Principles of Micro- and Nanofabrication for Electronic and Photonic Devices

Etching 刻蚀
Part III: Dry 干法

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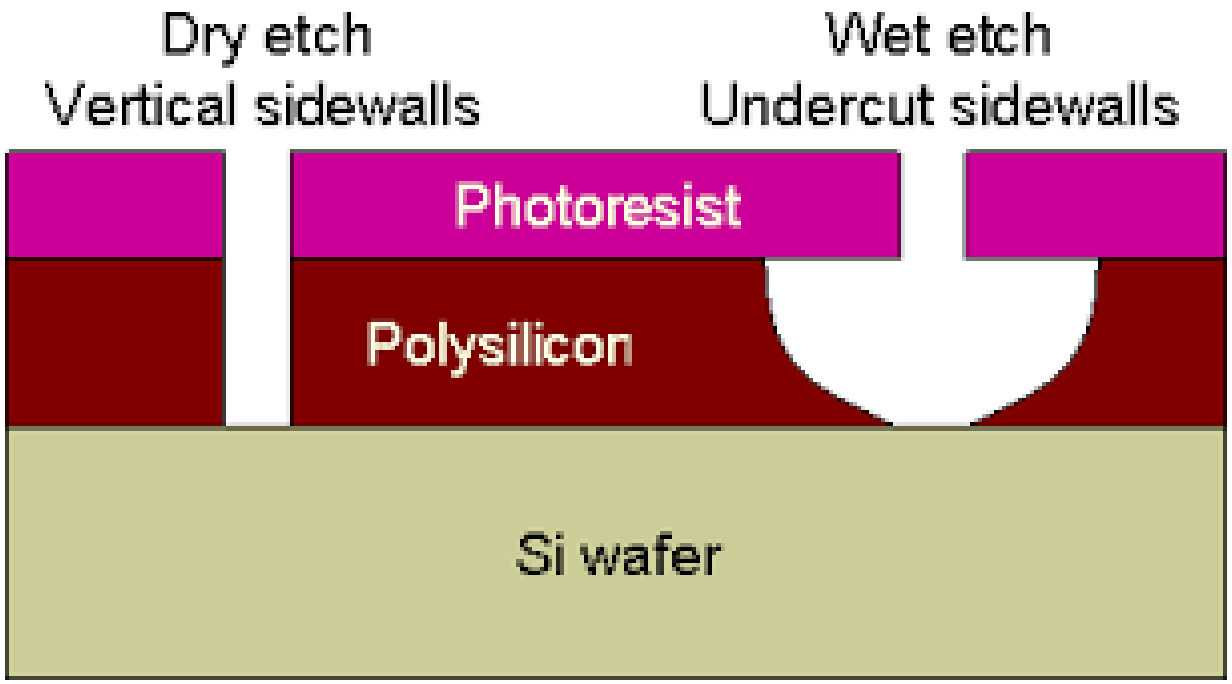
Etching Methods

- Wet Etching 湿法刻蚀
- Dry Etching 干法刻蚀
- CMP and other methods

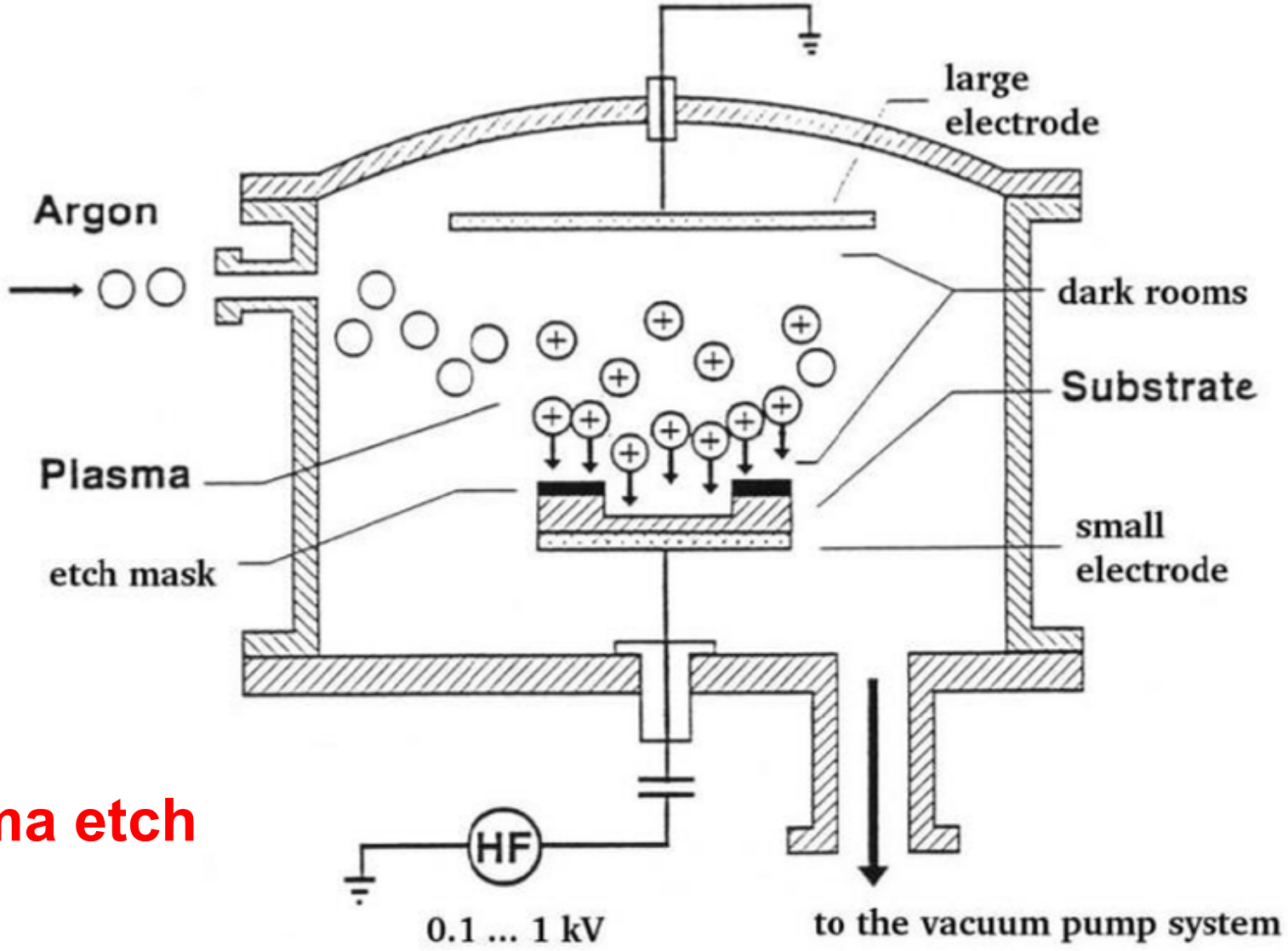
Challenges for Wet Etching

- **Most wet etching processes are chemical, isotropic**



- **For features < 3 μm, dry etching has much better resolution**

Dry Etching

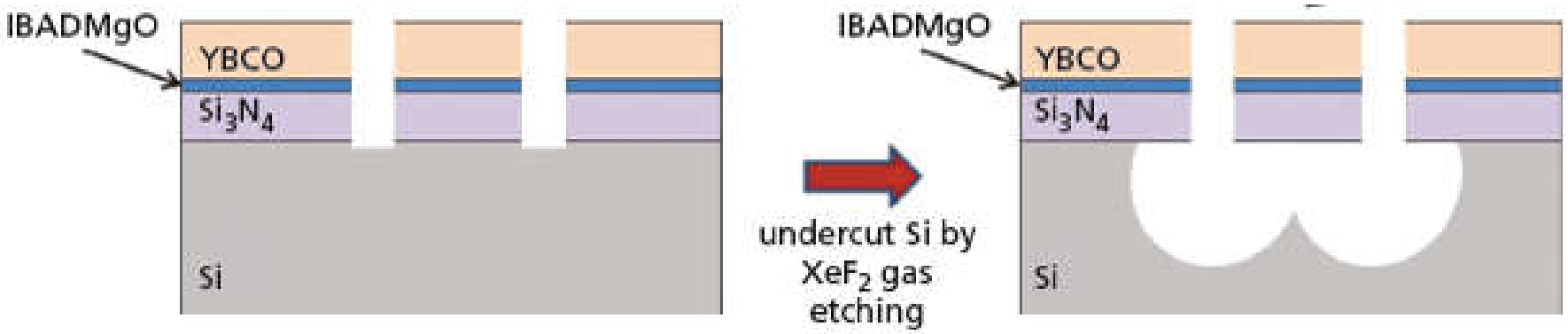


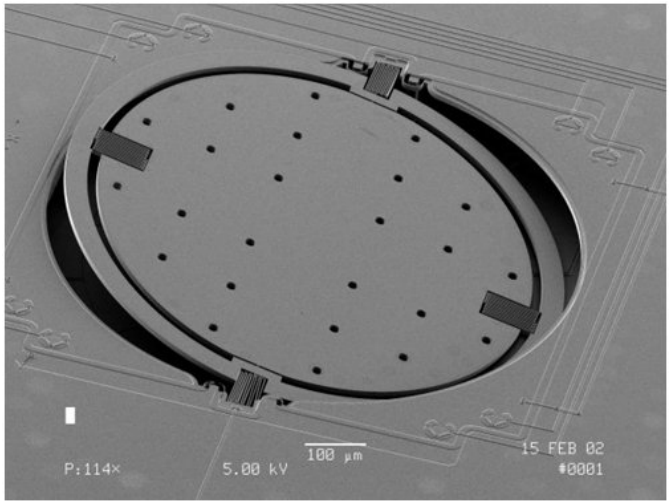
plasma etch

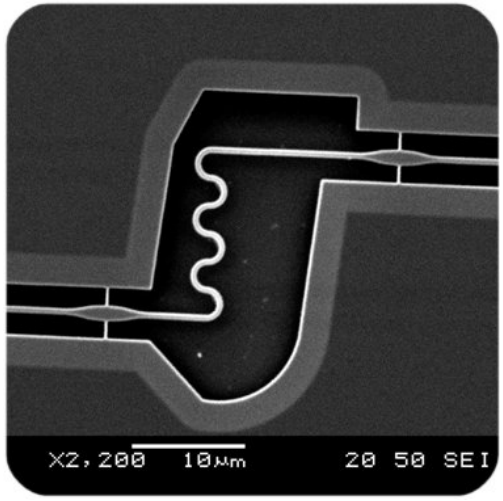
Dry Etch without Plasma

- $2XeF_2$ (g) + Si (s) = 2Xe (g) + SiF_4 (g)
  - very isotropic and selective

SiF_4 boiling point 4 °C

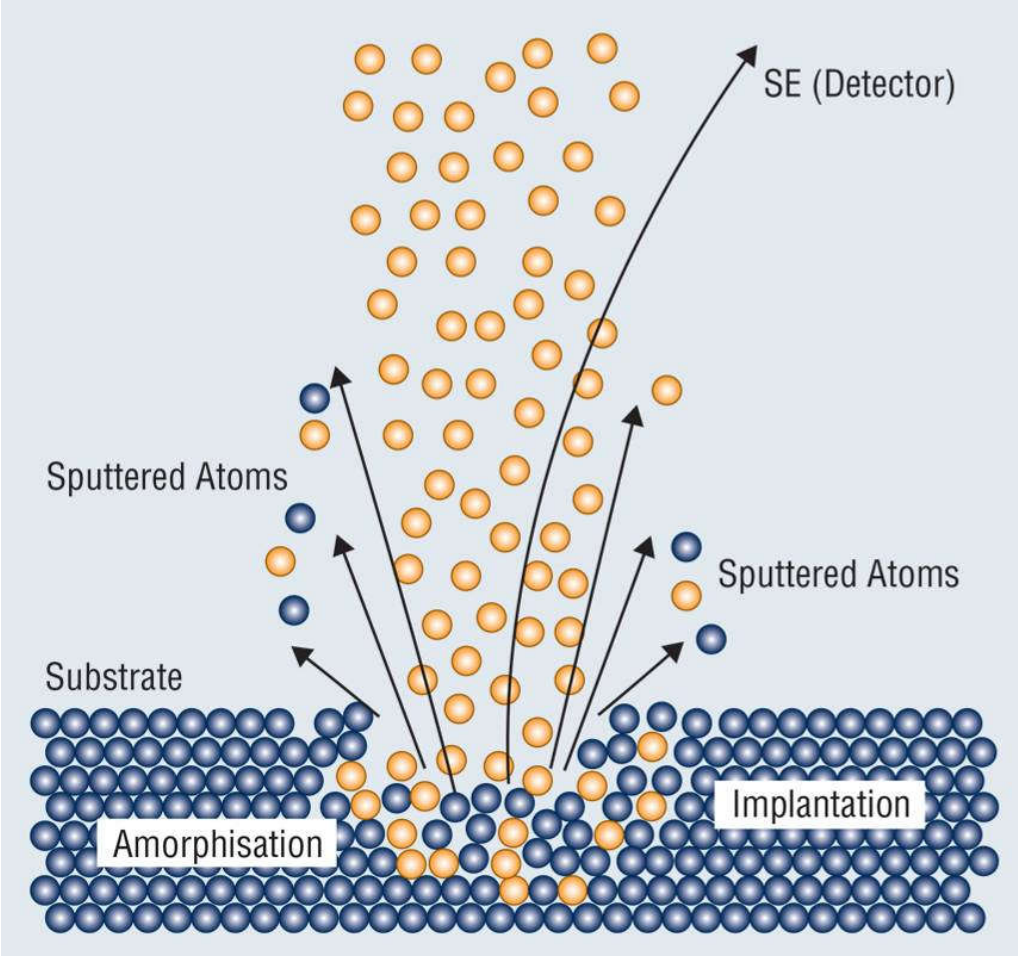






Ion Milling

- Heavy ions (e.g. Ar)
- Highly anisotropic
- Poor selectivity
  - for Au, Pt, ...



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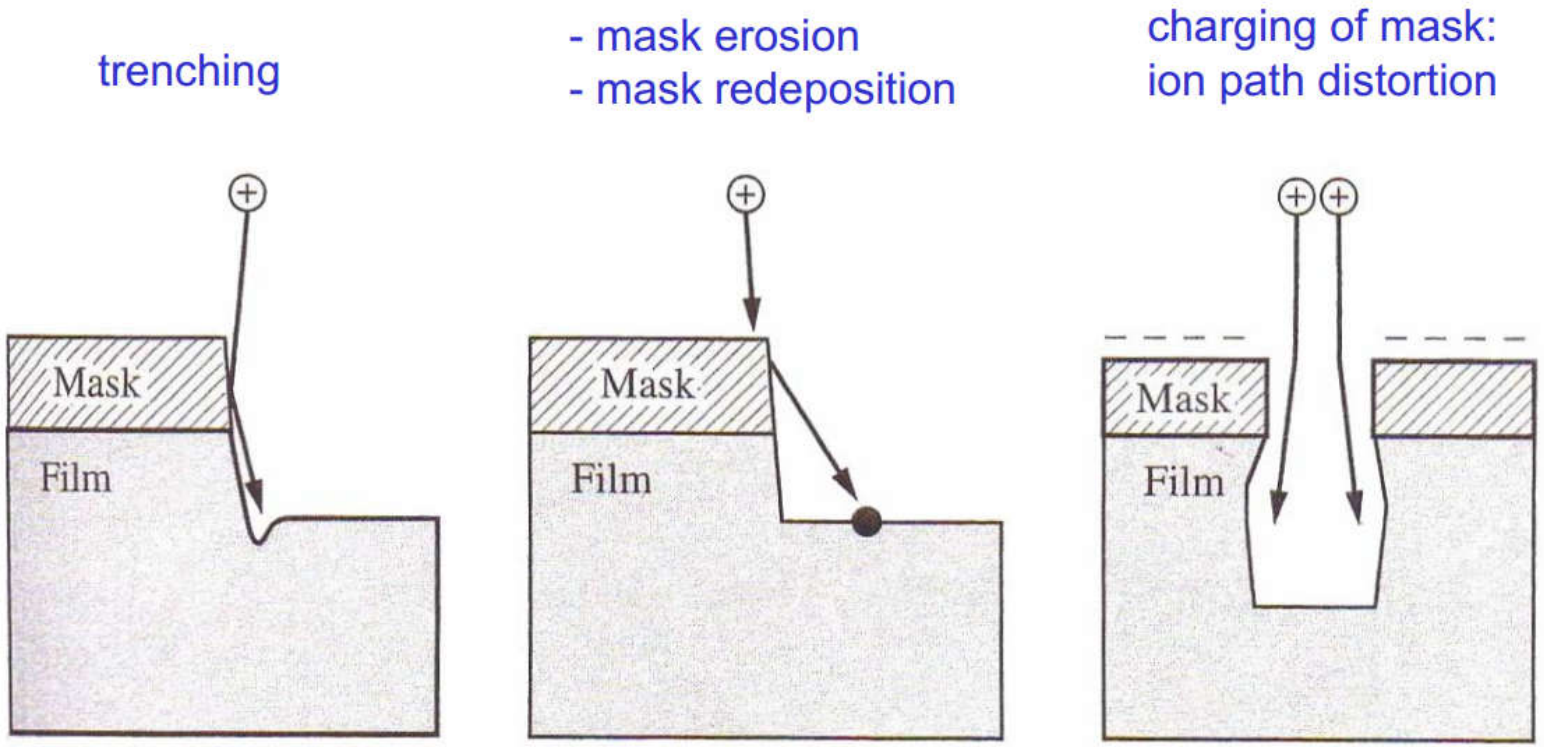
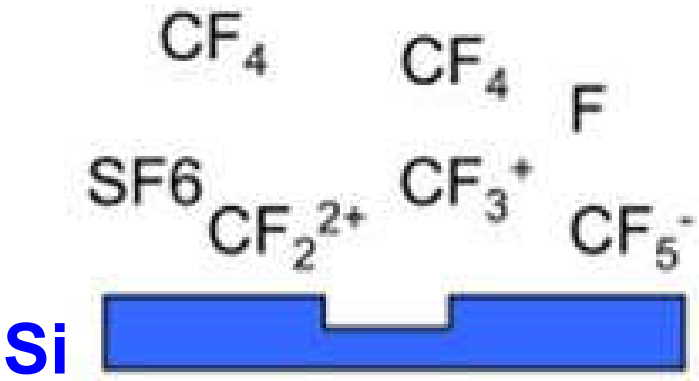


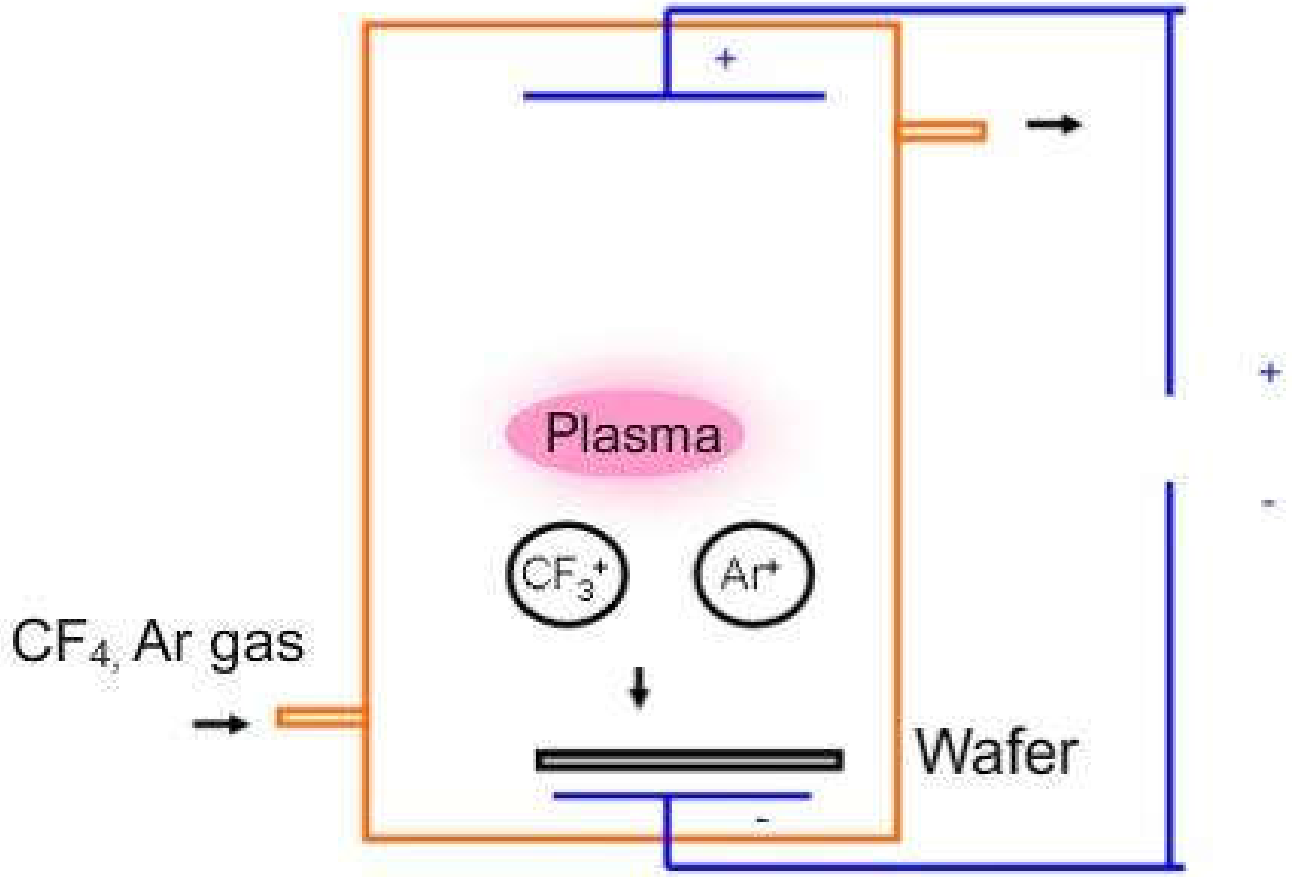
Plasma Etch

- **Chemically reactive ions**
  - improved selectivity
  - lower power
- **Example: Si etch**
  - CF_4 gas does not react with Si
  - energized F^- plasma can react with Si
  - SiF_4 is volatile (boiling point 4 ^oC)
- **Very isotropic**
  - no direction



Reactive Ion Etching (RIE)

- **Improved directionality by applied fields**
  - **more anisotropic**



RIE - Si and SiO_2

- Si
  - SF_6 plasma
- SiO_2
  - CF_4 / CHF_3 plasma
- Photoresists can be used as masks
  - F ions etch PR very slowly

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SF_6 is heavier than air

- Photoresists can be used as masks
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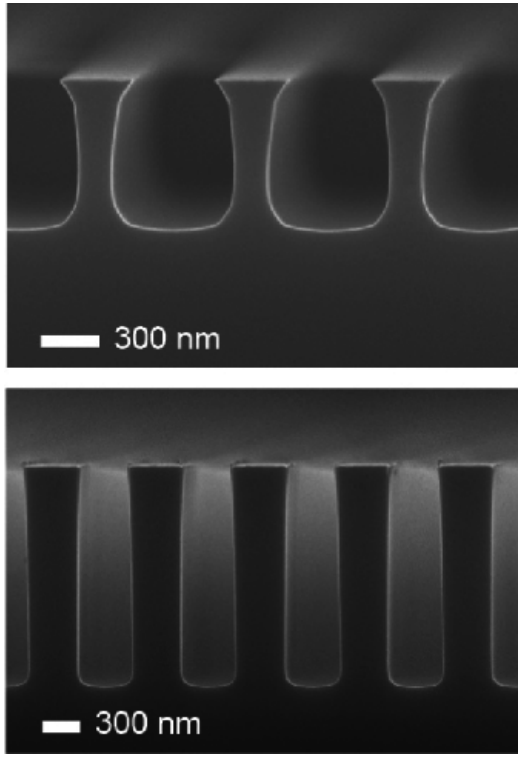
RIE - Organics

- O_2 plasma
  - $C\text{-}H\text{-}O + O^- = CO_2 + H_2O$
- O_2 plasma does not etch Si, SiO_2, or metals
  - SiO_2 / metal oxides are non-volatile

RIE - III-Vs

- Cl_2 / BCl_3 / $SiCl_4$ plasma
  - GaAs/AlGaAs, InP, GaN/InGaN, ...

Q: why?



GaAs trenches

product	boiling point (°C)
GaF_3	1000
AlF_3	> 1000
InF_3	> 1000
$GaCl_3$	200
$AlCl_3$	180
$AsCl_3$	130

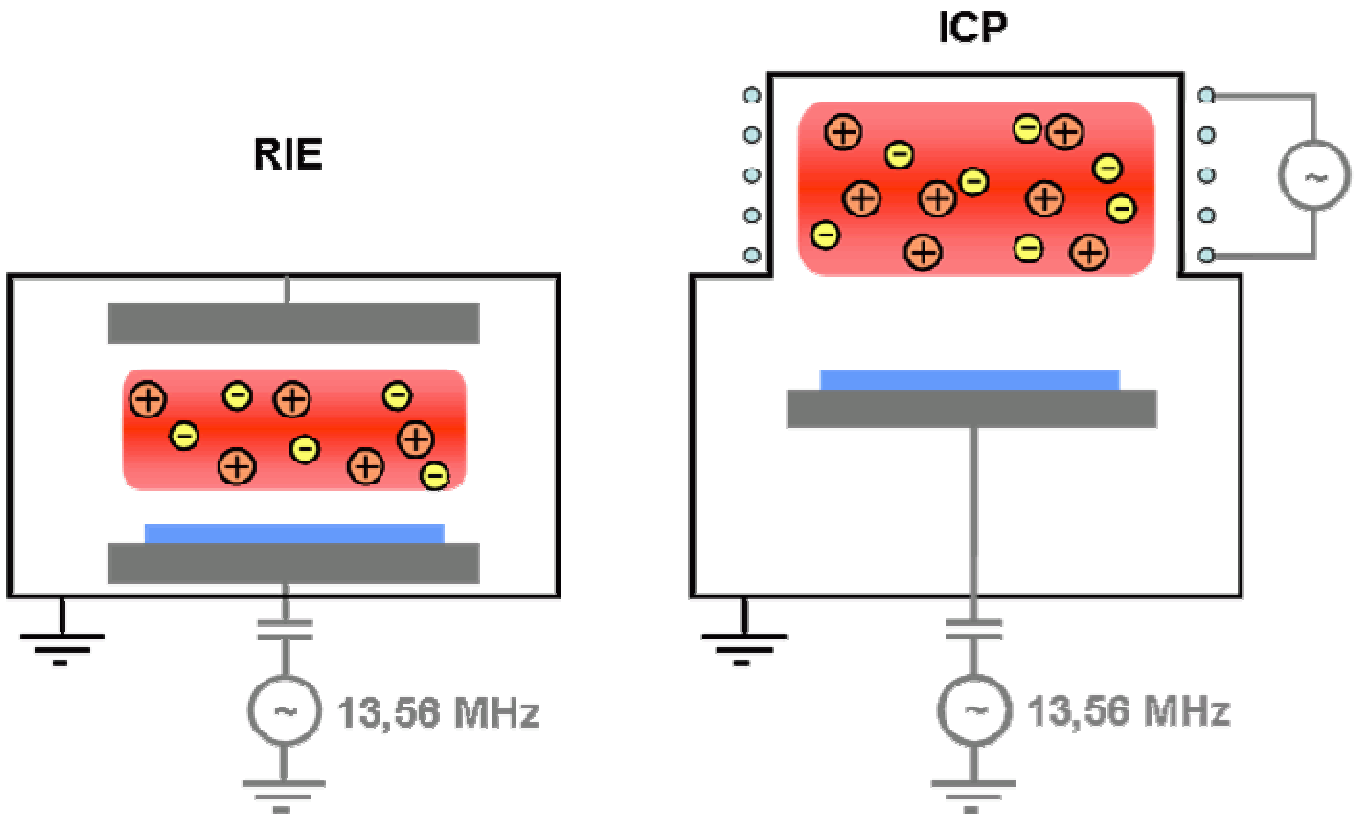
RIE - Recipes

Table 6.2 Materials and corresponding RIE gases

Materials to be etched	Chemical gases (multi choices)
Single-crystal silicon	CF_3Br, HBr/NF_3, SF_6/O_2
Polysilicon	$SiCl_4/Cl_2$, BCl_3/Cl_2, $HBr/Cl_2/O_2$, HBr/O_2, Br_2/SF_6
Al	$SiCl_4/Cl_2$, BCl_3/Cl_2, HBr/Cl_2
Al-Si-Cu, Al-Cu	$BCl_3/Cl_2 + N_2$
W	SF_6, NF_3/Cl_2
TiW	SF_6
WSi_2, $TiSi_2$, $CoSi_2$	CCl_2F_2/NF_3, CF_4/Cl_2
SiO_2	CCl_2F_2, CHF_3/CF_4, CHF_3/O_2, CH_3CHF_2
Si_3N_4	CF_4/O_2, CF_4/H_2, CHF_3, CH_3CHF_2
GaAs	$SiCl_4/SF_6$, $SiCl_4/NF_3$, $SiCl_4/CF_4$
InP	CH_4/H_2
Photoresists	O_2

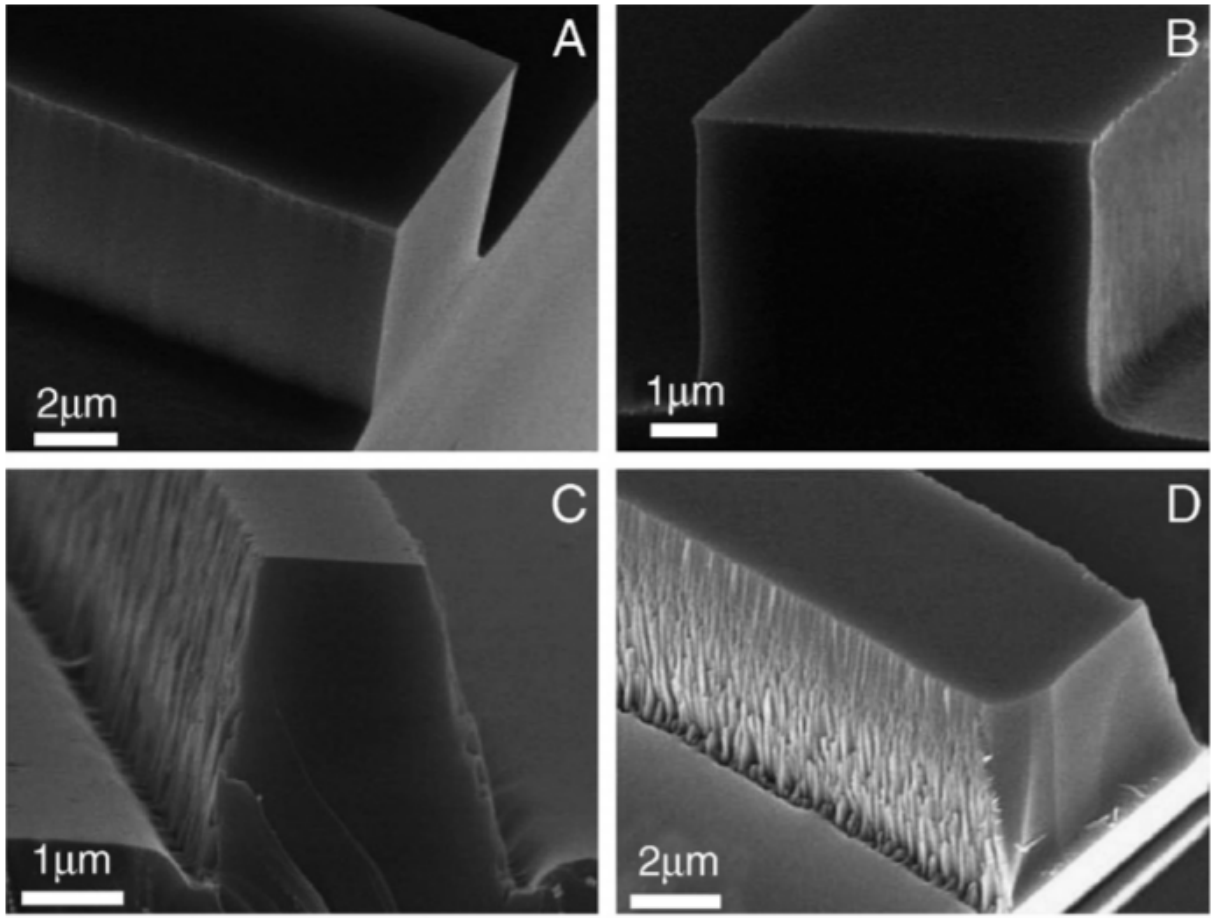
ICP-RIE

- **Inductively Coupled Plasma (ICP)**
  - **higher power**
  - **mostly for III-Vs**



Quality of Etching

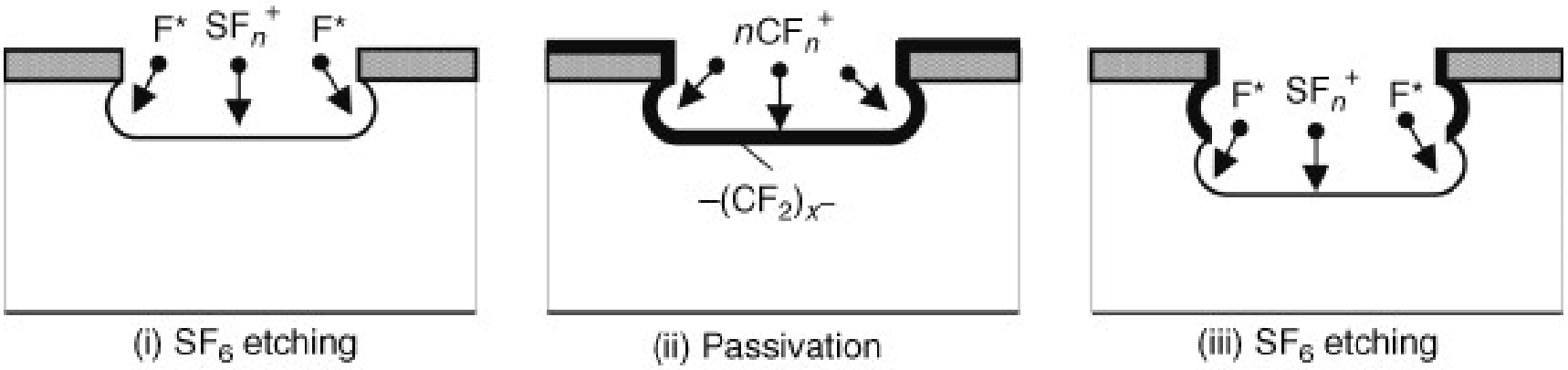
- **Quality is controlled by the experiments**
  - **gas type, pressure, power, ...**



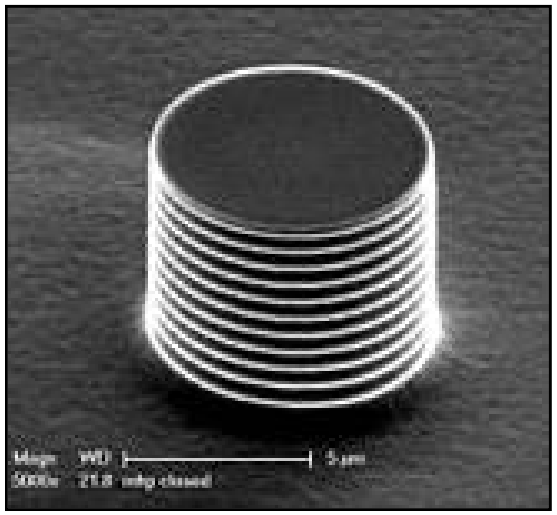
W. Li, *et al.*, *Suf. Coat. Tech.* **201,** 4979 (2007)

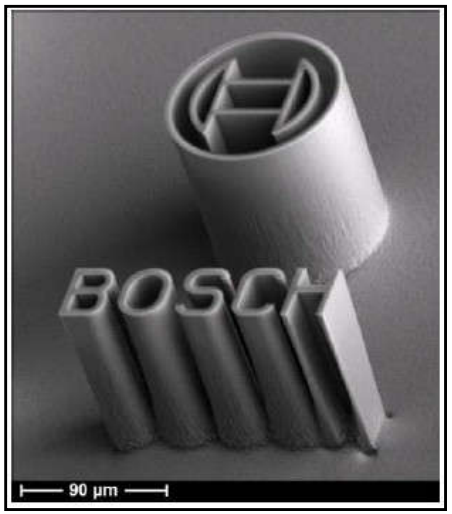
Deep RIE for Si

- **alternative etch / passivation** **'Bosch process'**

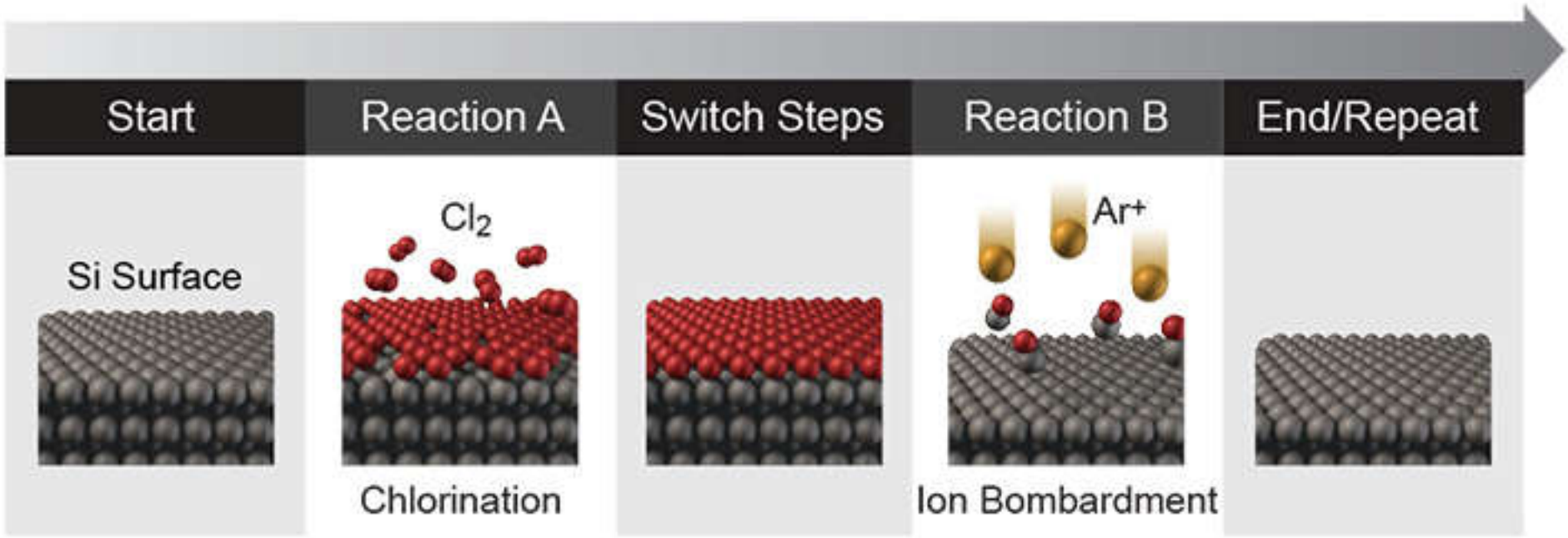


(i) SF_6 etching (ii) Passivation (iii) SF_6 etching





Atomic Layer Etching (ALE)



1. $Si + 2Cl_2 = SiCl_4$
2. $SiCl_4$ removed by plasma
3. Repeat 1 and 2

K. J. Kanarik, *et al.*, *J. Vac. Sci. Tech. A* **33,** 020802 (2015)

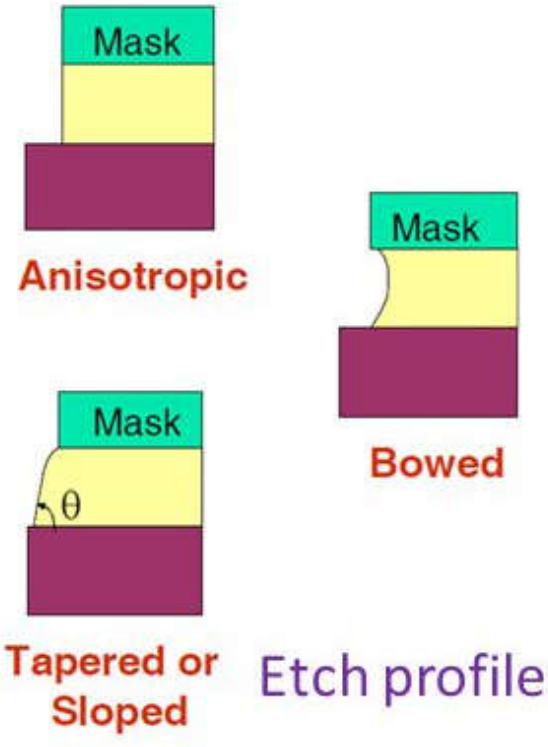
Issues in Dry Etch

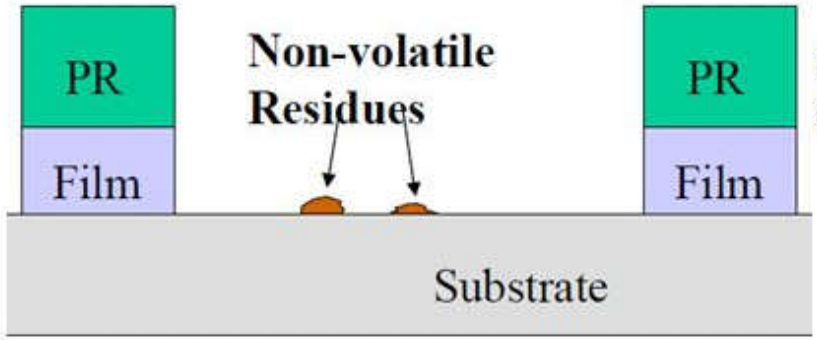
Profile → •Isotropic •Anisotropic •Mixed profile ← **Undercut, Aspect ratio, Pattern density**

Selectivity → •Flim/PR or Film/Mask •Film/Underlayer ← **CD Loss, Hard mask, Chemistry**

Uniformity → •Across a wafer (Local) •Variations with feature size •Wafer to wafer (Global) ← **Macro-loading, Micro-loading, ARDE effect**

Surface quality → •Contamination •Damage •Texture ← **Polymer Residue, Corrosion, Micro-trench & notch**





PR: photoresist
CD: critical dimension

Summary of Dry Etch

Type of Etching	Excitation Energy	Pressure
Gas/Vapor Etching	none	high (760-1 torr)
- isotropic, chemical, very selective (e.g. XeF_2 gas etch Si even without plasma)		
Plasma Etching	10's to 100's of Watts	Medium (>100 torr)
- isotropic, chemical, selective		
Reactive Ion Etching	100's of Watts	Low (10-100 mtorr)
- directional, physical & chemical, fairly selective		
Sputter Etching	100's to 1000's of Watts	Low (~10 mtorr)
- directional, physical, low selectivity (e.g. ion beam etching/milling using Ar^+)		