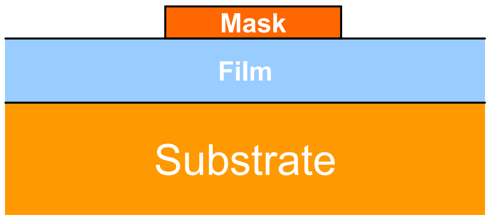
III. Wet and Dry Etching

	Wet	Dry
Method	Chemical Solutions	Ion Bombardment or Chemical Reactive
Environment and Equipment	Atmosphere, Bath	Vacuum Chamber
Advantage	1) Low cost, easy to implement 2) High etching rate 3) Good selectivity for most materials	1) Capable of defining small feature size (< 100 nm)
Disadvantage	1) Inadequate for defining feature size < 1um 2) Potential of chemical handling hazards 3) Wafer contamination issues	1) High cost, hard to implement 2) low throughput 3) Poor selectivity 4) Potential radiation damage
Directionality	Isotropic (Except for etching Crystalline Materials)	Anisotropic

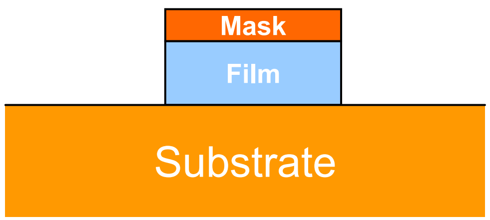
Pattern Generation (Transfer): Etch vs. Liftoff

Etching

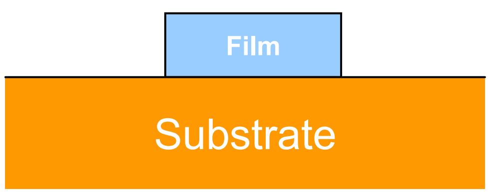
Lithography



Etching

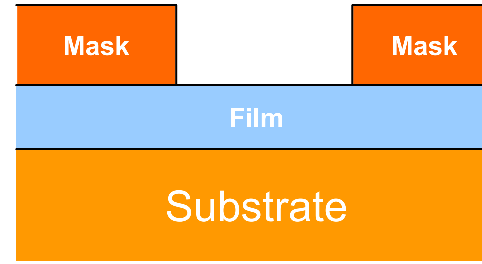


Strip
Mask (Resist)

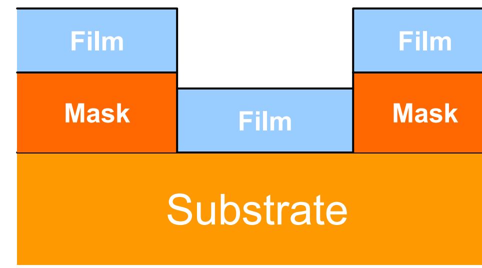


Liftoff

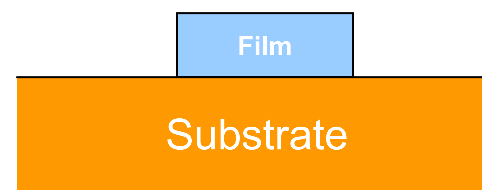
Lithography



Deposit
Film



Remove
Mask (Resist)
(Liftoff)



Isotropic vs. Anisotropic Etching

Isotropic Etching: Etching rate is the same in both horizontal and vertical direction

Anisotropic Etching: Etching rate is different in horizontal and vertical direction

Lateral Etch Ratio:

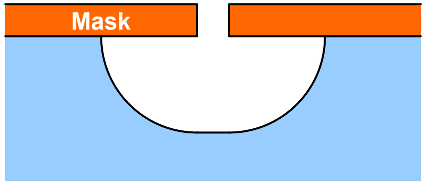
$$R_L = \frac{Horizontal\ \ Etch\ Rate\ (r_H)}{Vertical\ \ Etch\ Rate\ (r_V)}$$

Isotropic Etching: $R_L = 1$

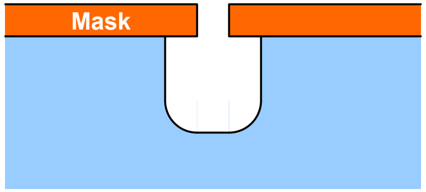
Anisotropic Etching: $0 < R_L < 1$

Directional Etching: $R_L = 0$

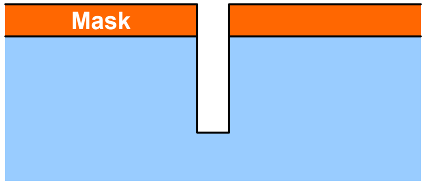
Bias: the difference in lateral dimensions between the feature on mask and the actually etched pattern
➡ smaller R_L results in smaller bias



$R_L = 1$

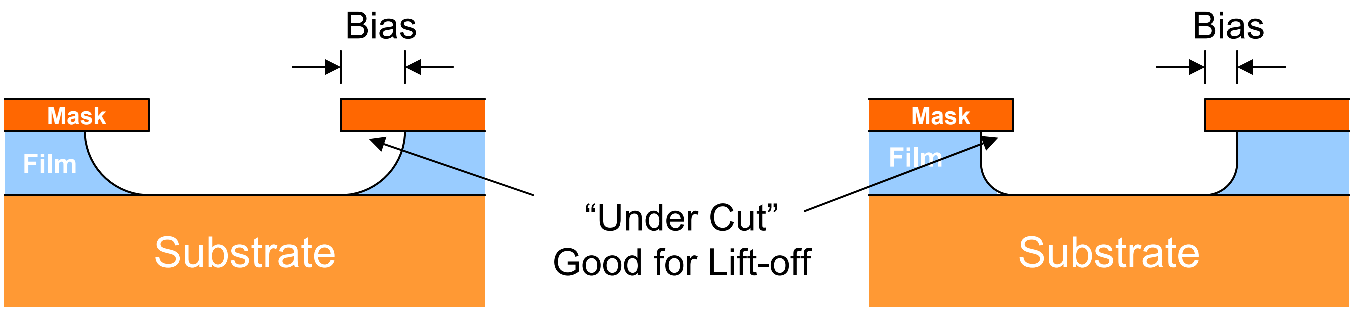


$0 < R_L < 1$



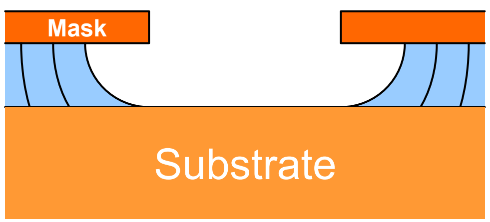
$R_L = 0$

"Under Cut" and "Over Etch"



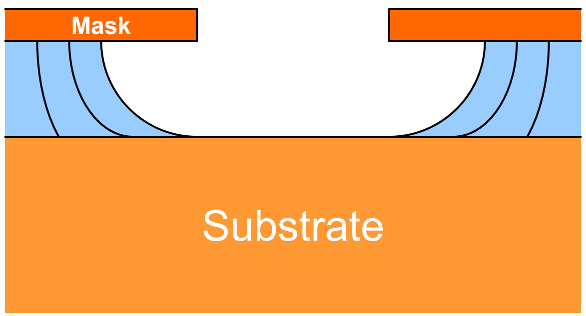
(R_l = 1, pattern dimension is poorly defined)

(R_l = 0.5, pattern dimension is better defined)



Over-Etch

- ➥ results in more vertical profile but larger bias



Worse in thick film

- ➥ Poor CD control in thick film using wet etch

Mask Erosion: Film-Mask Etching Selectivity

1) film horizontal etch rate (r_{fh}) < mask horizontal etch rate (r_{mh}):

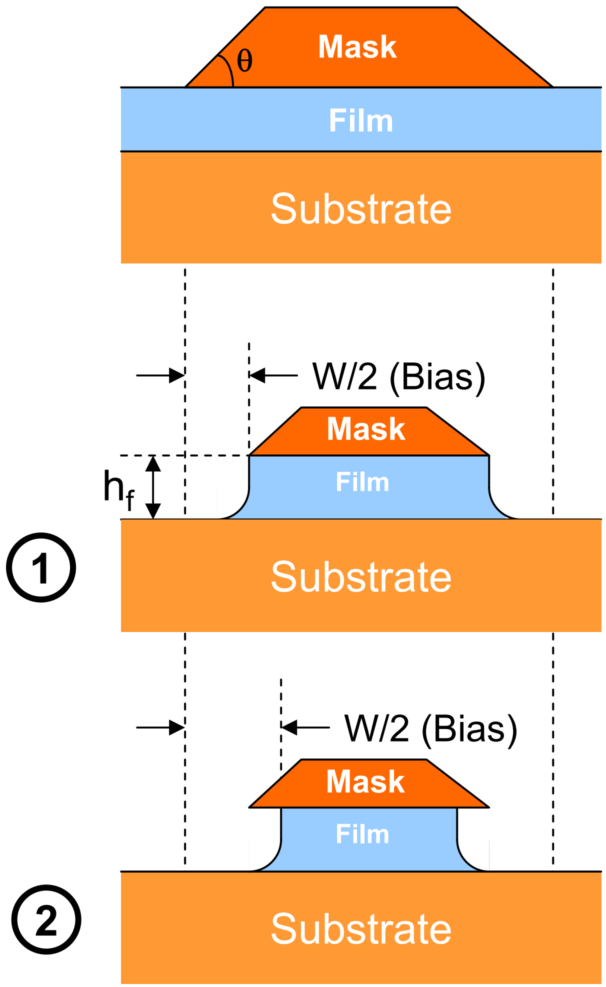
$$\frac{W}{h_f}(\%) = \frac{2}{S_{fm}}\left(\cot\theta + R_m\right)$$

$$R_{mL} = \frac{r_{mH}}{r_{mV}}$$ (mask lateral etch ratio)

$$S_{fm} = \frac{r_{fV}}{r_{mV}}$$ (ratio of film and mask vertical etching rate – **selectivity**)

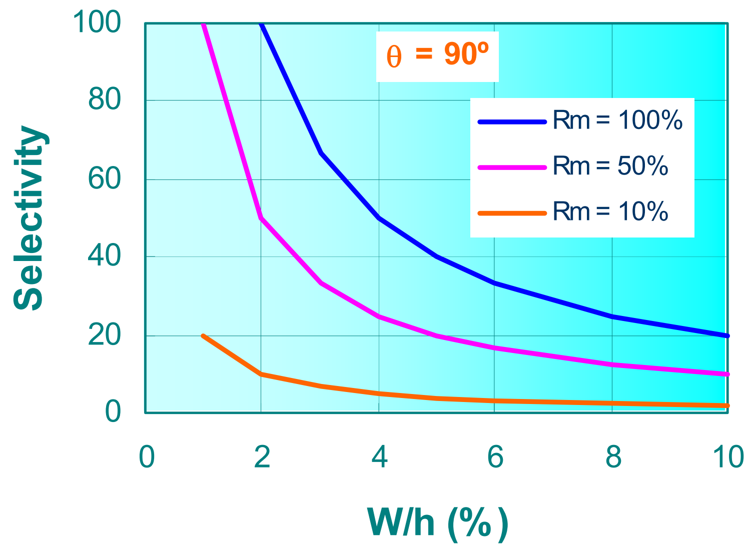
2) If film horizontal etch rate (r_{fh}) > mask horizontal etch rate (r_{mh}):

$$\frac{W}{h_f}(\%) = 2R_m$$

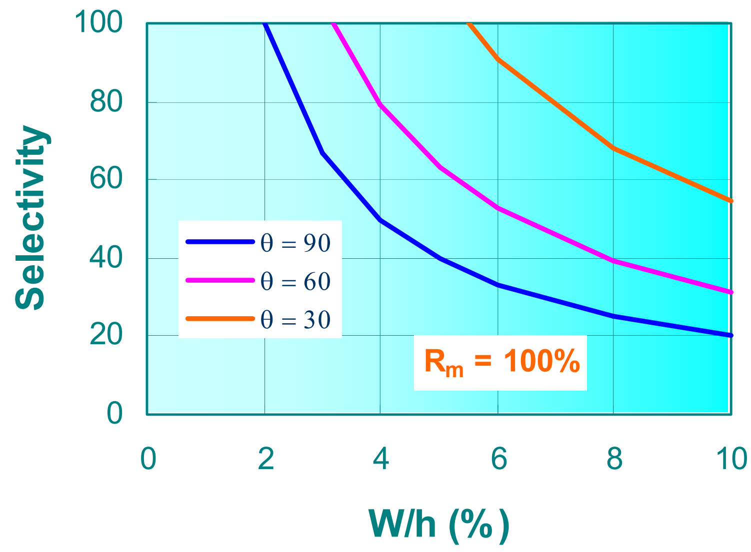


Film-Mask Selectivity (S_{fm}) vs. Etching Bias

Selectivity vs Mask Lateral Etch Ratio R_m



Selectivity vs Mask Wall angle θ



Most mask material etches isotropically

➡ Selectivity > 20:1

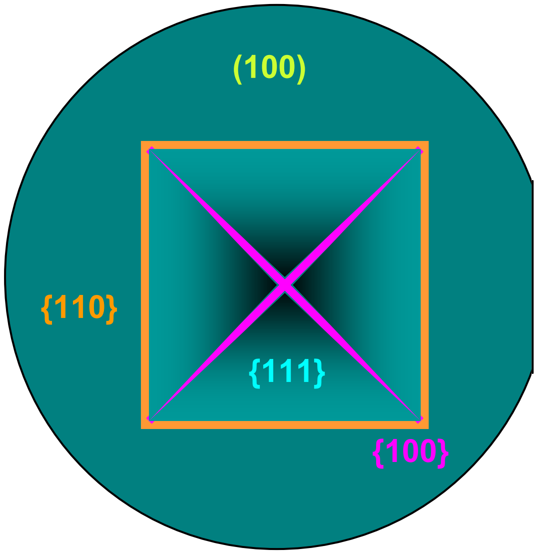
Wet Etch Crystalline Materials

- Typically, wet etching is isotropic
- However on crystalline materials, etching rate is typically lower on the more densely packed surface than on that of loosely packed surface

Si:
Diamond Lattice Structure

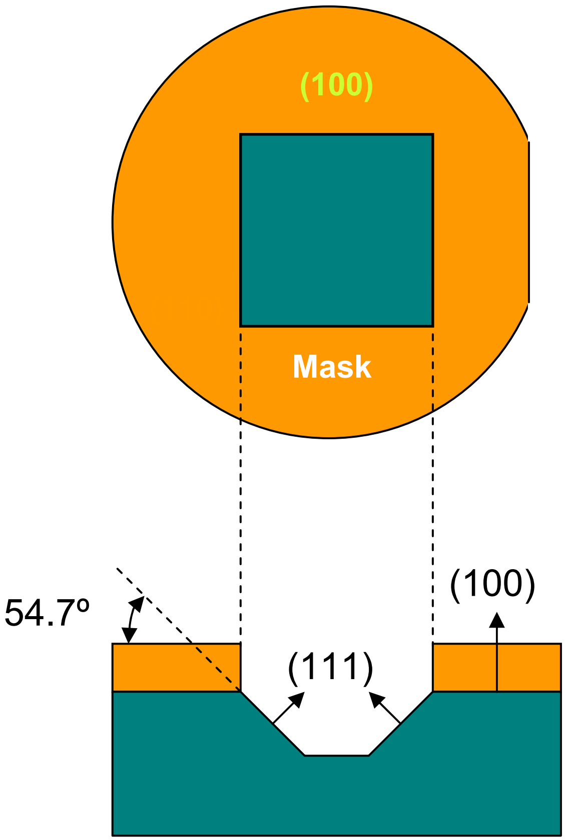
Surface Atom Density:
{111} > {100} > {110}

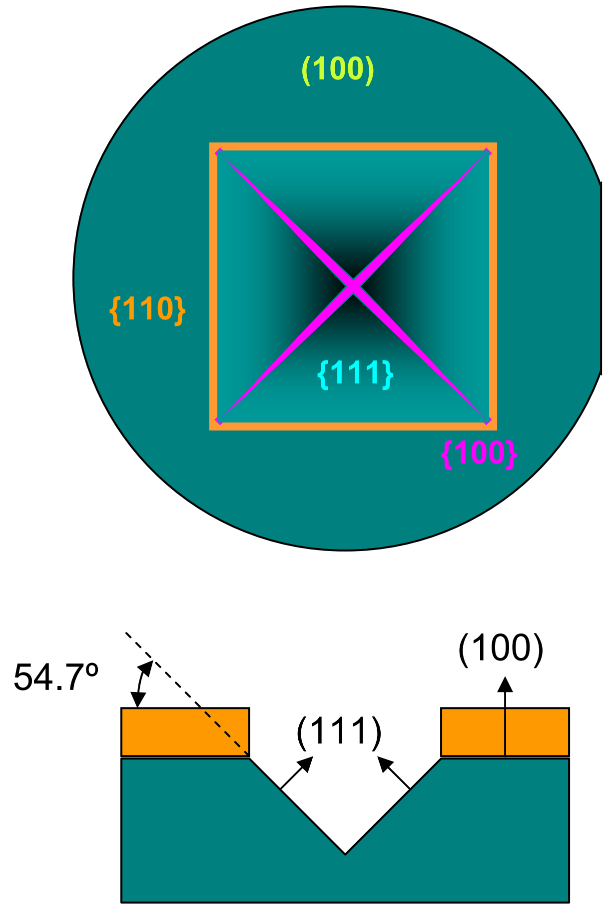
Etching rate:
R(100) ~ 100 x R(111)

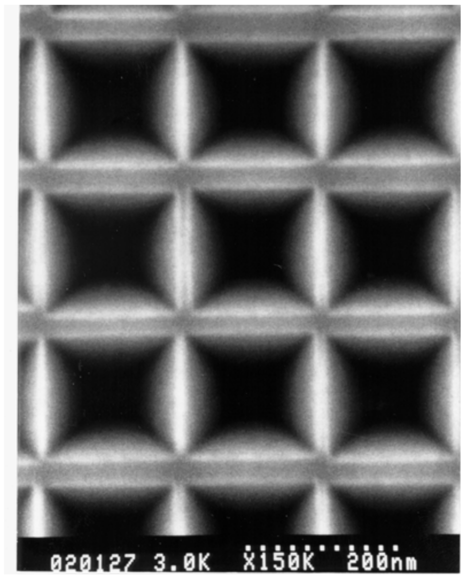


(100) Si Wafer

Si Wet Etch – (100) Wafer, Mask Aligned in <110> Direction

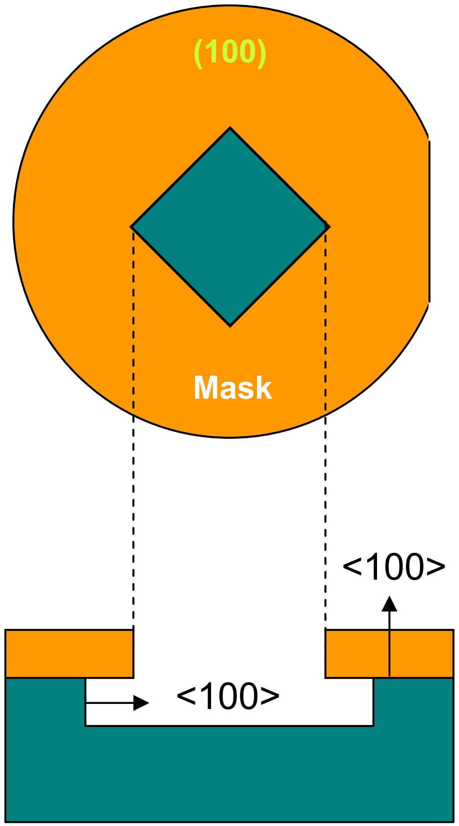




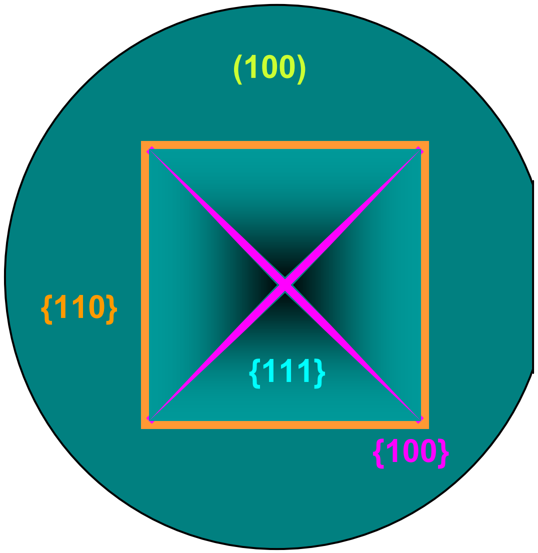


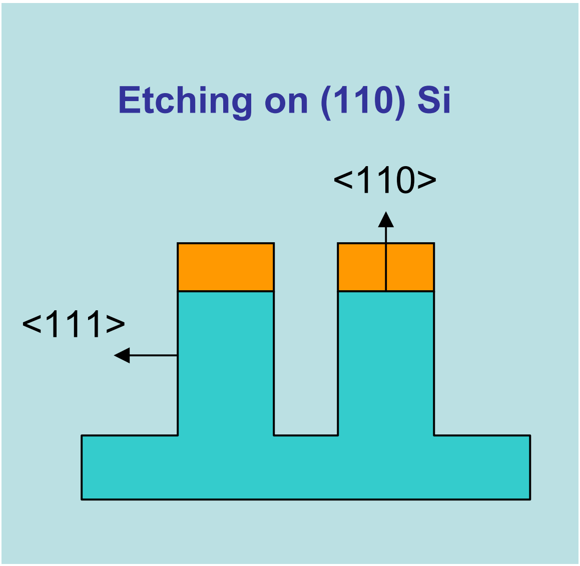
(200-nm size pyramidal pit on (100) Si substrate)

Si Wet Etch – (100) Wafer, Mask Aligned in <100> Direction

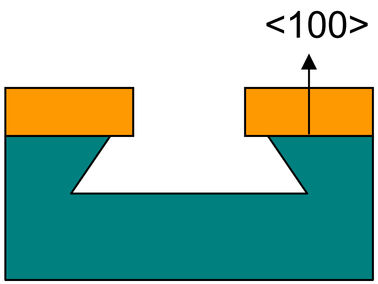


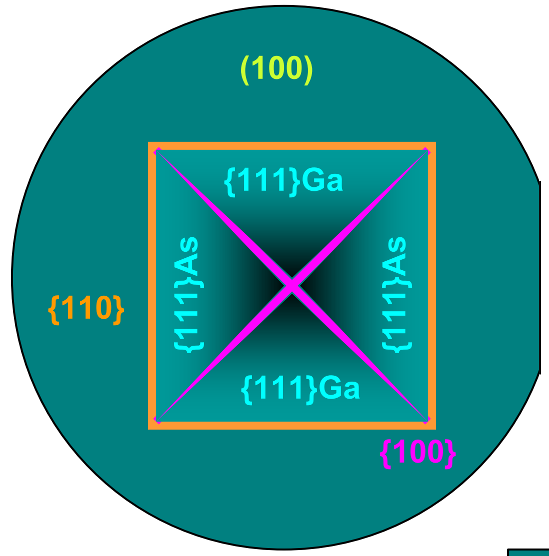
(Undercut!)

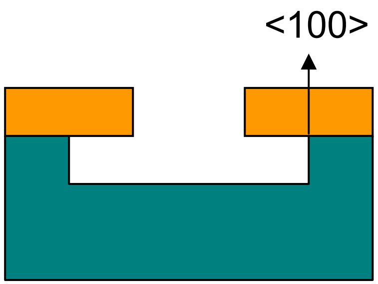


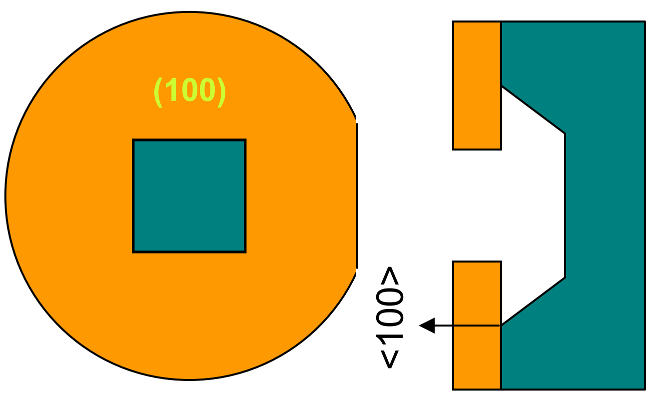


GaAs Wet Etch – (100) Wafer









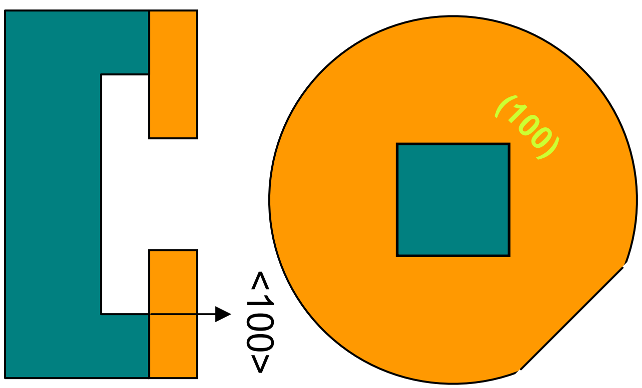
Zincblende Structure

Etching Rate:

R({111}As)

> R({100})

> R({111}Ga)



Typical Wet Etchants

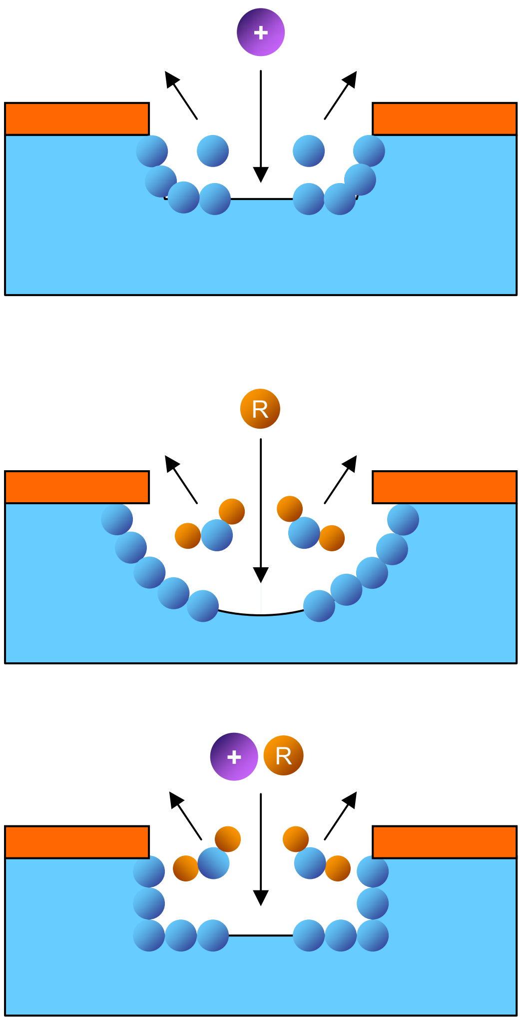
Material	Gas	Etching Rate	Mask	Selectivity
Si (a-Si)	1) KOH 2) HNO3 + H2O + HF	~ 6 – 600 nm/min (anisotropic) ~ 100 nm/min	Resist	> 50:1
SiO2	1) HF 2) BHF	~ 10 – 1000 nm/min	Resist	> 50:1
SI3N4	1) HF 2) BHF 3) H_3PO_4	~ 100 nm/min ~ 100 nm/min ~ 10 nm/min	Resist SiO_2	> 50:1
GaAs	1) H_2SO_4 + H_2O_2 +H_2O 2) Br + CH_3OH	~ 10 um/min	Resist	> 50:1
Au	1) HCl + HNO_3 2) KI + I_2 +H_2O	~ 40 nm/min ~ 1 um/min	Resist	> 50:1
Al	1) HCl + H2O 2) NaOH	~ 500 nm/min	Resist	> 50:1

Dry Etching

Problems with wet etching:

Isotropic ➡ unable to achieve pattern size smaller than film thickness

Main Purpose of Developing Dry Etching is to Achieve Anisotropic Etching



Type of Dry Etching Technology

Physical Sputtering

- Physical bombardment
    - Ion Mill
    - Plasma sputtering

Plasma Etching

- Plasma-assisted chemical reaction

Reactive Ion Etching (RIE)

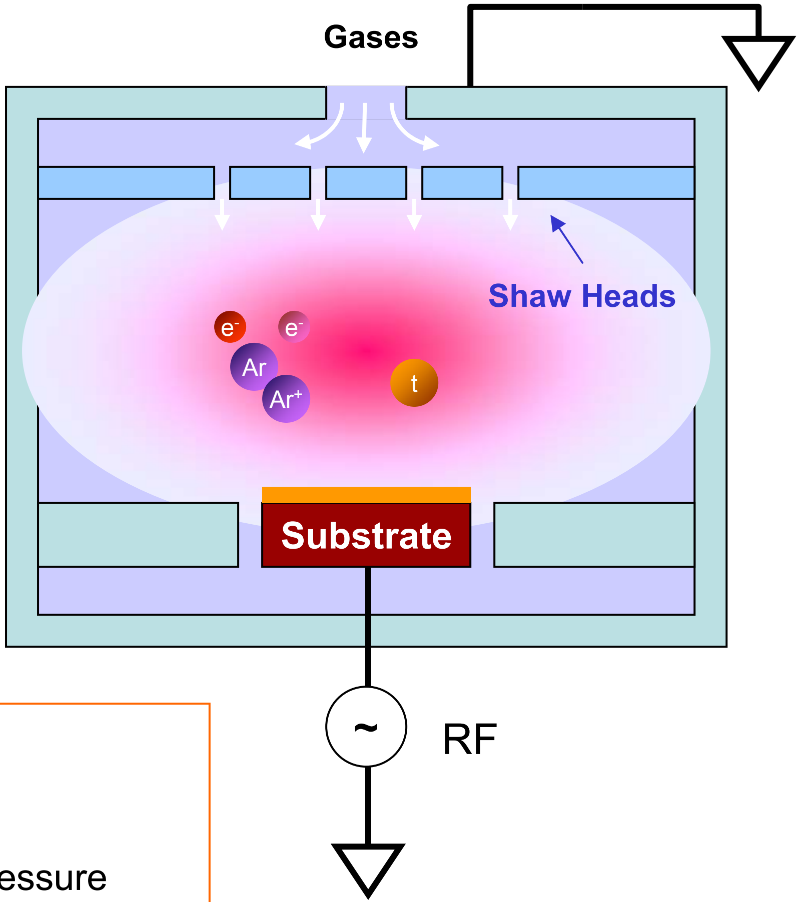
- Chemical reaction + ion bombardment

Dry Etching Comparison

Chamber Pressure	Beam Energy	Dry Etching	Anisotropy	Selectivity
High > 100 Mtorr	Low	**Plasma Etching** • Plasma assisted chemical reaction	Low	Very Good
Low 10 ~ 100 mtorr	Medium	**Reactive Ion Etching** • Physical bombardment + chemical reaction	Medium	Good
Very Low < 10 mtorr	High	**Physical Sputtering (Ion Mill)** • physical bombardment	High	Poor

Reactive Ion Etching (RIE)

- Etching gas is introduced into the chamber continuously
- Plasma is created by RF power
- Reactive species (radicals and ions) are generated in the plasma
  - radicals: chemical reaction
  - ions: bombardment
- Reactive species diffused onto the sample surface
- The species are absorbed by the surface
- Chemical reaction occurs, forming volatile byproduct
- Byproduct is desorbed from the surface
- Byproduct is exhausted from the chamber



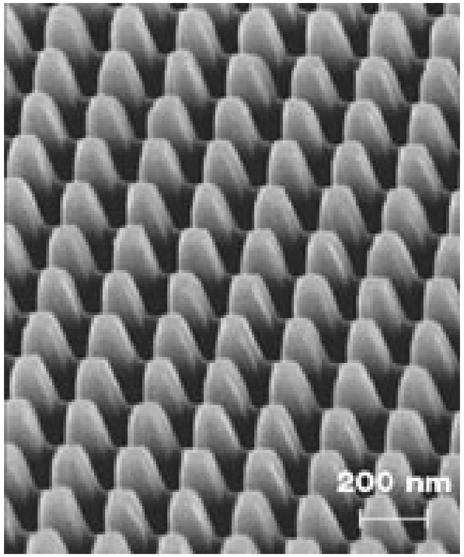
Gas Selection:

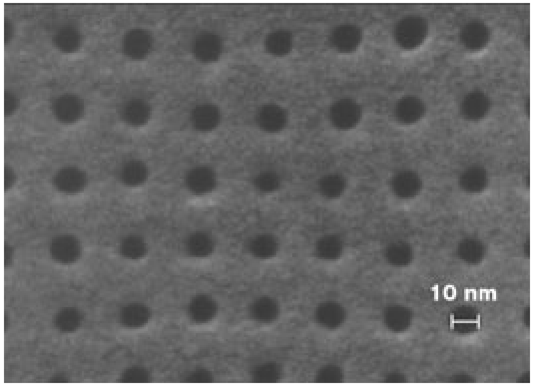
1) React with the material to be etched
2) Result in volatile byproduct with low vapor pressure

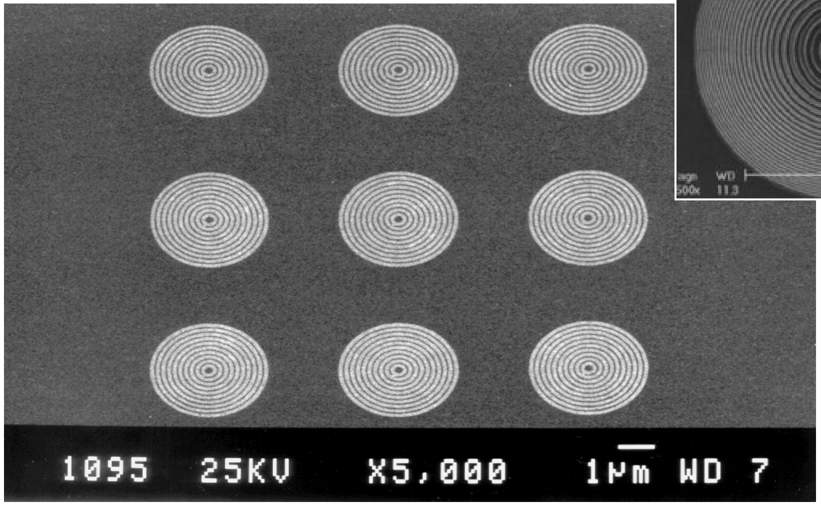
Typical RIE Gases

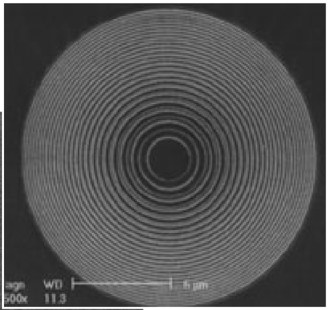
Material	Gas	Etching Rate (A/min)	Mask	Selectivity
Si (a-Si)	1) CF4 2) SF6 3) BCl2 + Cl2	~ 500	Resist Metal (Cr, Ni, Al)	~ 20:1 ~ 40:1
SiO_2	1) CHF3 + O2 2) CF4 + H2	~ 200	Resist Metal (Cr, Ni, Al)	~ 10:1 ~ 30:1
SI_3N_4	1) CF4 + O2 (H2) 2) CHF3	~ 100	Resist Metal (Cr, Ni, Al)	~ 10:1 ~ 20:1
GaAs	1) Cl2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

Arts of Nanofabrication: Nano-Dots, -Holes and -Rings

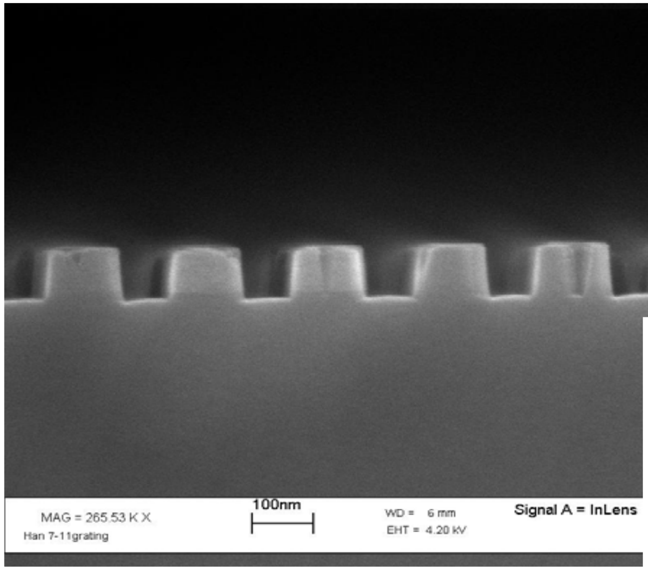


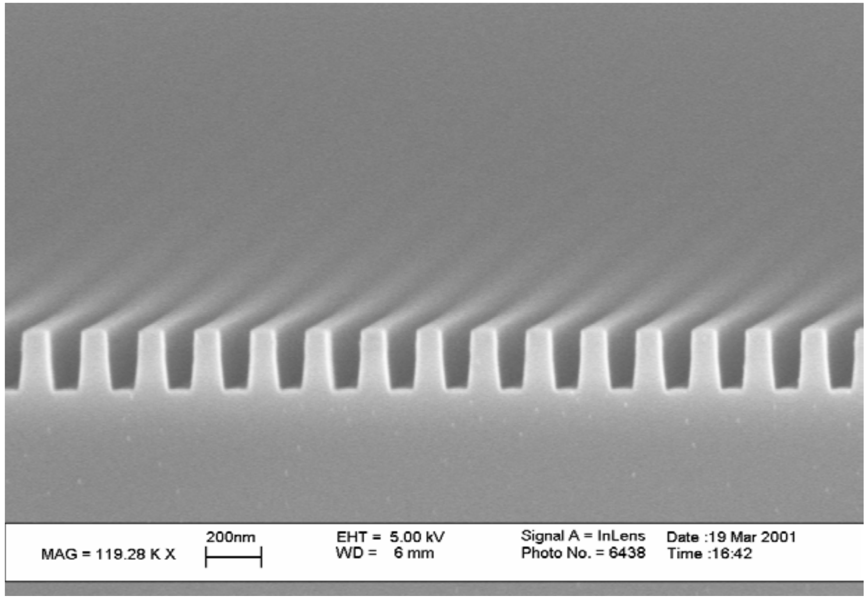






Arts of Nanofabrication : Nano-Gratings





Arts of Nanofabrication : Nano-Fluidic Channels