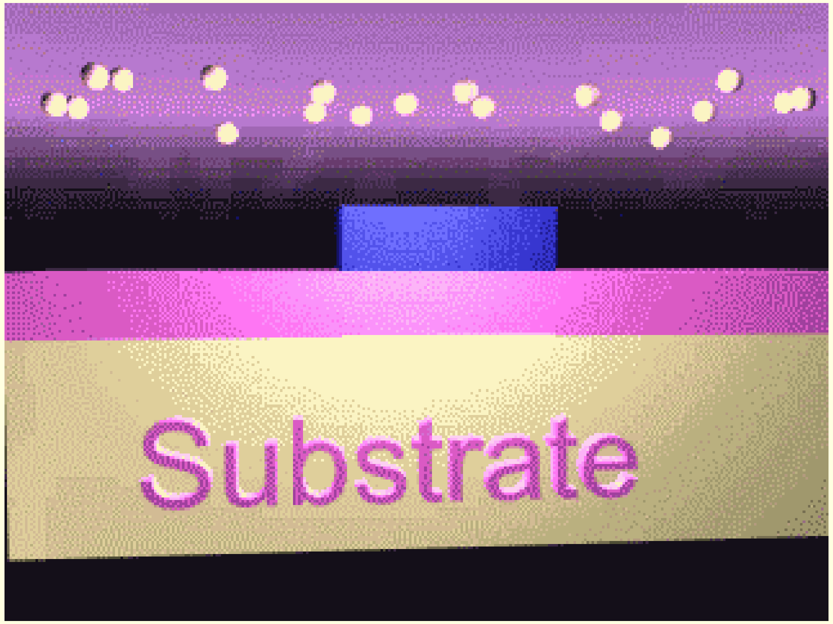


Material	Etchant	Comments
SiO_2	HF (49% in water) "straight HF"	對 Si 有選擇性（也就是說，Si 的蝕刻速率很慢）。蝕刻速率與薄膜密度和摻雜濃度有關。
	$NH_4F:HF$ (6:1) "Buffered HF" or "BOE"	蝕刻速率大約爲 HF 的 1/20。蝕刻速率與薄膜密度和摻雜濃度有關。與直接用 HF 一樣可能會掀掉光阻。
Si_3N_4	HF (49%)	蝕刻速率與薄膜密度、氧原子和氫原子在薄膜中的含量相關。
	$H_3PO_4:H_2O$ (boiling @ 130 ~ 150°C)	對 SiO_2 有選擇性。 需要氧化層遮蔽。
Al	$H_3PO_4:H_2O:HNO_3:CH_3COOH$ (16 : 2 : 1 : 1)	對 Si、SiO_2 和光阻有選擇性。
Polysilicon	$HNO_3:H_2O:HF$ ($+CH_3COOH$) (50 : 20 : 1)	蝕刻速率與蝕刻劑的成分有關。
Single-crystal Si	$HNO_3:H_2O:HF$ ($+CH_3COOH$) (50 : 20 : 1) $KOH:H_2O:IPA$ (23 wt. % KOH, 13 wt. % IPA)	蝕刻速率與蝕刻劑的成分有關。
Ti	$NH_4OH:H_2O_2:H_2O$ (1:1:5)	選擇性與矽晶格面的指數有關。相對蝕刻速率：(100) : 100 (111) : 1。
TiN	$NH_4OH:H_2O_2:H_2O$ (1:1:5)	對 $TiSi_2$ 有選擇性。
$TiSi_2$	$NH_4F:HF$ (6:1)	晶圓上沒有金屬時使用。
Photoresist	$H_2SO_4:H_2O_2$ (125°C) Organic strippers	晶圓上有金屬時使用。

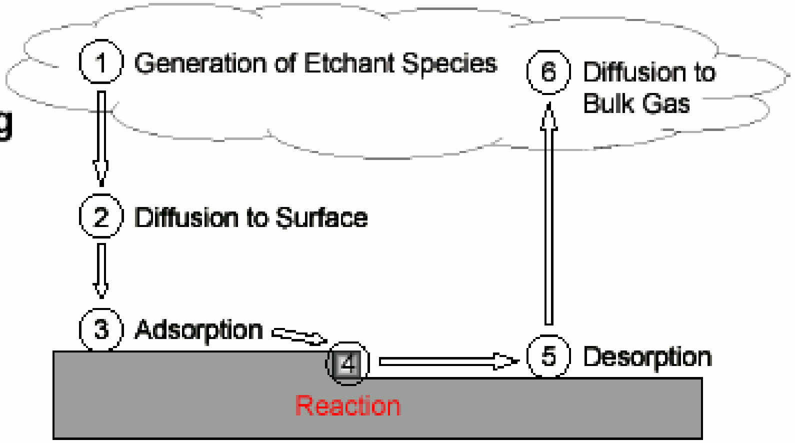
Dry Etching(乾式蝕刻)

乾式蝕刻(Dry etching)

- 乾式蝕刻法是利用氣體分子或其產生的離子及自由基，對晶圓上的材質進行物理式撞擊濺蝕及化學反應，來移除蝕刻部份。被蝕刻的物質變成揮發性的氣體，經抽氣系統抽離。以活性離子蝕刻爲例，就是利用電漿放電方式進行異向性蝕刻的方法。
- 在電漿的環境中，含有大量的活性自由基（reactive radical，爲中性的原子或分子物）及帶電荷離子，可以和被蝕刻物進行化學腐蝕反應，而正離子在蝕刻物表面產生垂直撞擊的效果，可以加速蝕刻物垂直方向蝕刻率，而得到異向蝕刻的結果。
- 氣態式及電漿式(現多採用)



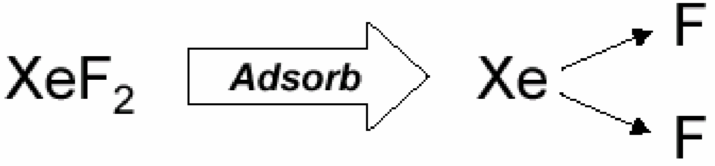
Mechanism of the Etching Process



- **Generation of Etching Species**
  - Without generating the etching species we cannot have etching
- **Diffusion to Surface**
  - etching species must get to surface to react or etch
  - the mechanics of getting to the surface can limit aspect ratio, undercutting, and uniformity
- **Adsorption and Surface Diffusion**
  - can also effect aspect ration (isotropic or anisotropic)
- **Reaction**
  - strong function of temperature (Arrhenius relationship)
  - obviously effect etch rate
- **Desorption**
  - can stop etch if the reacted species is not volatile
- **Diffusion to Bulk Gas**
  - can lead to non-uniform etching due to dilution of un-reacted etching species

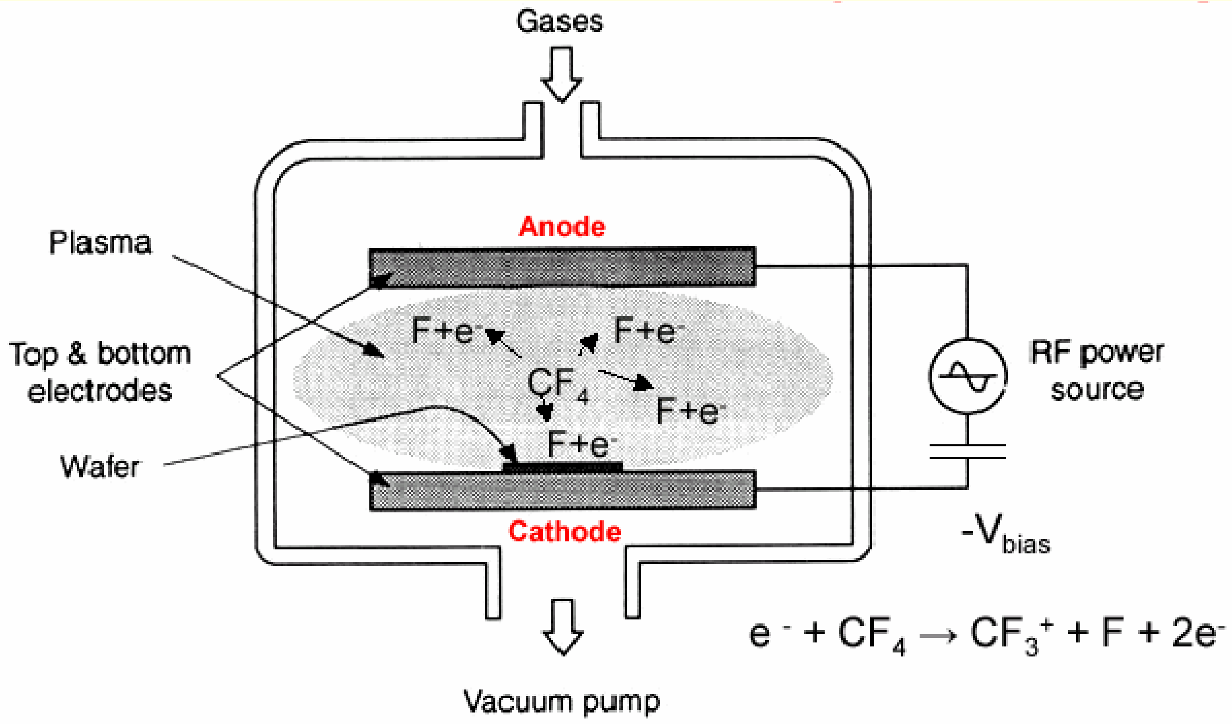
Gas Phase Dry Etching

- **Reactive Gas**
  - **gas adsorbs on the surface, disassociates, and then *reacts***



- **Particular features of XeF_2 etching**
  - **extremely selective**
  - **fast etch rate**
  - **Isotropic**

RF Plasma-Based Dry Etching

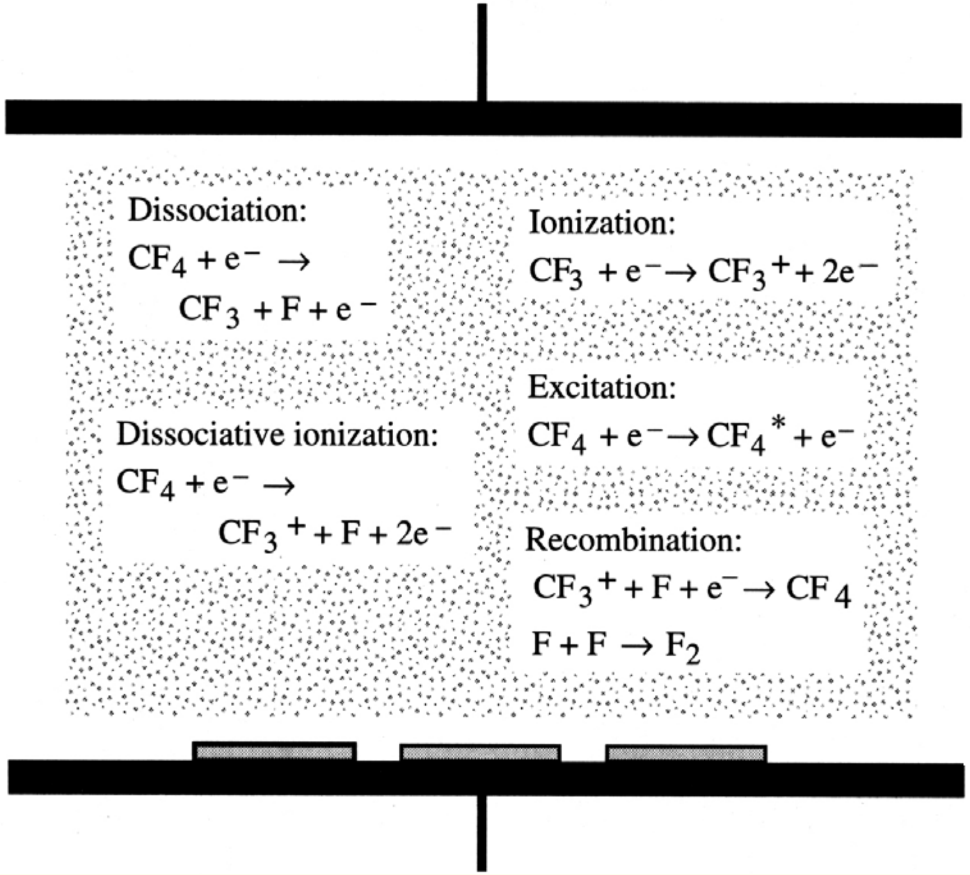


$$e^- + CF_4 \rightarrow CF_3^+ + F + 2e^-$$

RF: Frequencies (typically 13.56 MHz)

- **Electrons oscillating in the glow region <u>acquire enough energy to cause *ionization*</u>**
- **Gas ions are *too massive to respond* to the high-frequency field**

Plasma Etching Mechanism



Dissociation:

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

Dissociative ionization:

$CF_4 + e^- \rightarrow CF_3^+ + F + 2e^-$

Ionization:

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

Excitation:

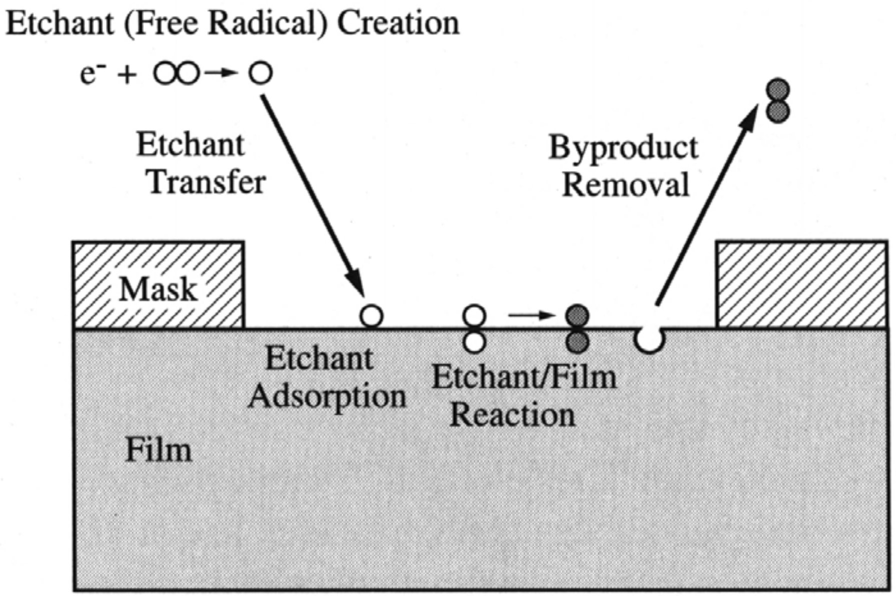
$CF_4 + e^- \rightarrow CF_4^* + e^-$

Recombination:

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

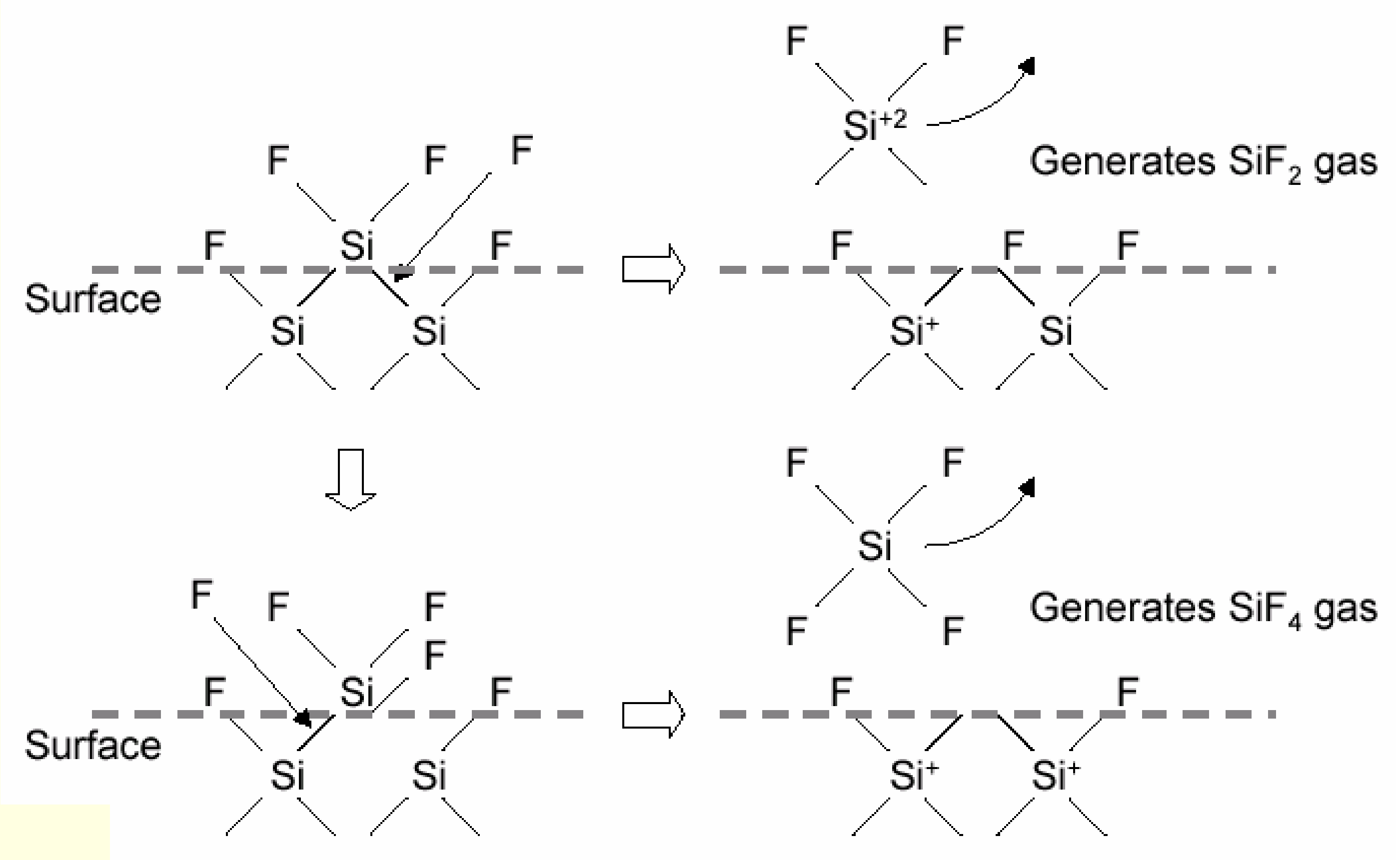
$F + F \rightarrow F_2$

Typical reactions and species present in a plasma used for plasma etching

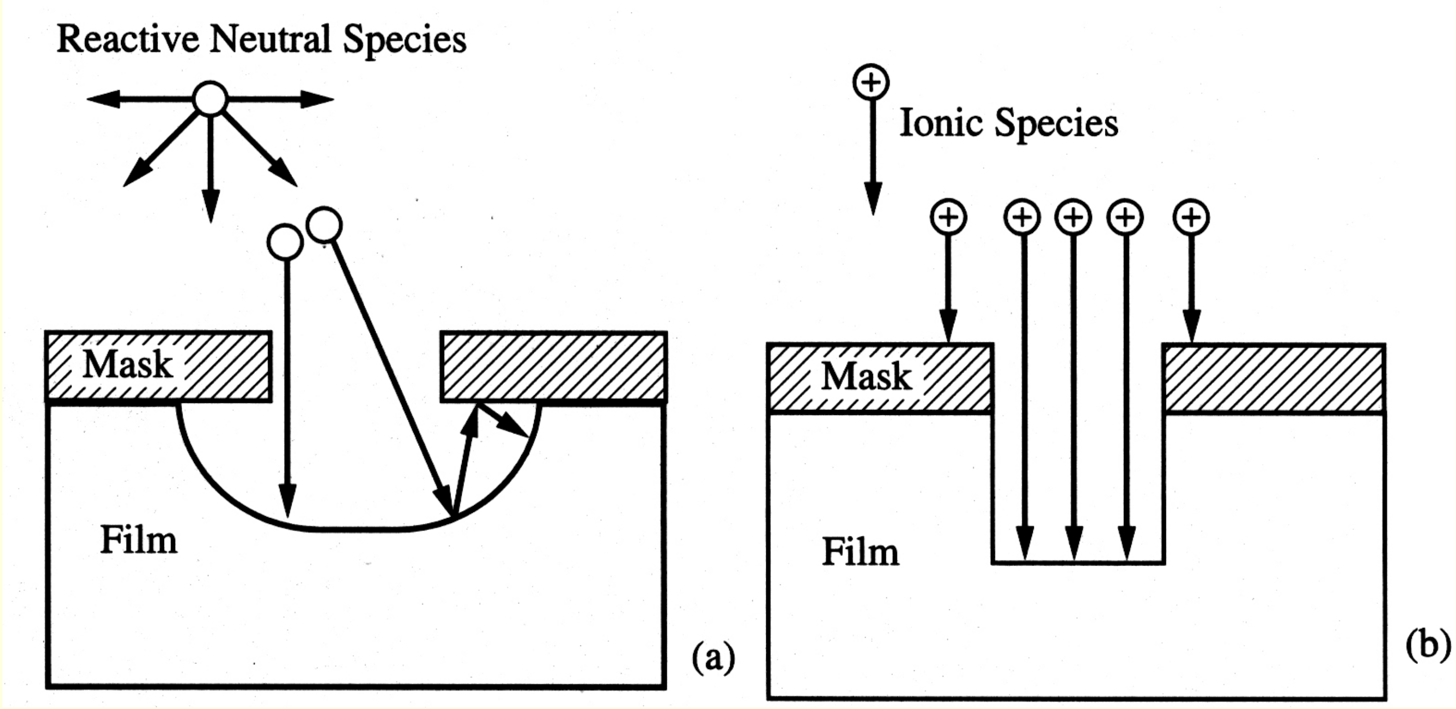


Processes involved in chemical etching during plasma etch process

Etching of a Silicon Surface



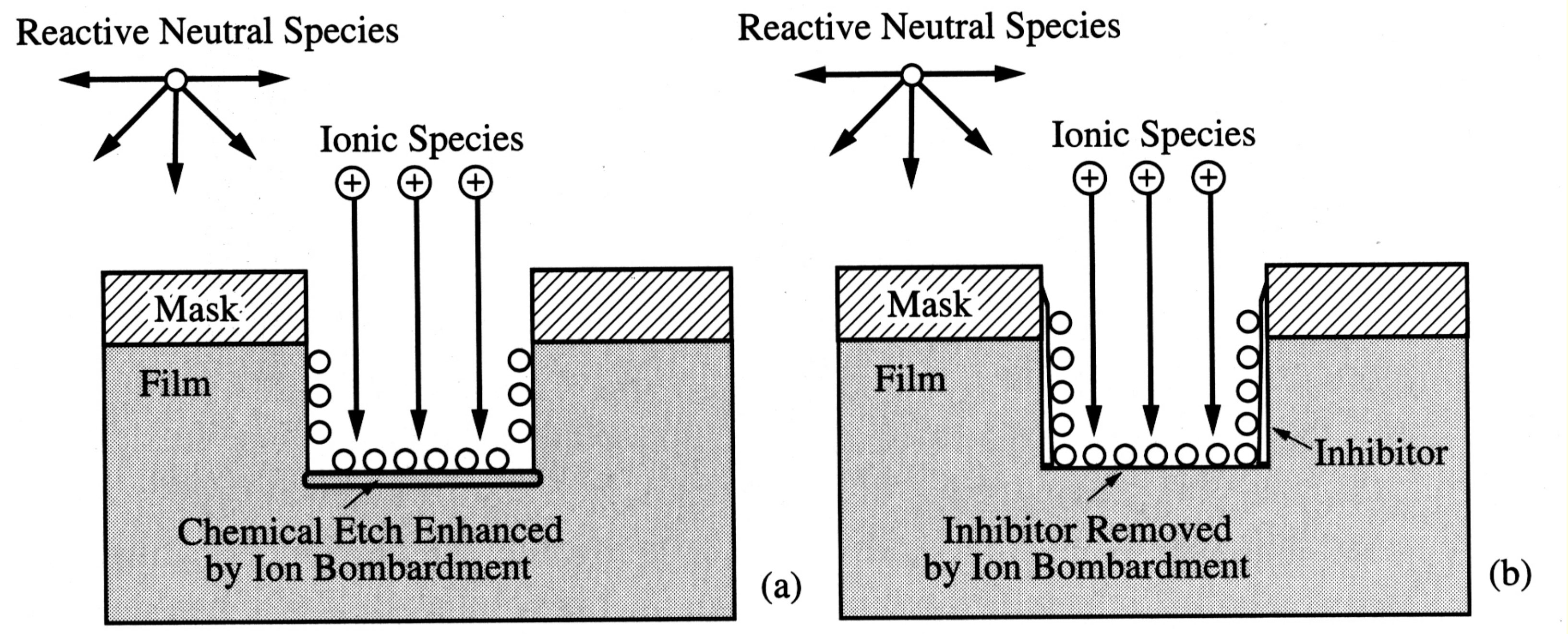
Fluxes of Species in Plasma Etching



(a) Fluxes of reactive neutral chemical species (such as free radicals), with a wide arrival angle distribution and low sticking coefficient

(b) Fluxes of ionic species, with a narrow, vertical arrival angle distribution and high sticking coefficient

Ion-Enhanced Etching

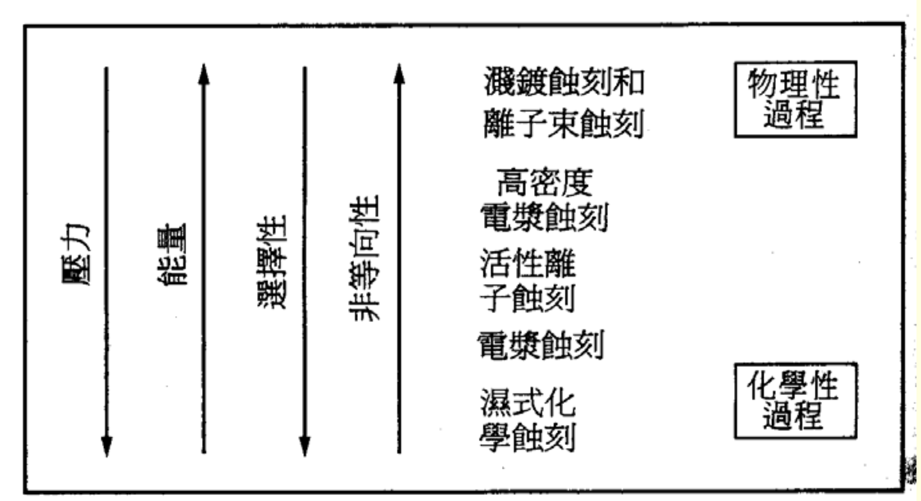


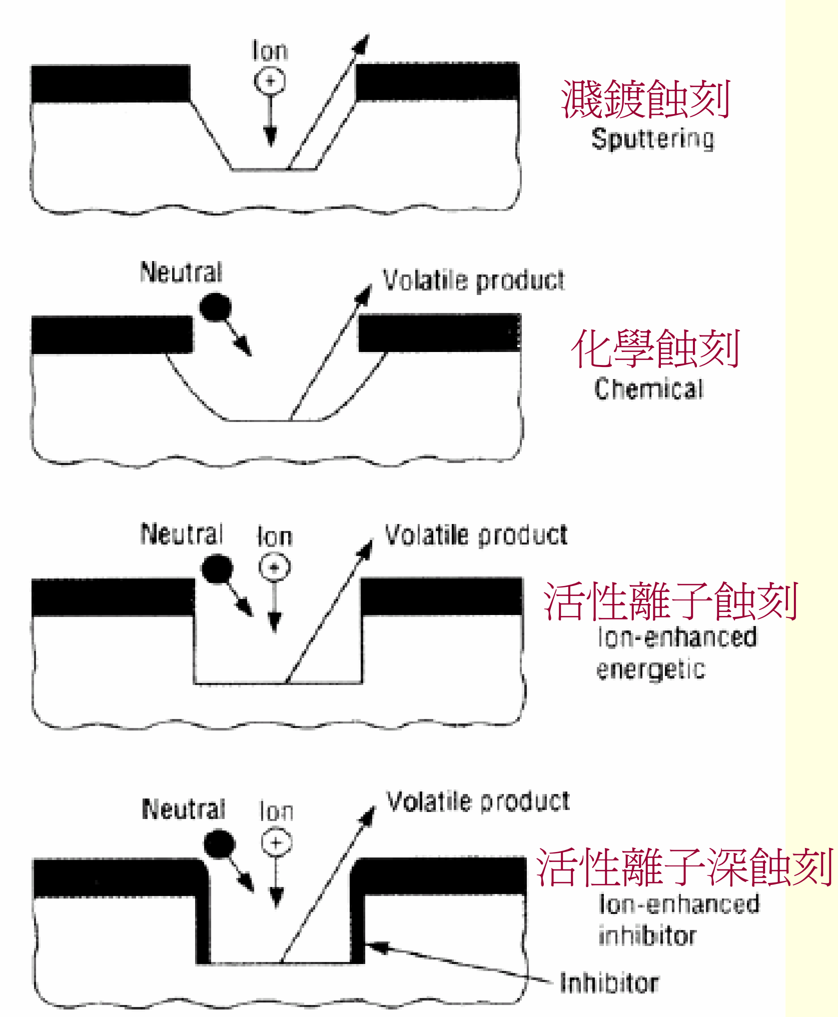
(a) The chemical etch reaction is enhanced by ion bombardment (RIE)

(b) An inhibitor is formed which is removed by ion bombardment, allowing chemical etching to proceed (Deep RIE)

Types of Dry Etching Processes

- Cross Section Depends On:
  - Energy
  - Pressure (mean free path)
  - Bias
  - Directionality
  - Crystal orientation





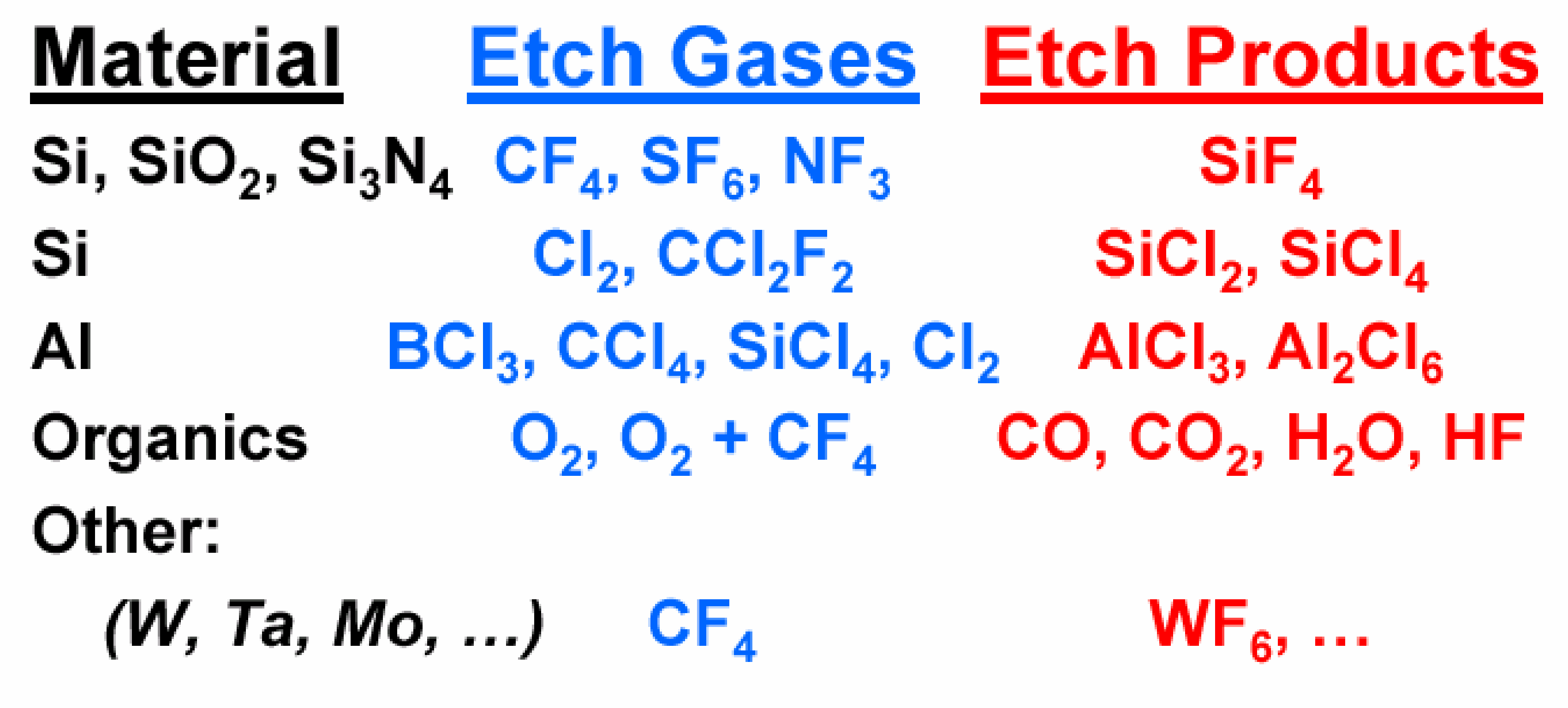
Types of Dry Etching Processes

Type of Etching	Excitation Energy	Pressure
Gas/Vapor Etching *- isotropic, chemical, very selective*	none	high (760-1 torr)
Plasma Etching *- isotropic, chemical, selective*	10's to 100's of Watts	Medium (>100 torr)
Reactive Ion Etching *- directional, physical & chemical, fairly selective*	100's of Watts	Low (10-100 mtorr)
Sputter Etching *- directional, physical, low selectivity*	100's to 1000's of Watts	Low (~10 mtorr)

Dry Etching Control Parameters

- **Etchant Species Generation**
  - gas selection
  - flow rate and pumping speed (pressure)
  - excitation power and frequency
- **Etchant Interaction with Surface**
  - geometrical factors (structure being etched)
  - temperature of surface
  - potential of surface
  - nature of surface (chemical, stress, …)

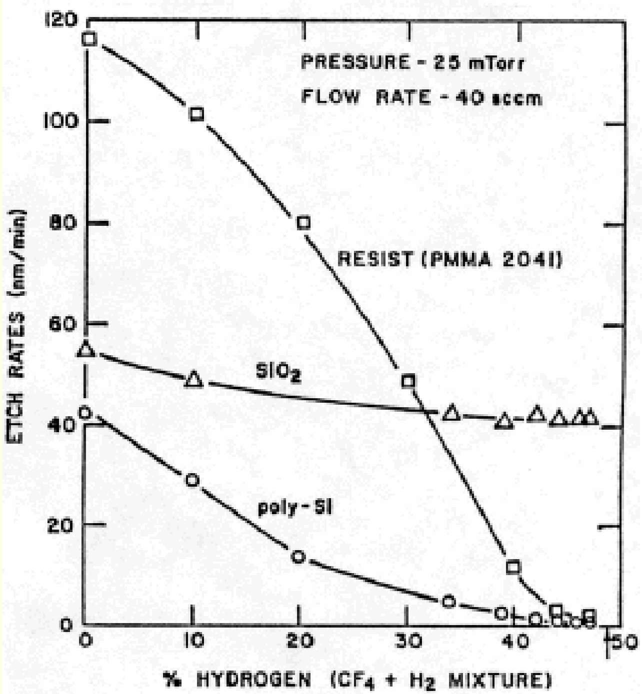
Dry Etch Chemistries



Material	Etch Gases	Etch Products
Si, SiO_2, Si_3N_4	CF_4, SF_6, NF_3	SiF_4
Si	Cl_2, CCl_2F_2	$SiCl_2$, $SiCl_4$
Al	BCl_3, CCl_4, $SiCl_4$, Cl_2	$AlCl_3$, Al_2Cl_6
Organics	O_2, O_2 + CF_4	CO, CO_2, H_2O, HF
Other:		
(W, Ta, Mo, …)	CF_4	WF_6, …

Etching Si/SiO$_2$ in CF$_4$: Selectivity

- Adding H$_2$ drastically lowers Si etch rate
  - lowers F concentration ($H^+ + F + e^- \rightarrow HF$)
  - nearly 0 at 40% H$_2$
- However, etch rate of SiO$_2$ remains nearly constant

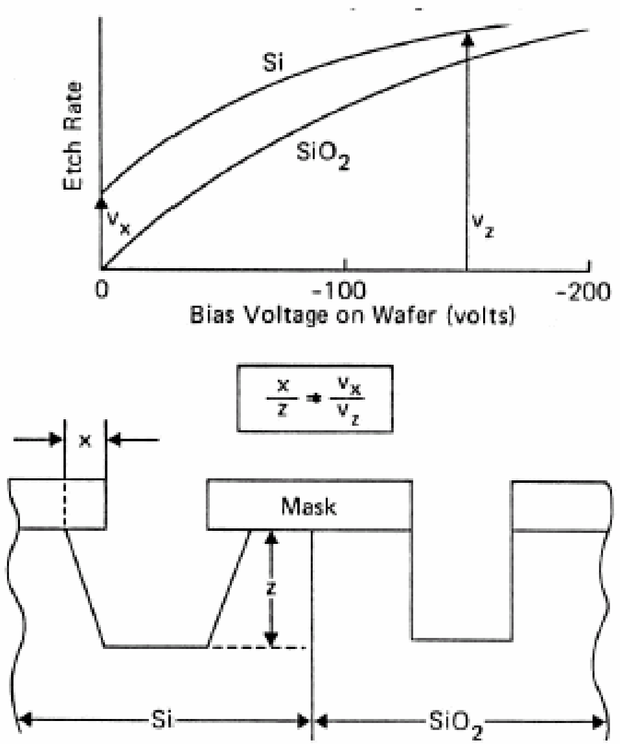


- Allows etch selectivity to be increased tremendously
- Mechanism for increased selectivity has two components
  - deposition of a non-volatile residue
  - role of O$_2$ in etching of SO$_2$

Deposition of a Nonvolatile Residue

- CF_4-H_2 plasmas deposit carbon-based residues (nonvolatile) on all surfaces inside an etch chamber
  - disassociation of CF_3^+ and other fluorocarbon radicals when chemisorbed
  - called POLYMERIZATION
- Less accumulation is observed on SiO_2 surfaces than on Si surfaces
  - some carbon combines with O_2 in the SiO_2 to form CO and CO_2 which are volatile
  - allows SiO_2 etch to continue while Si etch has been stopped
  - however, even the SiO_2 etch can be stopped if the deposition rate of the carbon residue is high enough (stops all etching)
- Controlling the relative deposition and etching rates of Si and SiO_2 is a powerful way to control selectivity
  - typically the right settings are empirically determined for each etching chamber

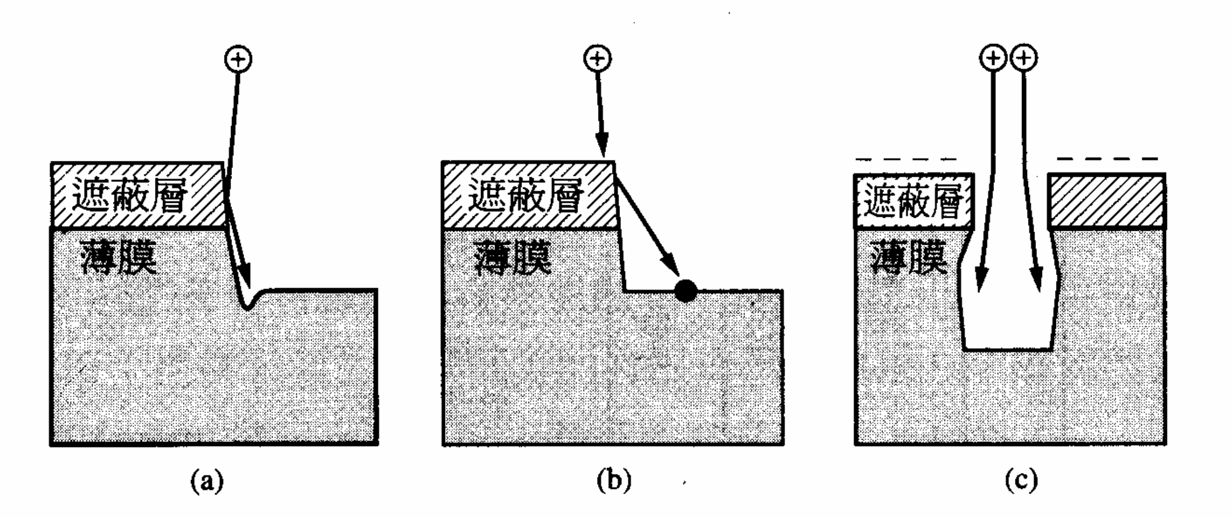
Anisotropy in Dry Etching



- If etching is ***purely chemical*** it will be ***isotropic***
- **Etch rates can be increased by using ion bombardment to damage the surface**
  - **creates broken and weakened bonds to react with**
- **Ions (positive) are accelerated by applying a bias voltage (-V)**

- **SiO_2 is not etched without bombardment (vertical)**
- **Si etch rate is not zero without bombardment**
- **Leads to very different etch profiles (sidewalls)**

Dry Etching Problems



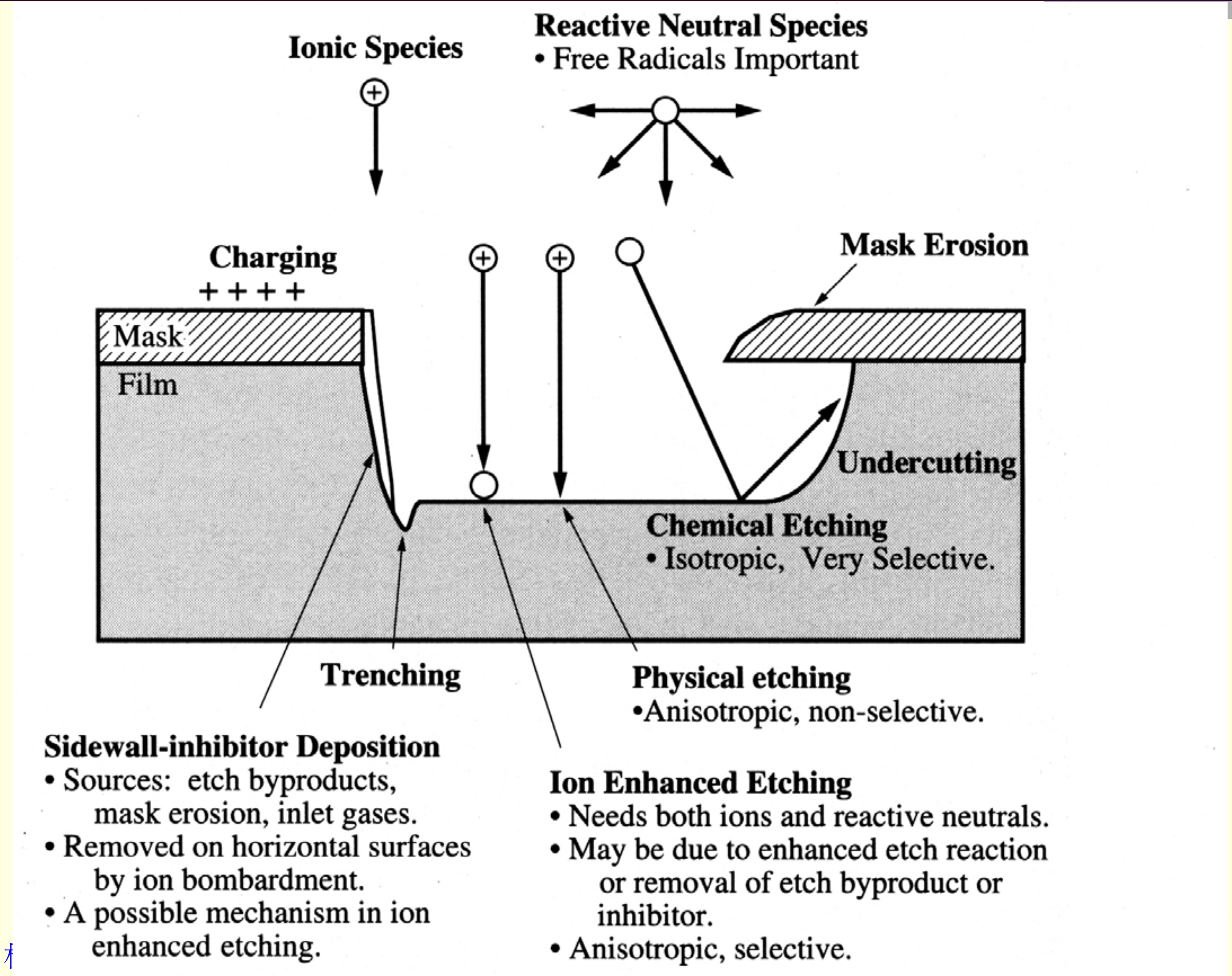
(a) 側壁底部有凹槽

(b) 光阻和其他材料的再沉積

(c) 電荷累積和離子路徑歪曲

- Flow rate effect
- Loading effect
- Aspect ratio effect
- Undercutting

Summary of Different Processes in Dry Etching



Chemical Etching
- Isotropic, Very Selective.

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.

介電薄膜活性離子蝕刻系統 (Dielectric RIE)

- 服務項目：
  - 蝕刻二氧化矽、氮化矽等材料。
- 重要規格：
  - RF產生器最大可輸出100W，頻率13.56MHz，本蝕刻系統有：　可通入CF4、O2等氣體蝕刻二氧化矽、氮化矽等材料。

（試片上不得有參雜及金屬材料）

高密度活性離子蝕刻系統 (HDP-RIE)

- 儀器功能：
  - 乾式蝕刻，以蝕刻Al材料爲主
- 重要規格：
  - 使用氣體包含BCl3、Cl2、CF4、CHF3、Ar、O2、SF6，ICP RF最大功率900W，Bias RF最大功率300W，
  - 以He gas系統冷卻
  - 4" wafer爲主

Deep Reactive Ion Etching

- **Reactive Ion Etching can be used to etch Si as discussed before. However, it is often desired in MEMS and 3-D packaging applications to fabricate very narrow and tall structures or grooves which can't be done using the standard RIE process.**
- **A new process, called DRIE process, has been successfully developed. The process utilizes special gas chemistry to form a polymer on the sidewalls or the trench as it is being etched.**
- **The thin layer of polymer prevents lateral undercutting and etching of the Si on the side wall. The result is a very high aspect-ratio etch.**

Cont.

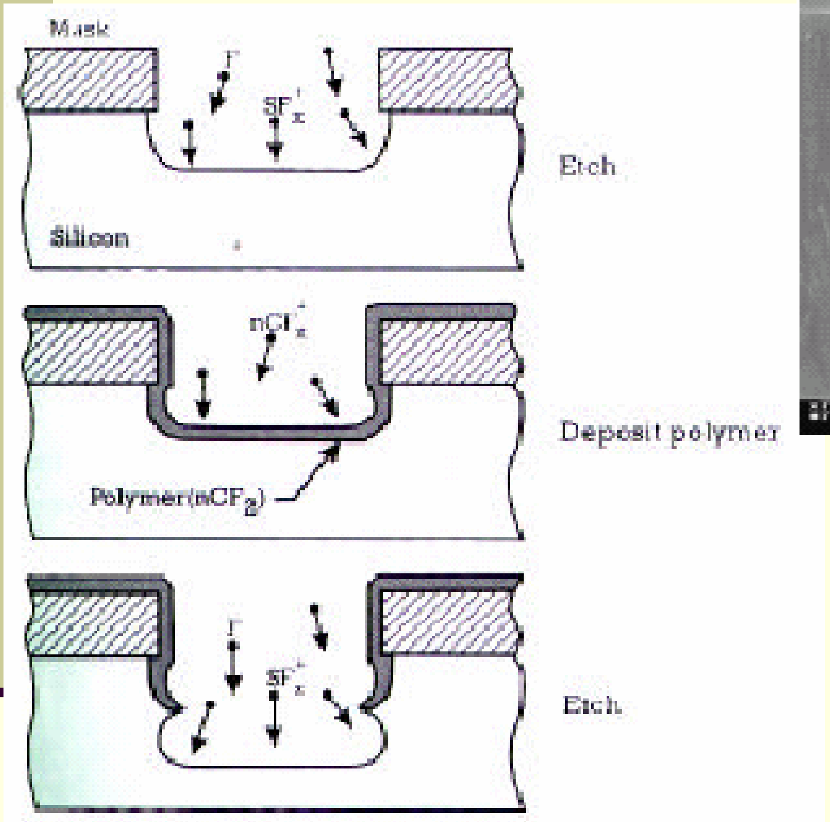
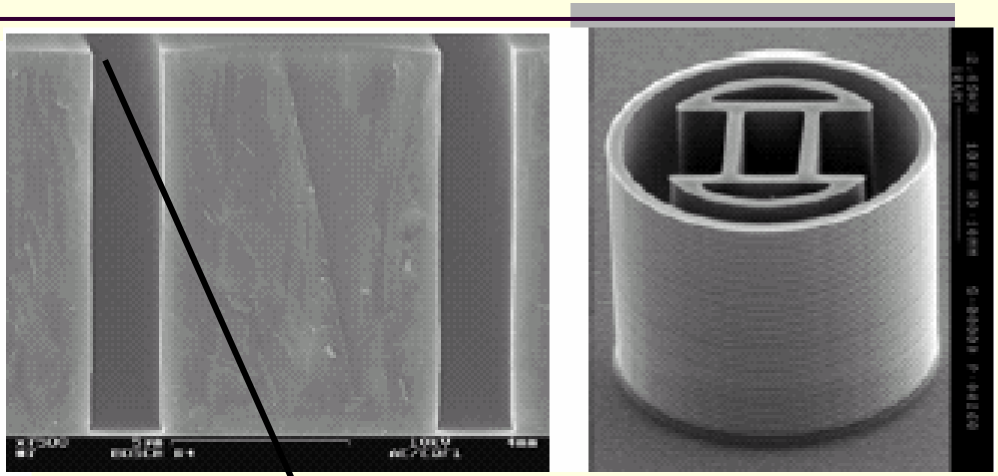
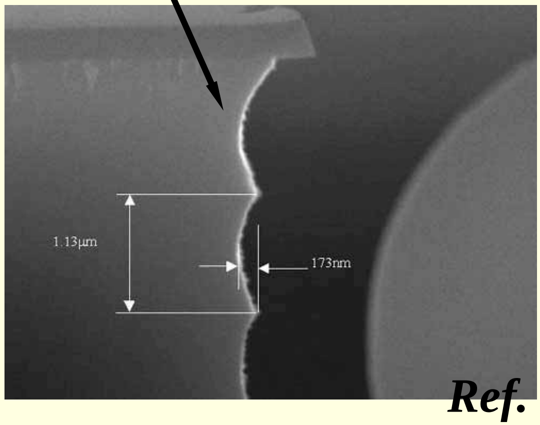


Figure 6: Bosch Process

Ref. Tith et al.,



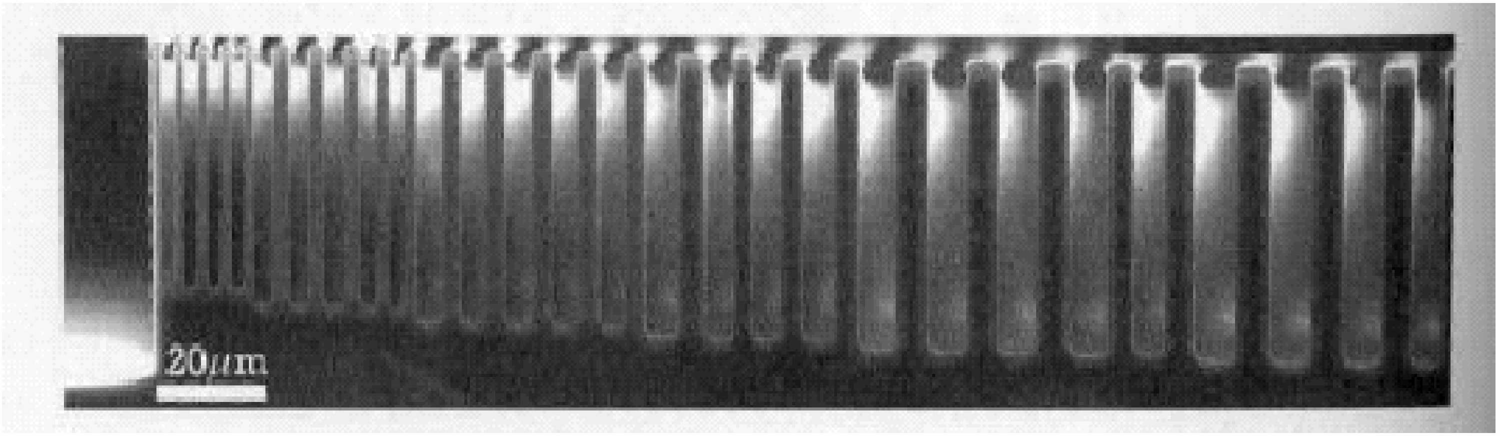
Ref. Gahn et al.,



Ref. BCO Tech.

DRIE Lag

- The main characteristic associated with DRIE etch is that the etch depth depends on a number of factors, most importantly the width of the feature that needed to be etched.
- The etching depth of open areas on a silicon substrate will vary with the opening size. The larger the area is, the deeper the trench can be. That is not desirable but not much can be done about it.



Ref. Tith et al.,

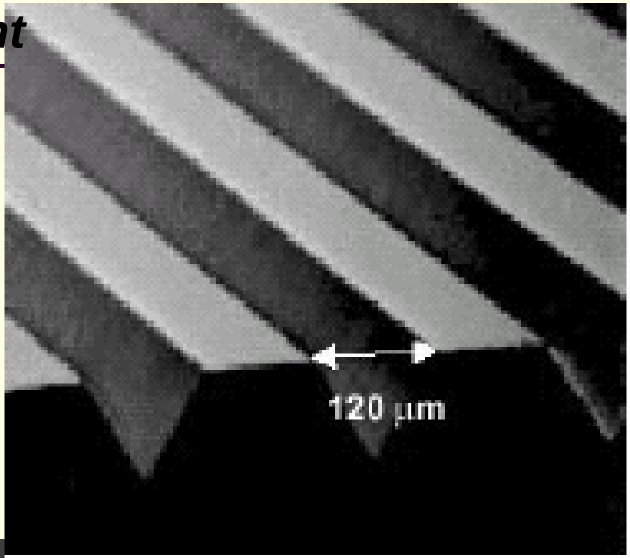
Figure 2: Example of RIE lagging

Cont.

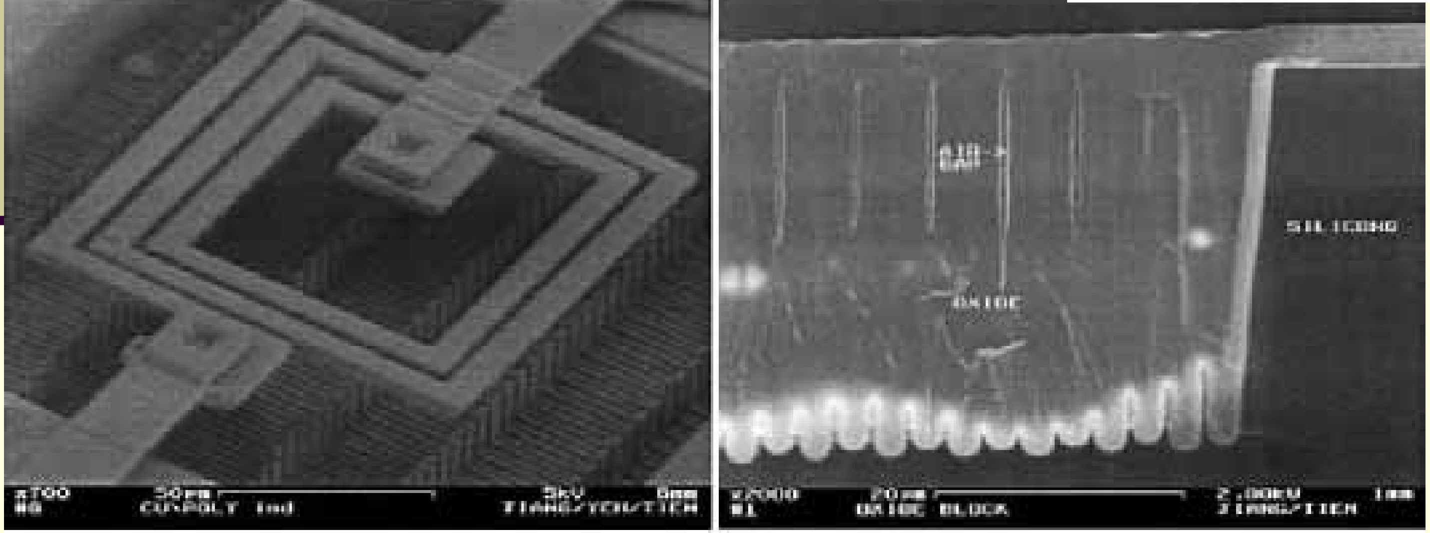
V grooves for optical alignment

Ref. Prof. Lu

course handout



For high Q RF passive components & thick isolation layer for RF packaging applications



(a) (b)

化學機械研磨機(CMP)

- 儀器功能：
  - 研磨各種氧化矽（SiO2,TEOS-Oxide,PECVD-Oxide,BPSG）
- 重要規格：
  - 研磨晶片大小爲6吋

Laser Drilling

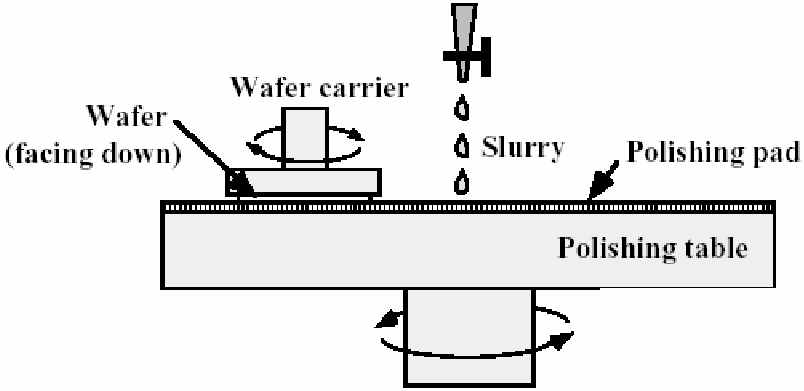
- Laser assisted chemical etching (LACE) uses localized heating to drive etching reactions.
- Laser drilling is an ablative process.
- LACE can be very slow but can offer 1 μm^3 voxel resolution.

$$Si + 2Cl_2 \xrightarrow{\text{laser beam}} SiCl_4$$

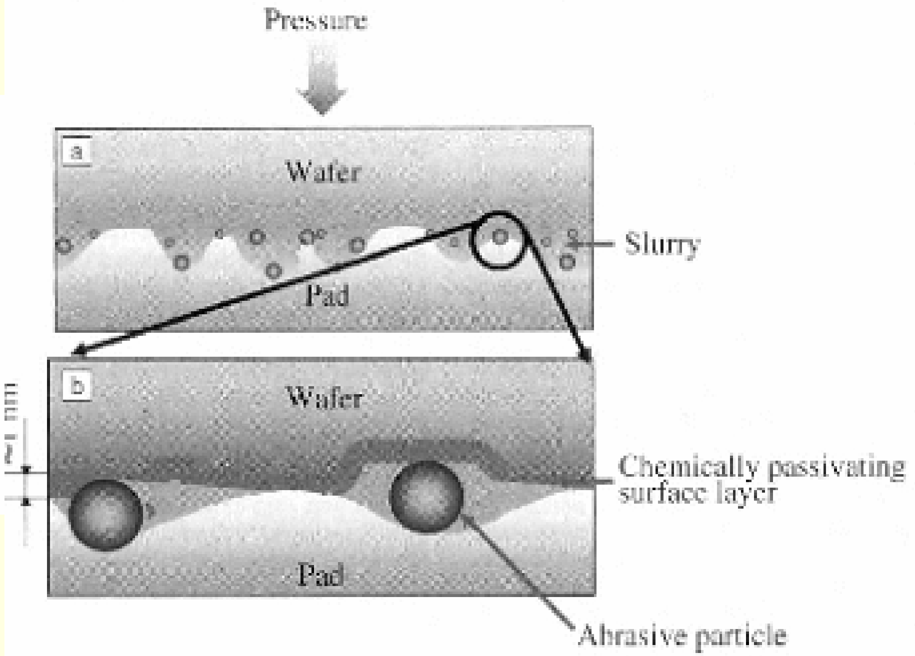
Ref. Lexno Laser

Chemical Mechanical Polishing (CMP)

- ***CMP has become a very useful technique for either polishing and planarizing the surface of wafers which have tall feature and topologies, or for thinning wafers***
- ***The process involves both mechanical polishing and chemical etching, like HNA, It is possible to create very flat and polished surfaces using this technique.***



Plummer et al., Silicon VLSI Tech.



Chemical Mechanical Polishing (CMP)

- ***The CMP materials include SiO_2, Si, W, Al, and Cu.. Etc.,***
- ***A good CMP should require:***
  - Low WIWNU (Within Wafer Nonuniformity)
  - High planarization rate (~2000 to 6000Å/min)
  - A given selectivity versus underlying layers
  - Low defectivity of the surface after CMP
  - Low defectivity of the stop layer surface after CMP
- ***Two examples of CMP are illustrated for the introduction :***
  - Polysilicon with amorphous silica slurry (Klebosol)
  - Tungsten CMP with KIO_3 and H_2O_2
  - Copper CMP

Polysilicon CMP

- ***Polysilicon CMP are used for polysilicon plugs, polysilicon STI, MEMS. The applications require different polishing selectivity versus the underlying layer (SiO_2). Several slurries have been successfully developed for different selectivity ranging from 1:1 to 1:25***
- ***Polysilicon film removal rate varies drastically with the pH.***
  - OH^- anions react with Si-Si to create two products Si-H and $Si(OH)_4$ which dissolved into the slurry.
  - The pH of a basic amorphous silica slurry is around 11. With the adjustment of the slurry chemistry, we can decrease significantly the oxide removal rate, keeping a high polysilicon removal rate.

Defectivity Induced by CMP

- ***CMP characterization is generally based on AFM measurement.***
- ***A good CMP can provide defects with the size less than 0.01μm***

Ref. Joray et al.,

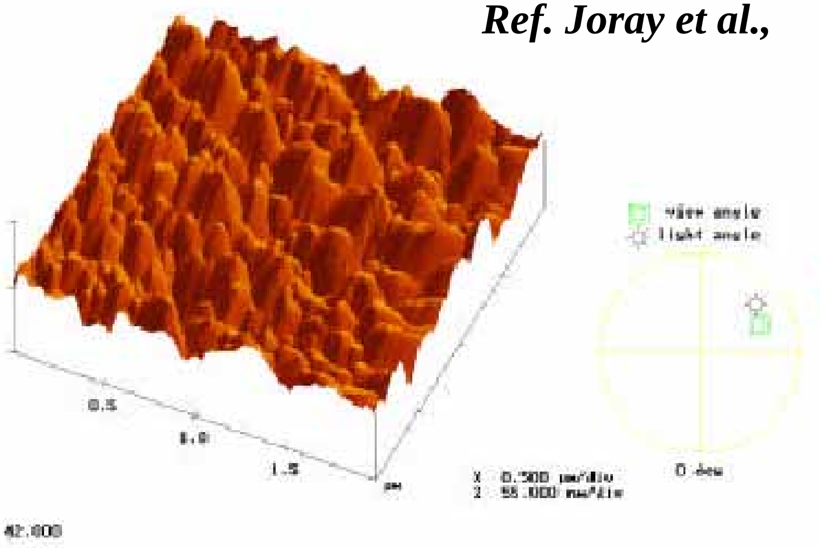


Figure 2:
Polysilicon roughness before polishing
(AFM measurement)

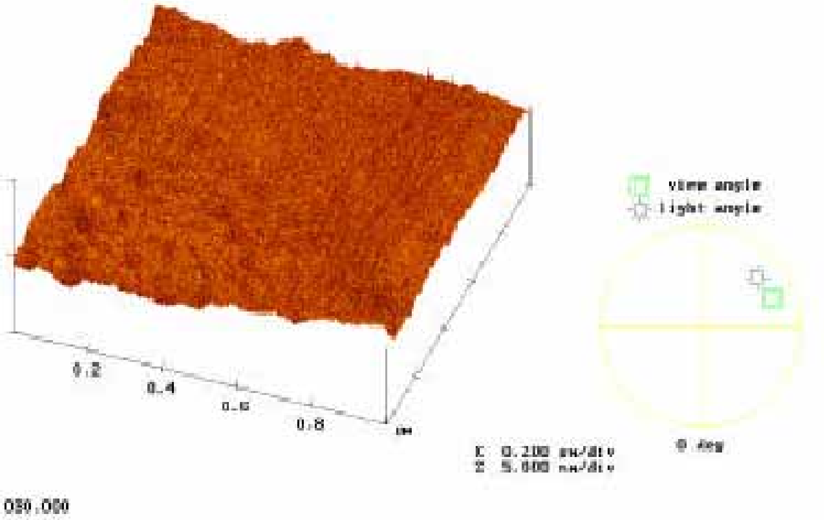


Figure 3:
Polysilicon roughness after polishing
(AFM measurement)

Tungsten CMP

- **Tungsten CMP is used for tungsten plug and damascene which have the same requirements in terms of selectivity versus the underlying layer SiO_2, removal rate and defectivity.**
- **Tungsten is a very hard material. In order to get acceptable removal rate, it is necessary to oxide the tungsten surface since three different tungsten oxides (WO_2, W_2O_5, and WO_3) are softer.**
- **The most interesting oxidizer in terms of removal rate are a combination of potassium iodate (KIO_3) and hydrogen peroxide (H_2O_2).**
  - The etching rate is as high as 4000Å/min.
  - The removal mechanism is not an actual polishing mechanism, but rather an etching mechanism.
  - The CMP rate depends on polishing pressure, speed, oxidizer concentration and the pH of the slurry but not on the abrasive concentration.

Copper CMP

- **The slurry contains ethylenediaminetatra acetic acid (EDTA) or glycine (amino acid) . Both kinds of additives not only ease the dissolution of Cu and provide certain level protection on Cu surface to prevent dishing. (Aksu, et al, 2001)**

Copper dishing

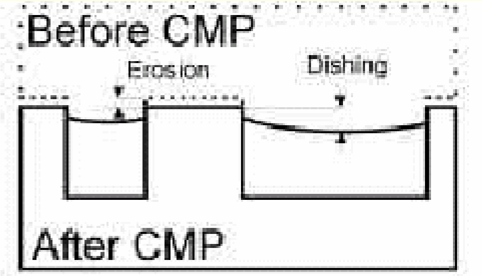
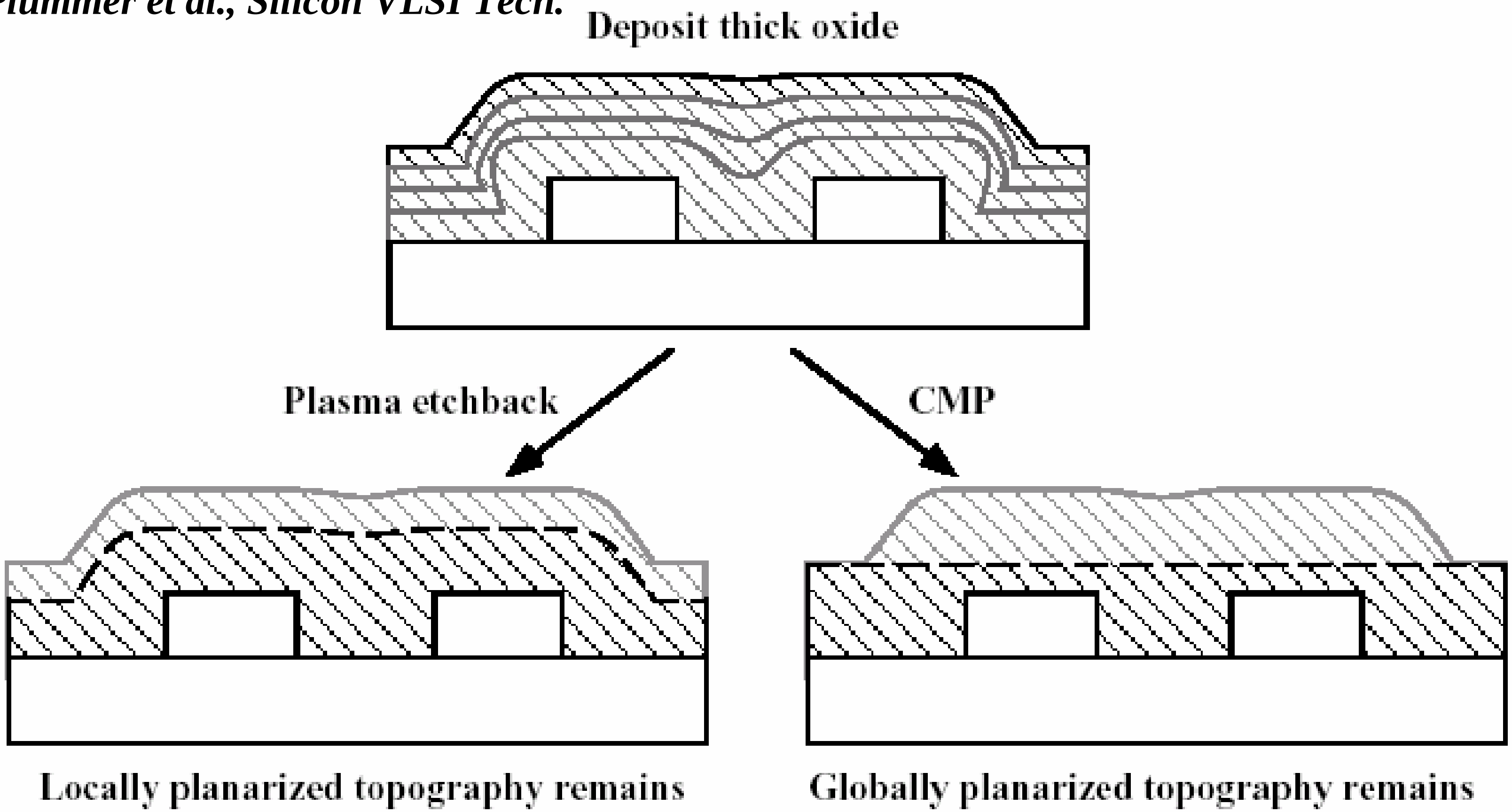


Figure 7. Schematic diagram of Dishing and Erosion

- **The process challenges in copper CMP:**
  - Copper is a soft material and prone to surface defects.
  - It is very difficult in finding the slurry with proper chemistry and a pad with suitable physical properties; Excessively high pad roughness results in dishing on the surface. Low pad roughness results in low polishing rate.
  - Redeposition of copper and copper oxide particulates due to incomplete dissolution in the slurry could reduce the mechanical polishing efficiency and increase the surface density.

Topology Comparisons

Plummer et al., Silicon VLSI Tech.



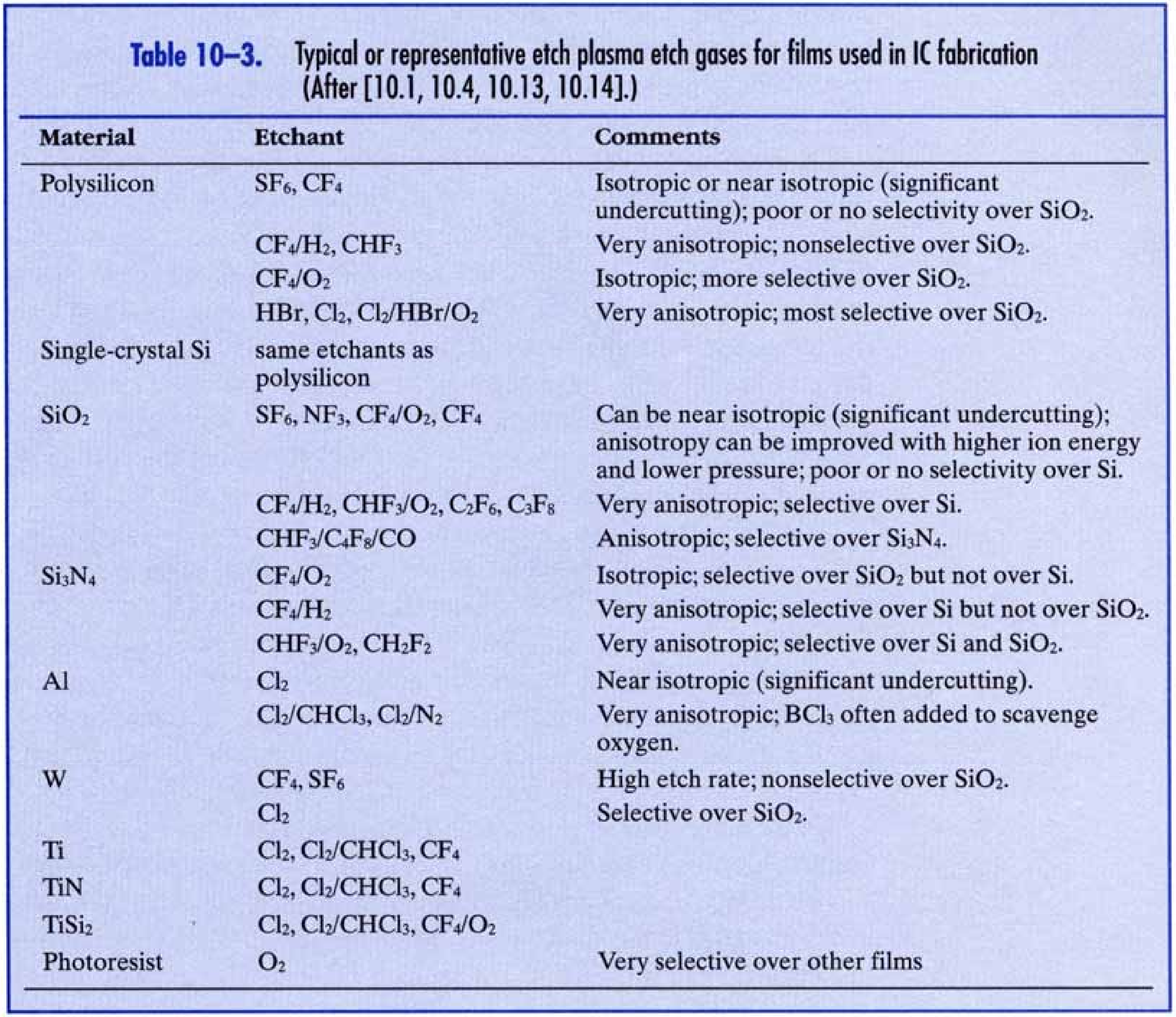


Table 10–3. Typical or representative etch plasma etch gases for films used in IC fabrication (After [10.1, 10.4, 10.13, 10.14].)

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; nonselective 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; nonselective 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

Thank you!

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