Characteristics of Neutral Beam Generated by a Low Angle Reflection and Its Etch Characteristics by Halogen-Based Gases

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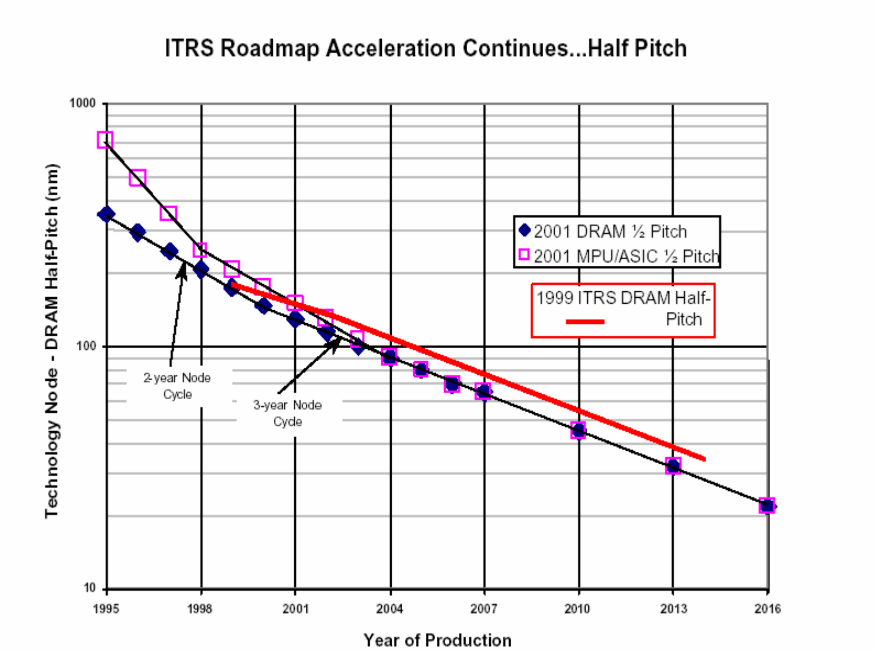
SungKyunKwan University

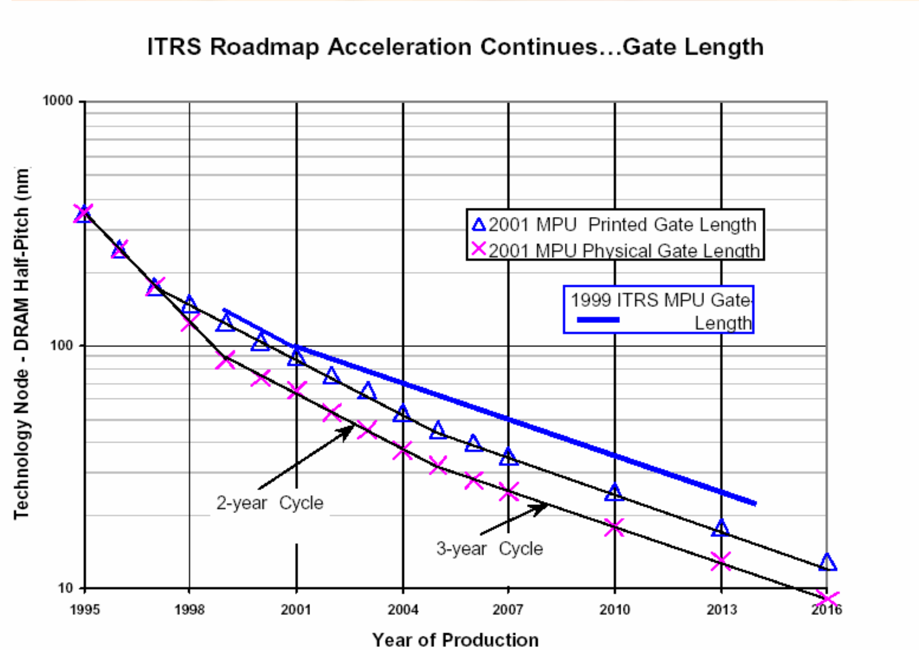
Tera Level Nano Devices

Problems of Current Etch Technology

- Scaling down of the device to nano-scale : increased volunability to processing damage
  - Physical damage
  - Electrical damage (Charging damage)

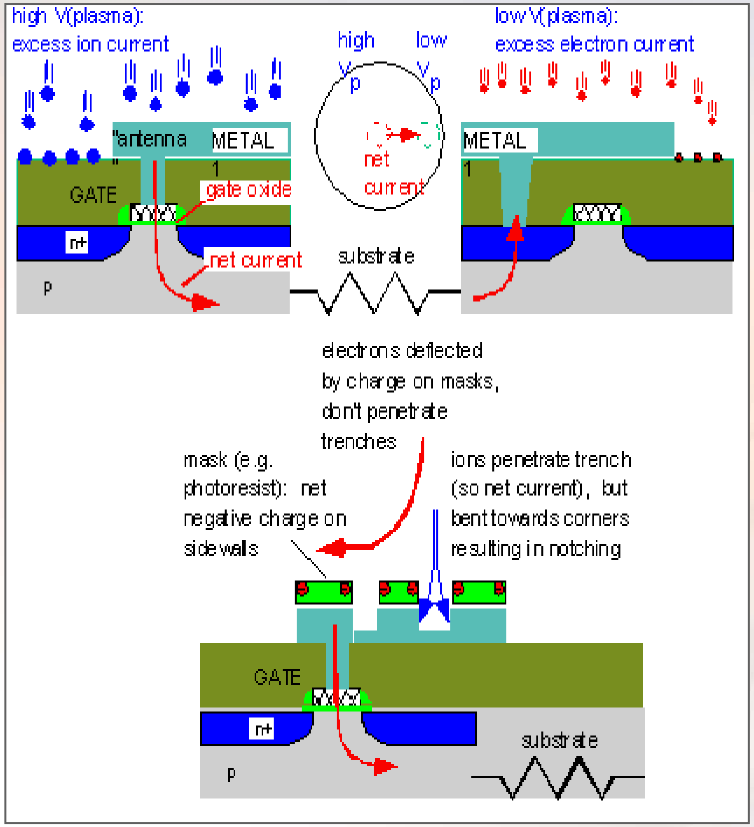


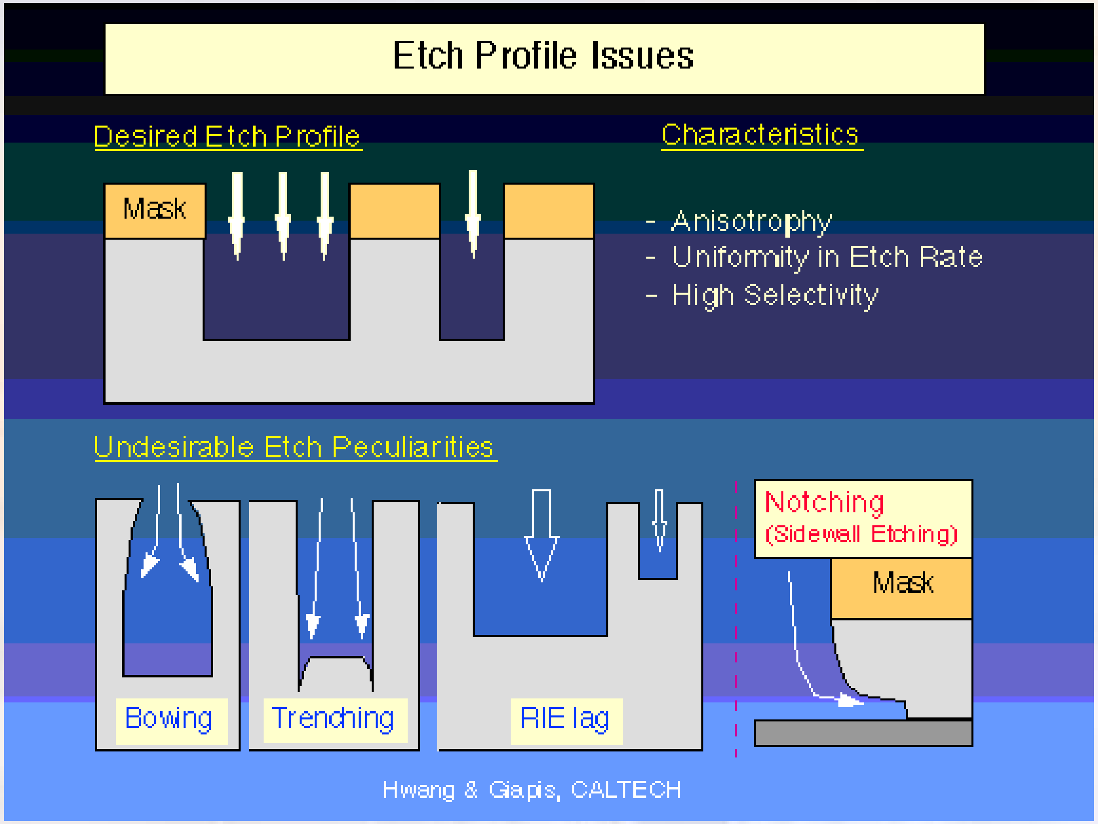
DRAM Half Pitch



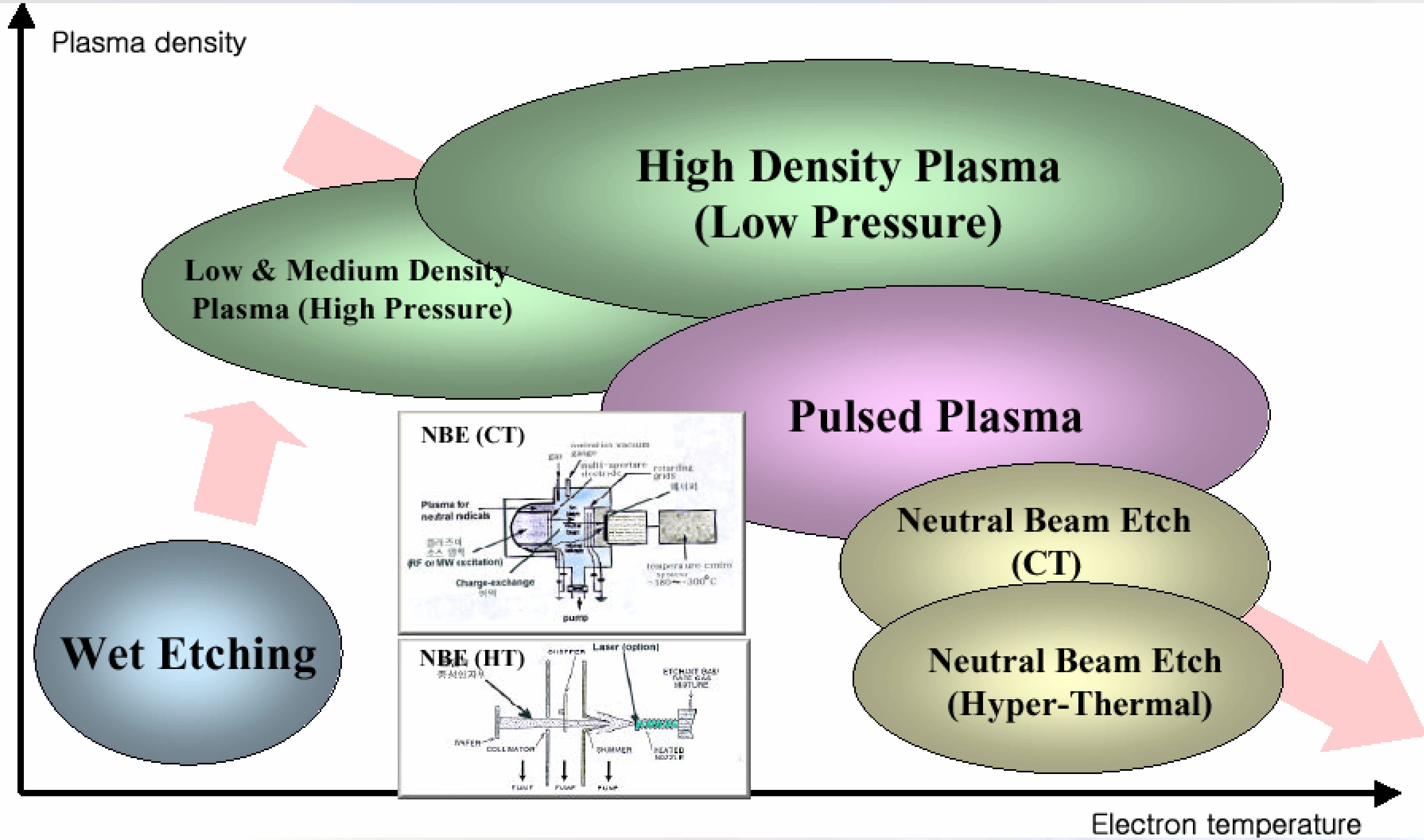
Gate Length

Charging Effects





Trend of Etching Tools Development



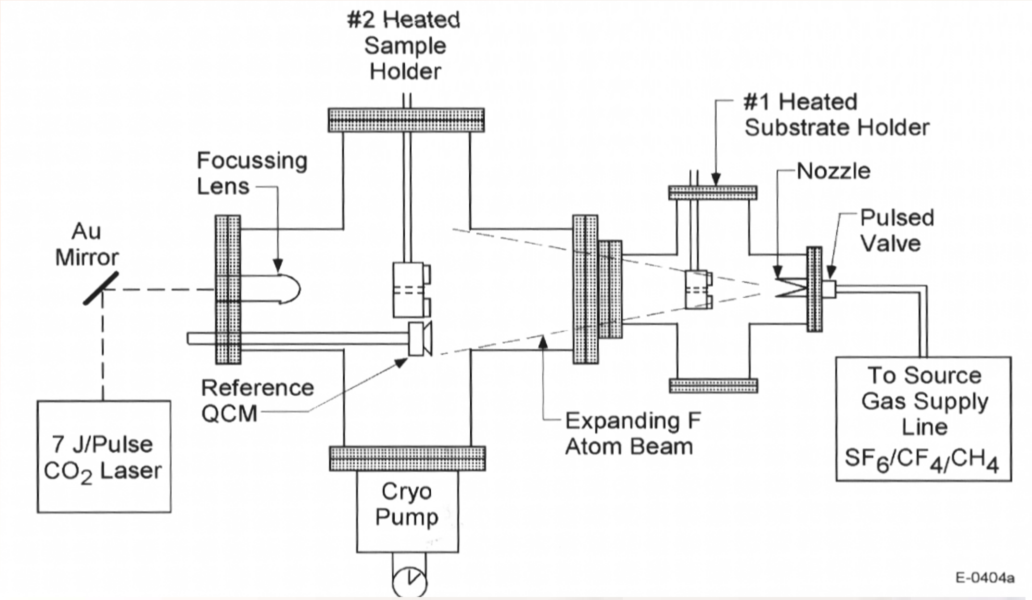
Researtch Status of Neutral Beam Etching Technologies

1) Gas dynamics or hyperthermal atomic beam (Heating of gas)
   - Caltech by Giapis in 2000 (laser), PSI Inc. in 2000 (laser), NEC by Nishiyama in 1995 (thermal heating), etc. Oklahoma Univ. in 2000 (hyperthermal)

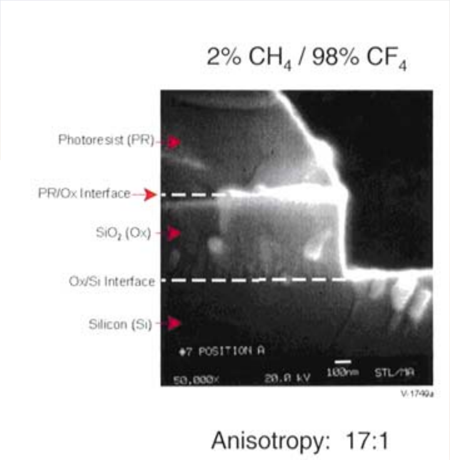
2) Ion-neutral scattering (charge exchange process)
   - Hitach by Mizutani in 1995 (ion removal by retarding grid), NTT by Matuso in 1995 (ion removal by magnetic field), etc.

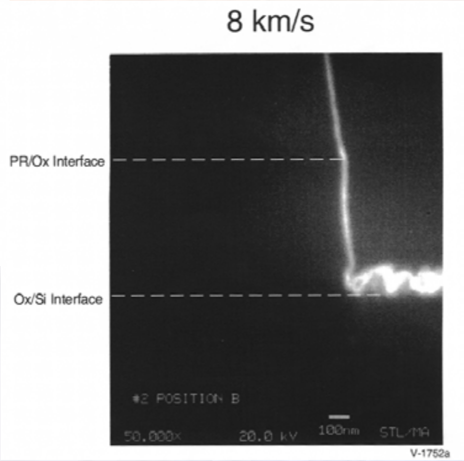
3) Ion-electron recombination (surface neutralization)
   - IBM by Chen in 1997 (sheath recombination by ion and electron)
   - Tohoku University in 2002
   - Ebara Research Co. in 1995 (capillary hole)
   - Tokyo Univ. in 2000 (focused fast atom beam)

Neutral Beam Etching using Gas Dynamics



PSI Inc. in 2000 (laser)





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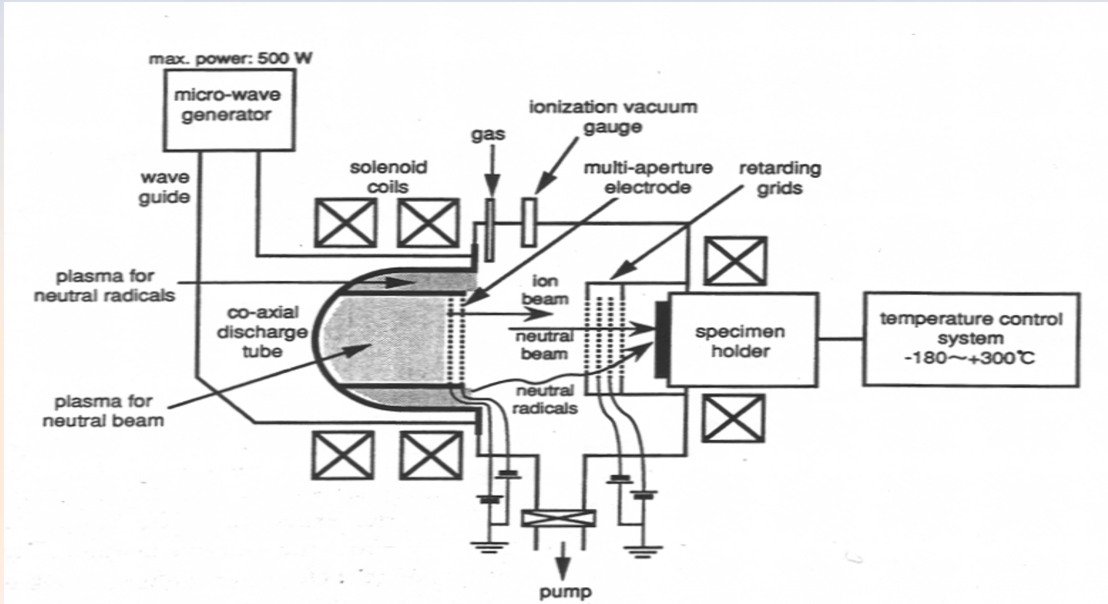
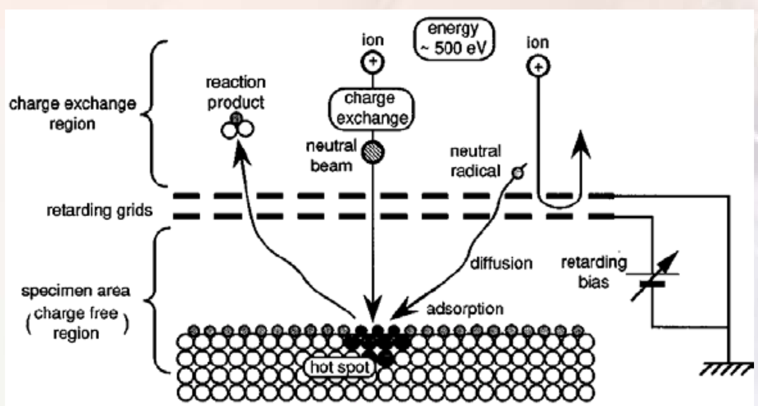
Neutral Beam Etching by Ion – Neutral Scattering





(Tatsumi Mizutani et. al, hitachi, 1995)

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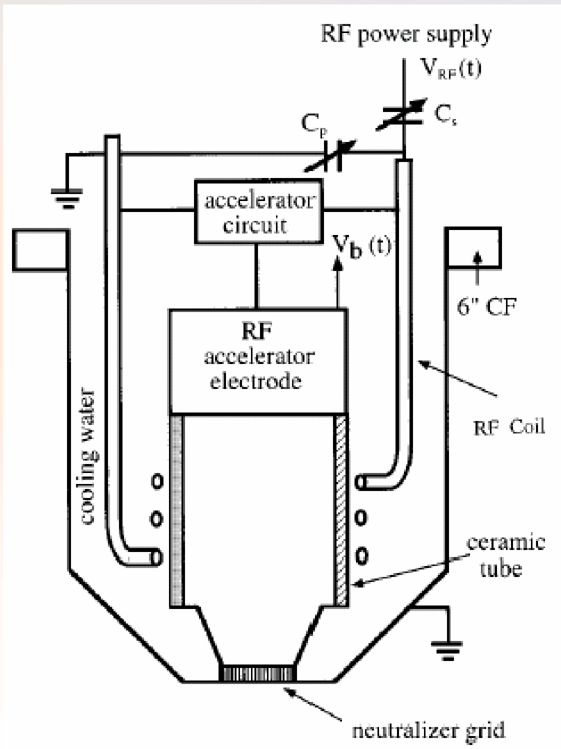
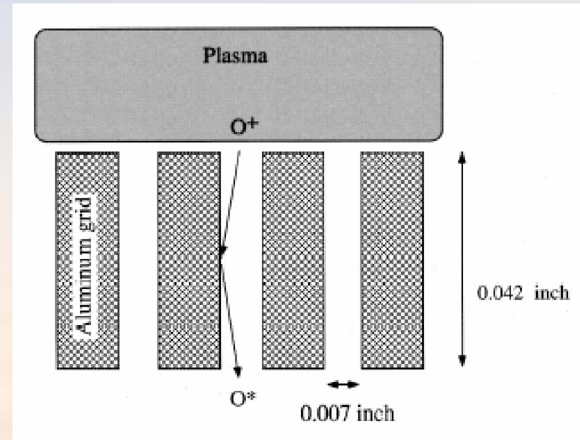
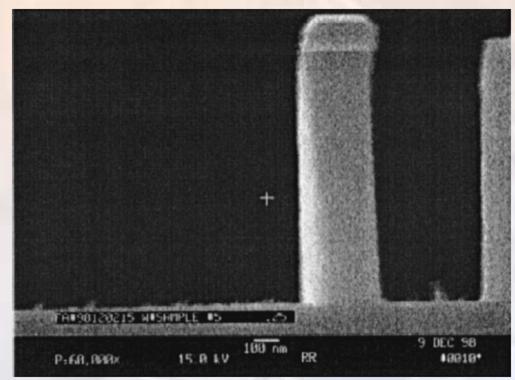
Neutral beam etching by Ion-Electron Recombination (I)



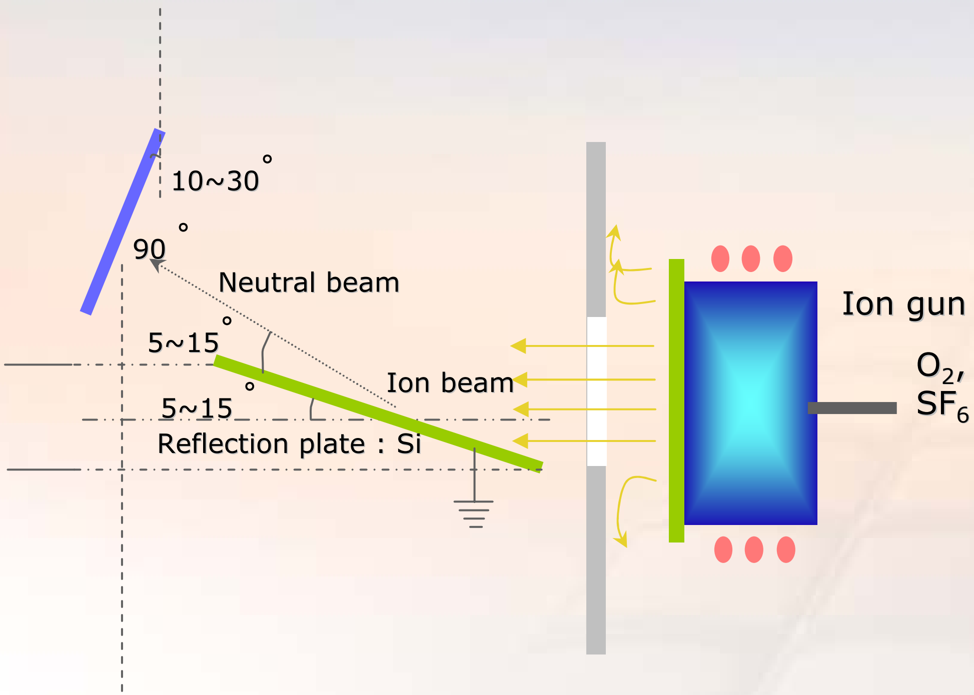


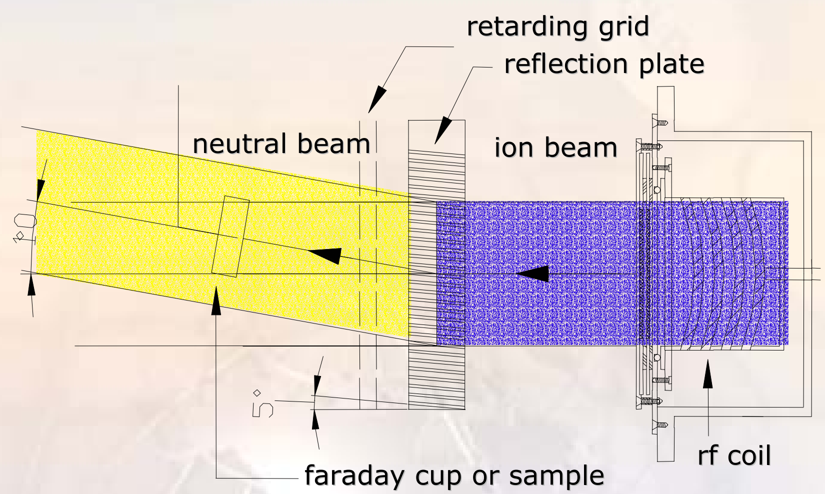


(Demetre J. Economou et.al, Houston Univ., 2000)

Generation of Directional Neutral Beam by Low Angle Reflection

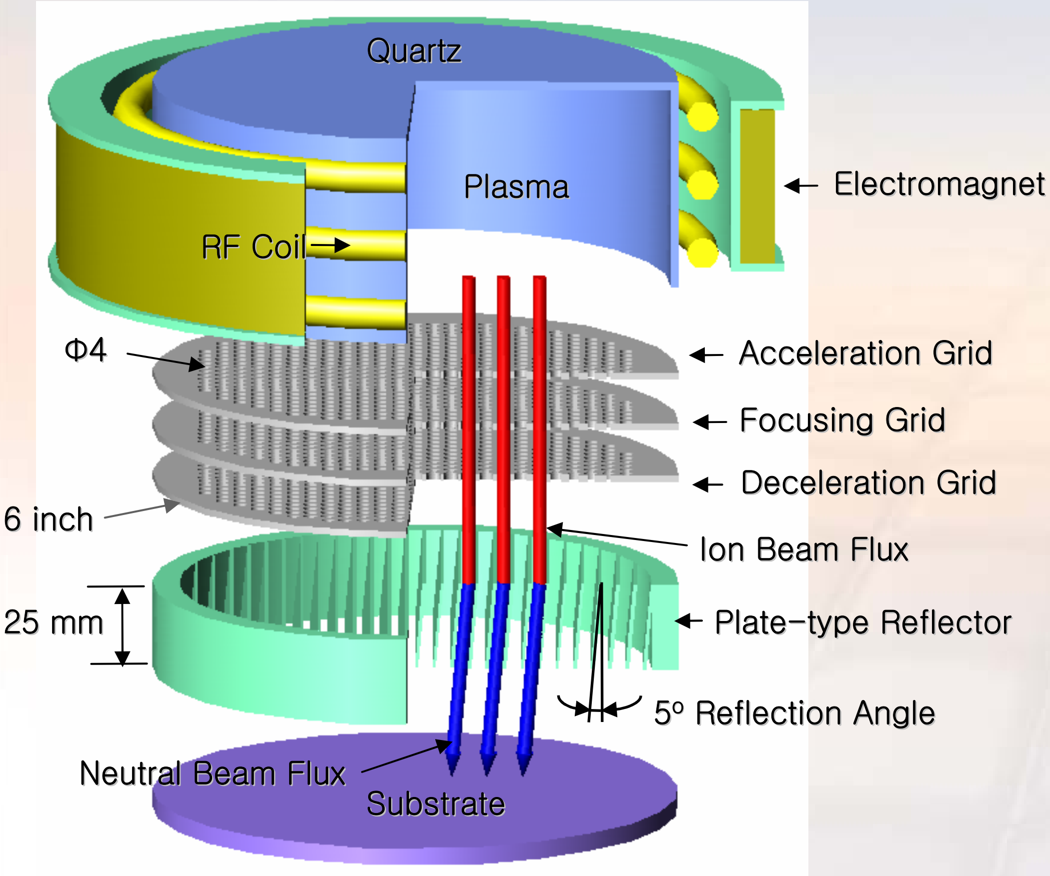
- Recombination by low angle forward scattering

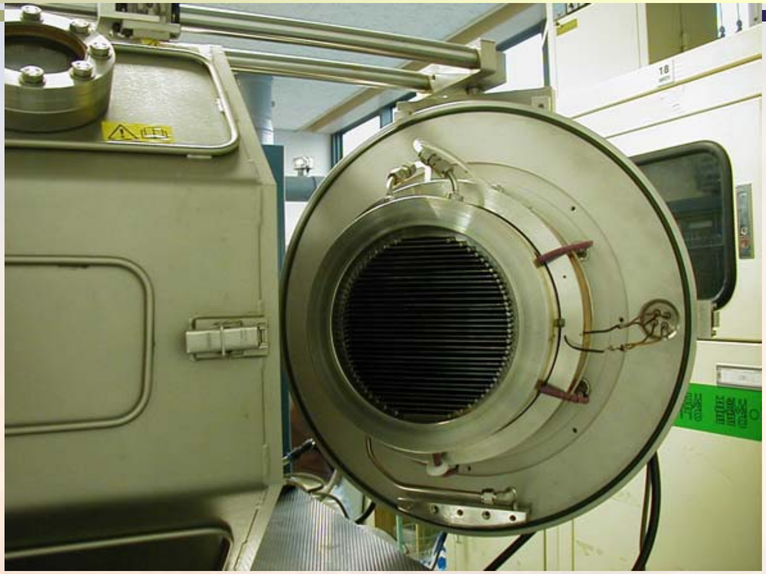


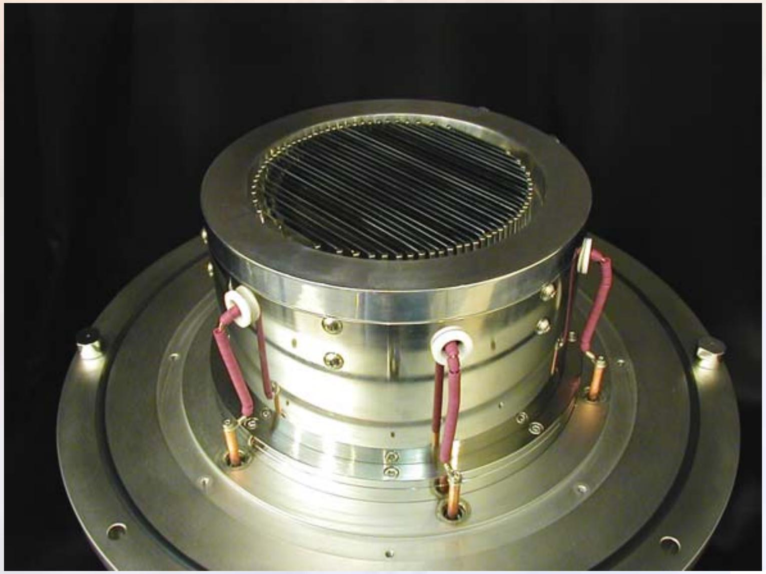


- When the ion beam was reflected by a reflector at the angles lower than 15˚, most of the ions reflected were neutralized and the lower reflector angle showed the higher degree of neutralization.

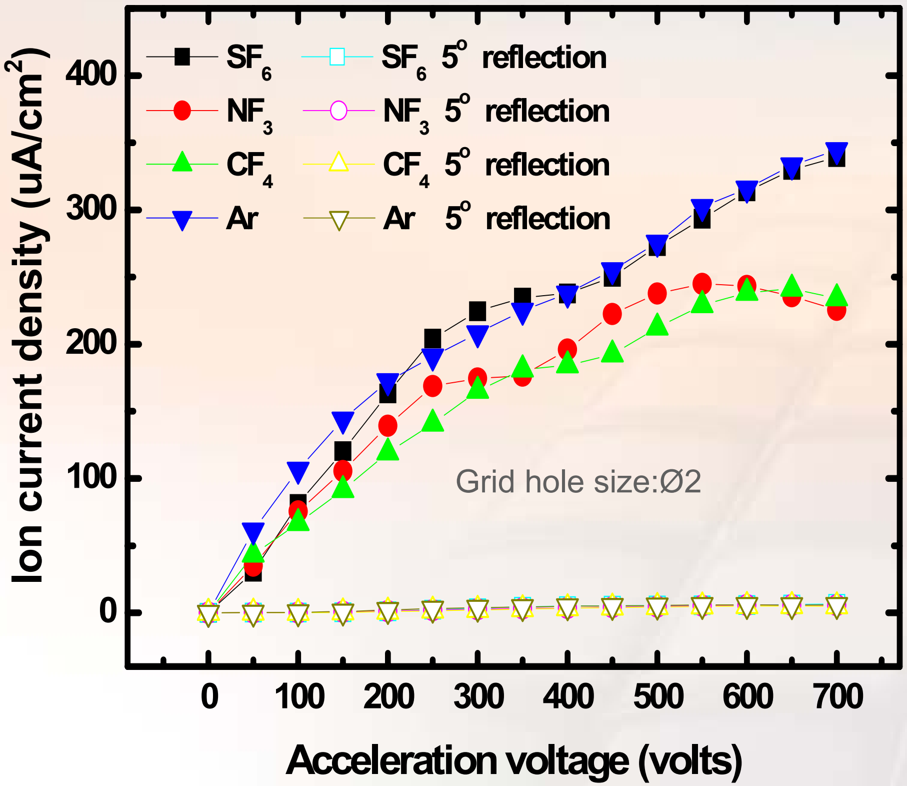
Experimental Low Angle Reflected Neutral Beam System

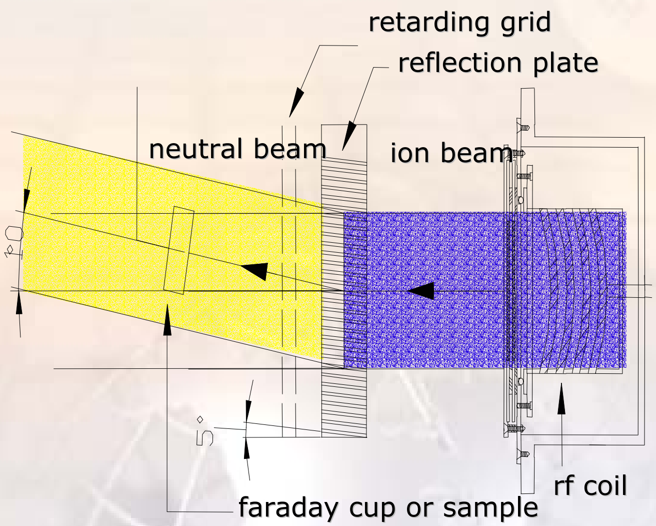






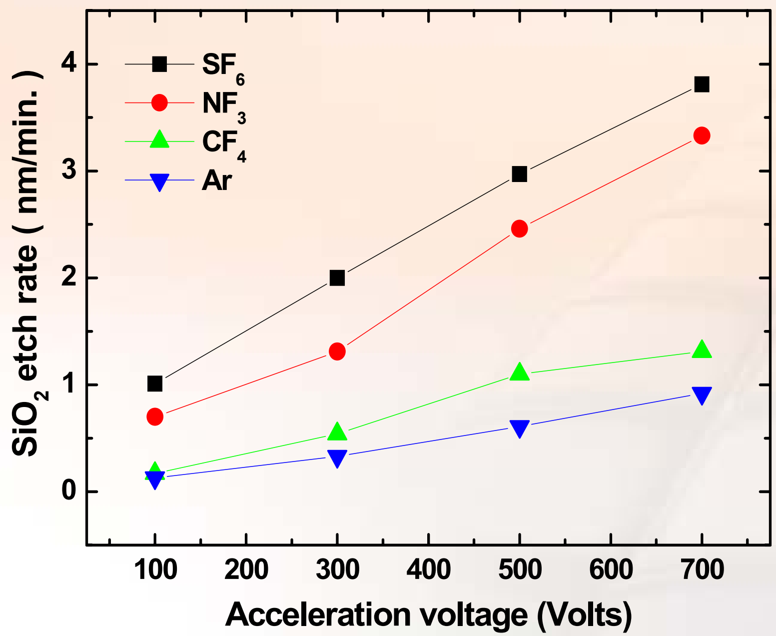
Ion Flux and Neutral Flux as a function of Acceleration Voltage



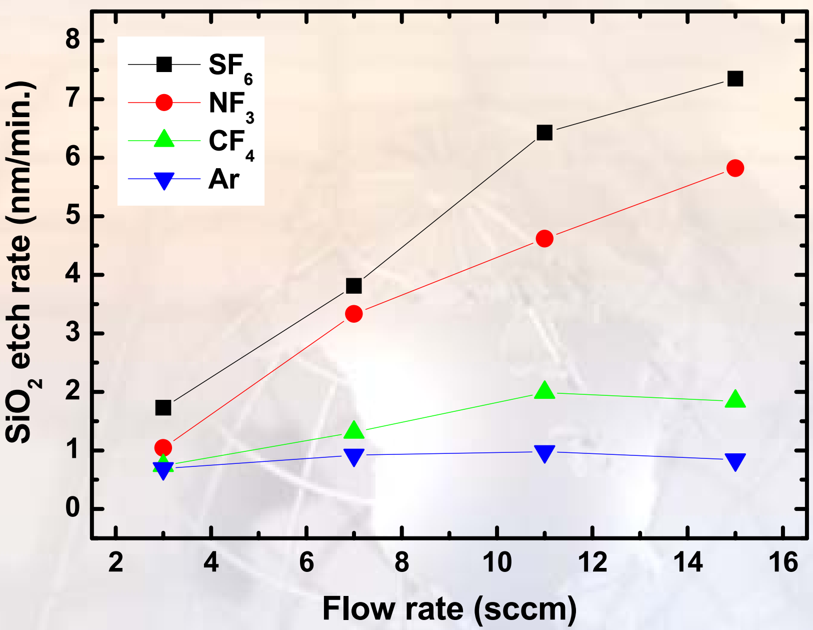


SiO_2 Etch Rate as Functions of Acceleration Voltage and Gas Flow Rates for SF_6, NF_3, CF_4, and Ar

Condition :
reflector angle: 5˚ , rf power: 500W
SF_6 gas flow rate: 7 sccm

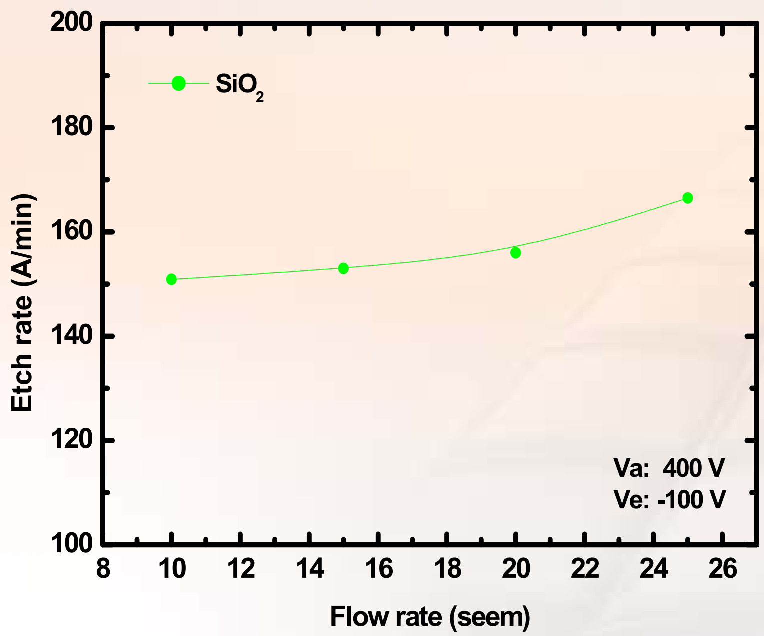


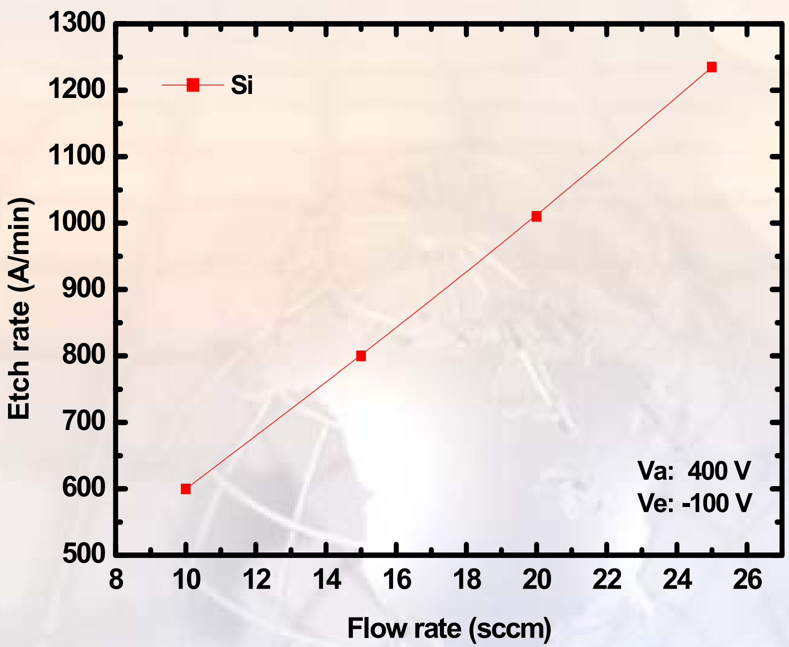
Condition :
reflector angle: 5˚ , rf power: 500W
Va : 700V



SiO_2 and Si Etch Rate as a Function of SF_6 Gas Flow Rate

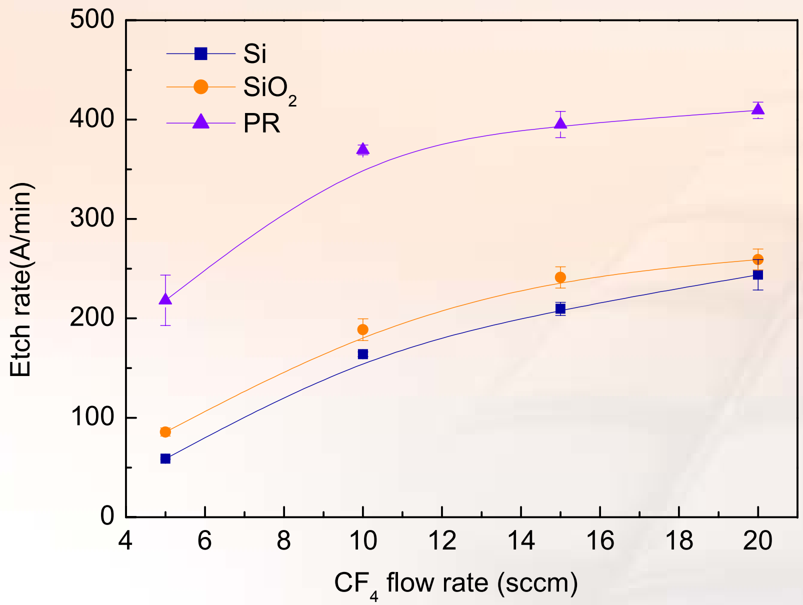
- Condition : reflector angle: 5˚ , rf power: 400W, distance between reflector and sample : 4 cm, pure SF_6, Va: 400 V, Ve: −100 V

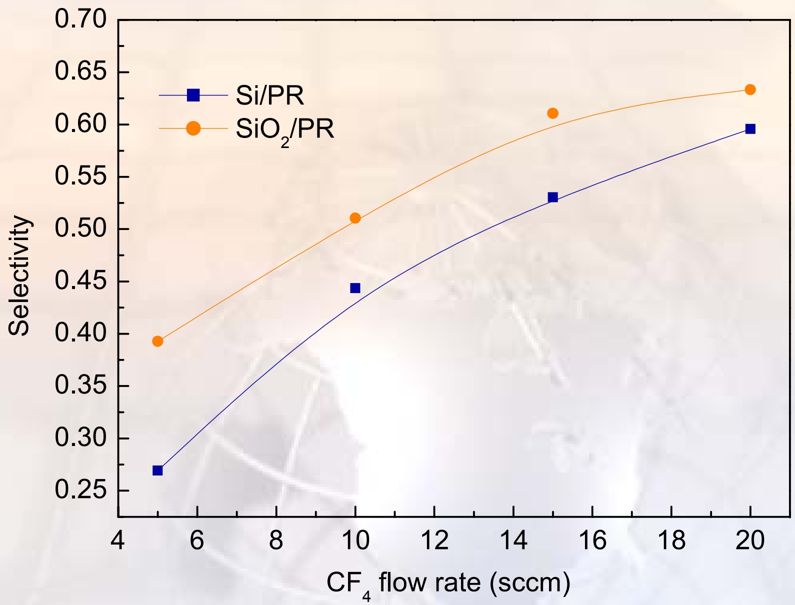




Etch Rate and Etch Selectivity as a Function of Gas Flow Rate Using the Neutral Beam Etching System

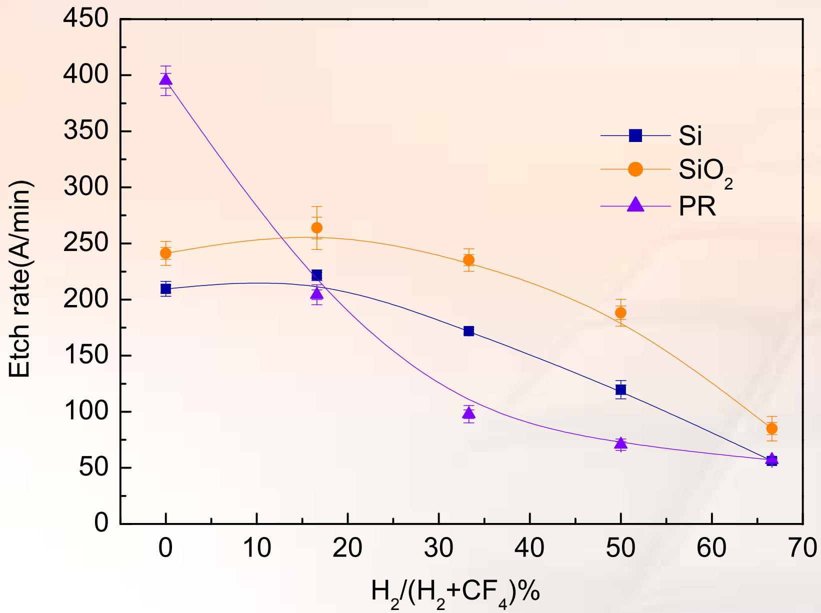
- Condition : rf power: 300W , acceleration voltage: 400V, reflector angle: 5°
  reflector material: Si

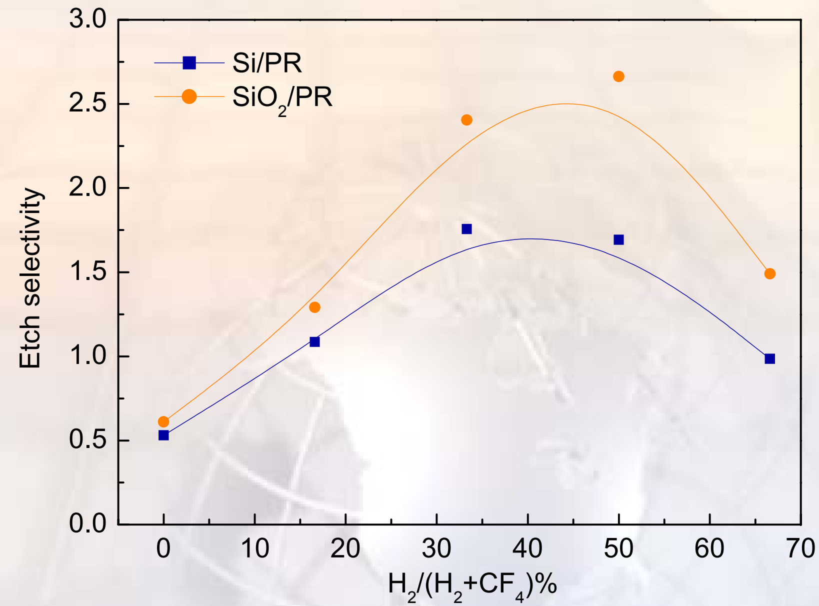




Etch Rate and Etch Selectivity as a Function of H_2 to CF_4 Using Neutral Beam Etching System

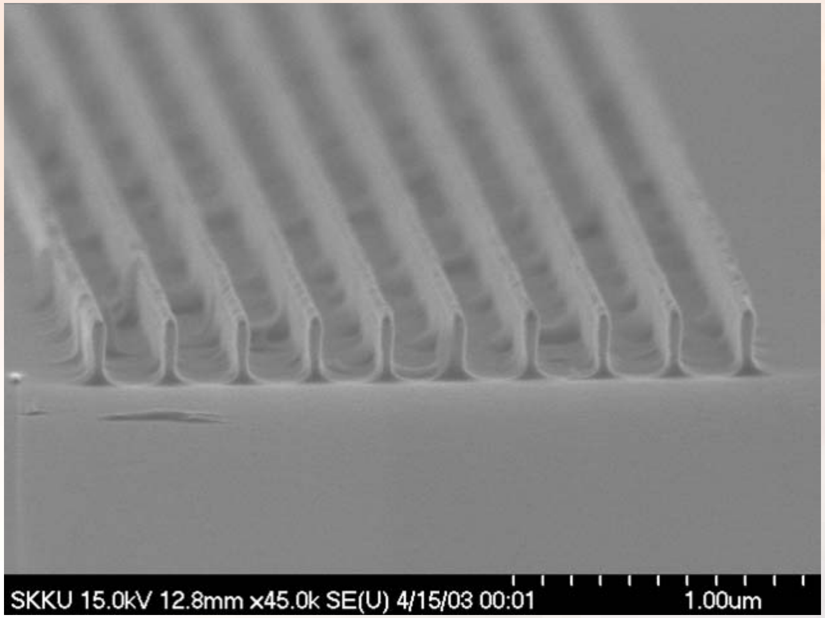
- Condition : rf power: 300W , CF_4+H_2: 15sccm, acceleration voltage: 400V, reflector material: metal, reflector angle: 5°

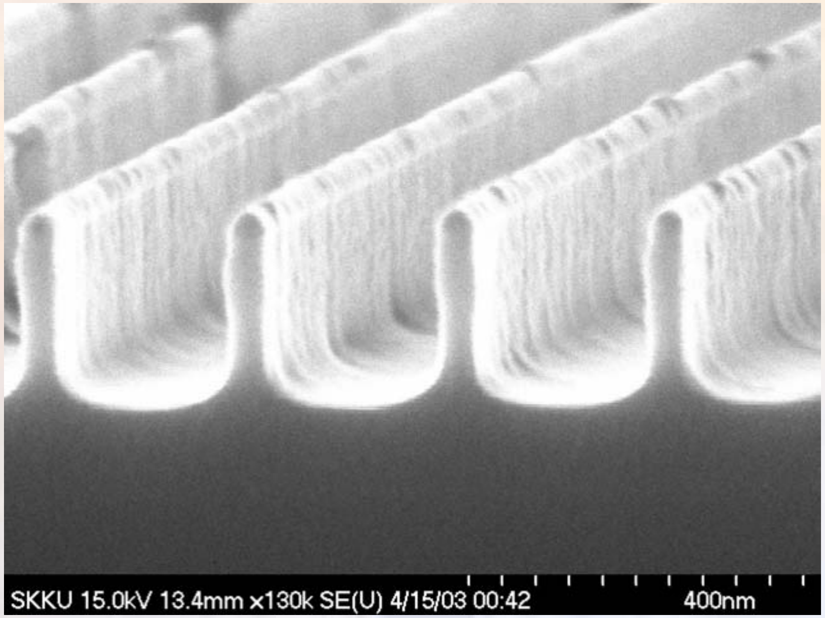




SEM Micrograph of SiO_2 Etch Profiles (Neutral Beam Etching)

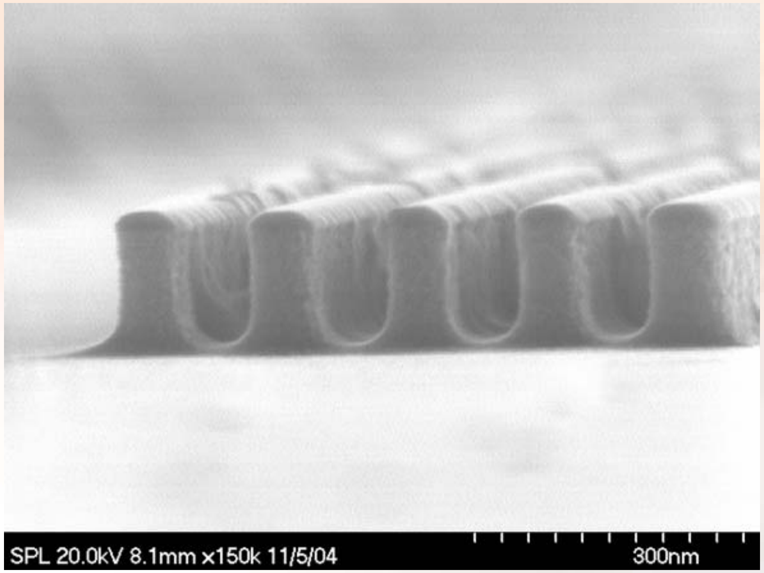
- Condition : SF_6 2.5 sccm, rf power: 400 W , acceleration voltage: 400V, reflector angle: 5º
  etch mask : Cr

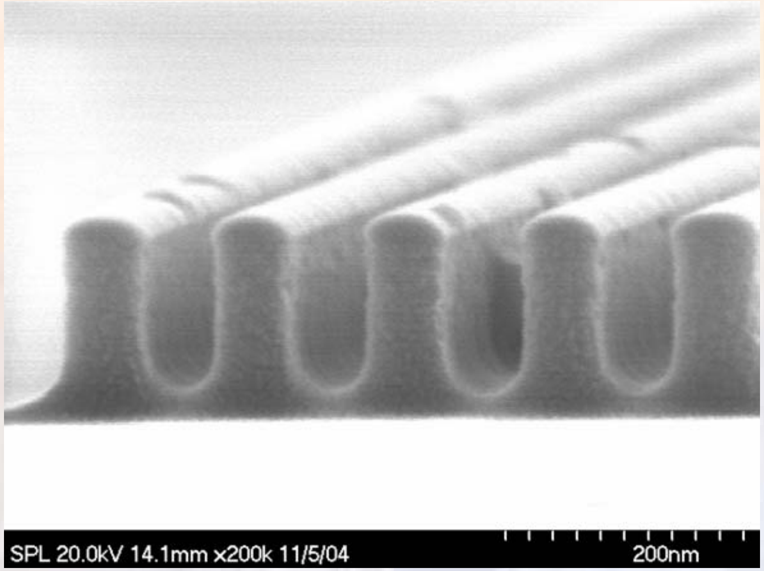




SEM Micrograph of Si Etch Profiles

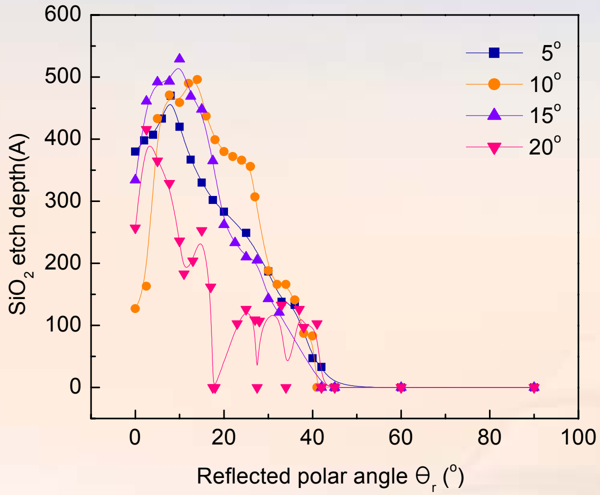
- Condition : CF_4 15sccm, rf power: 300W , acceleration voltage: 400V, reflector material: metal, reflector angle: 5°

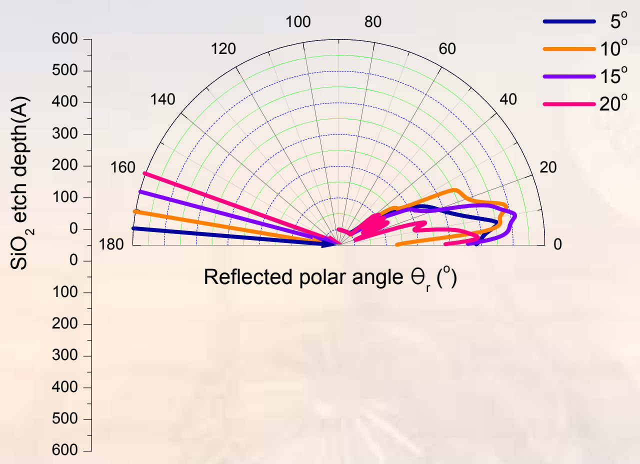


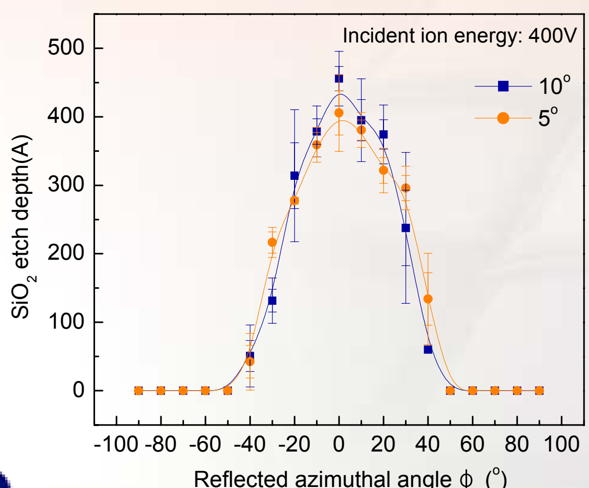


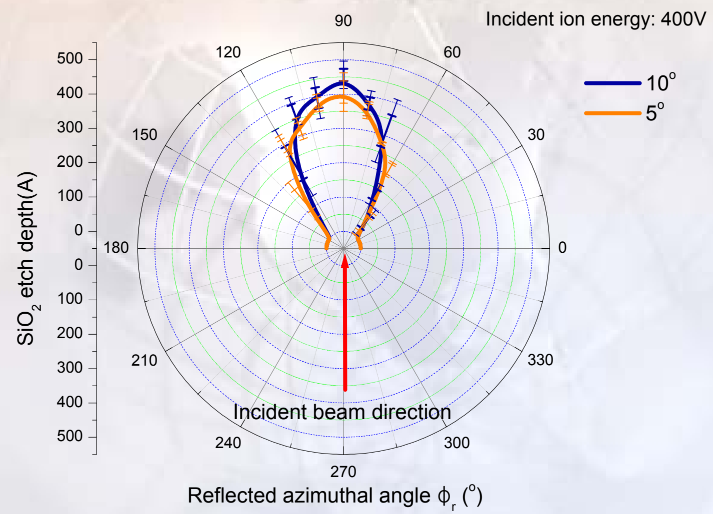
Effect of Reflector Angle on Reflected Angle and Flux of the Neutrals

- Condition : SF_6 10 sccm(0.6 mTorr), rf power: 400W , acceleration voltage: 400V
  reflector material: Si



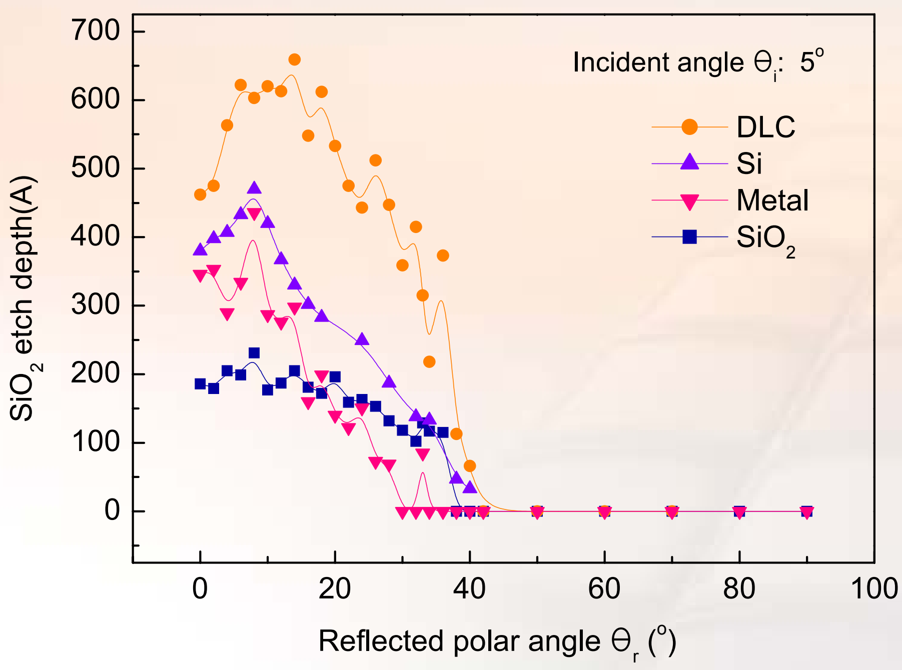


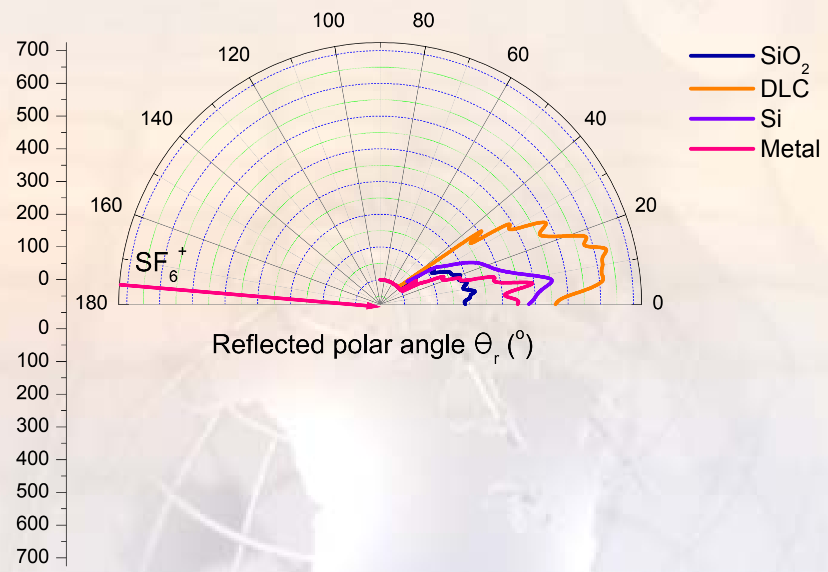




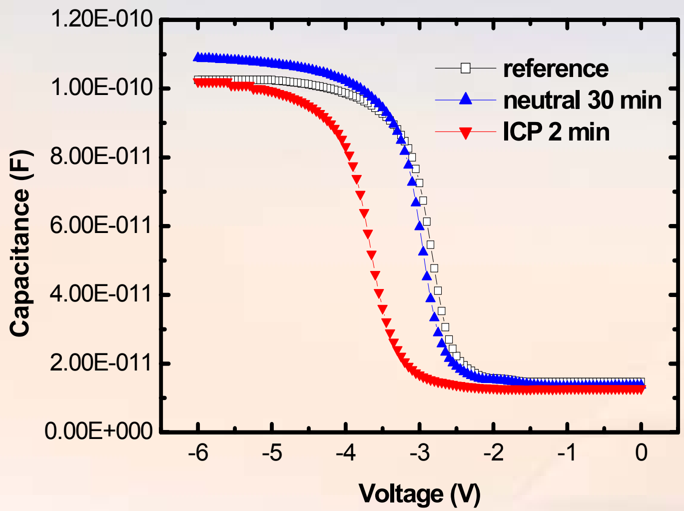
Effect of Reflector Materials on Reflected Angle and Flux

- Condition : SF_6 10 sccm(0.6 mTorr), rf power: 400W , acceleration voltage: 400V
  reflector angle: 5°

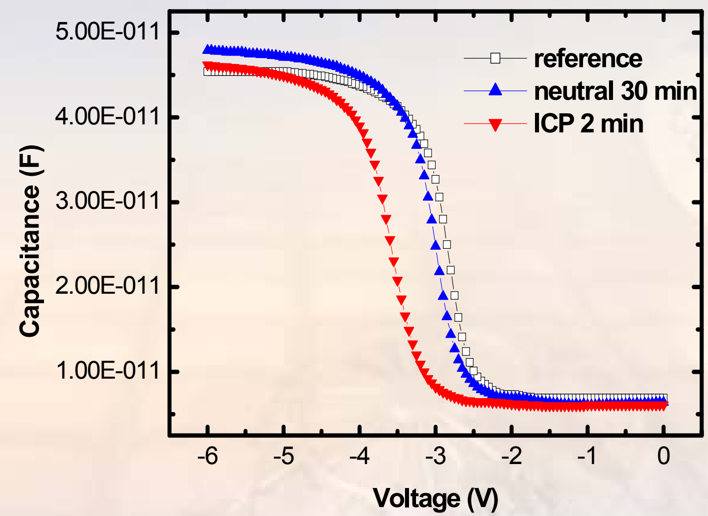




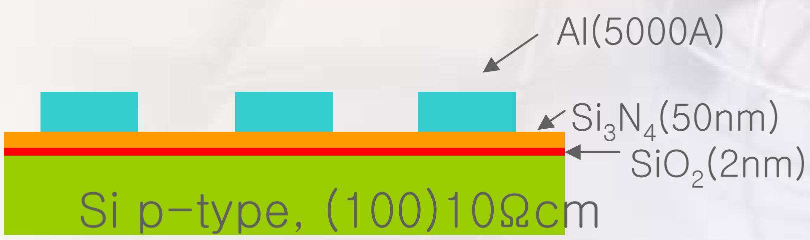
C-V Characteristics Before and After Neutral Beam & ICP Etch



<Big dot: 300um x 300 um >

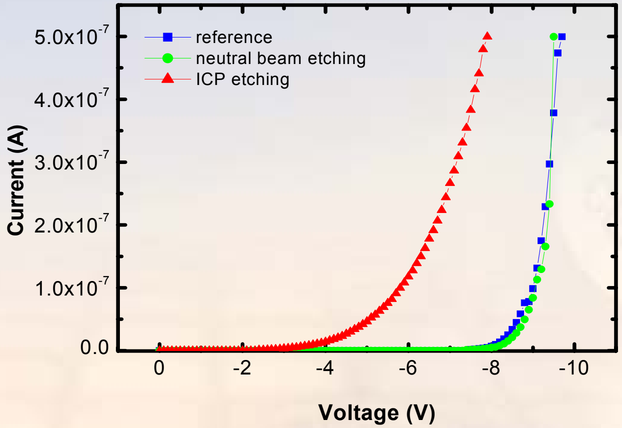


<middle dot: 200um x200um>

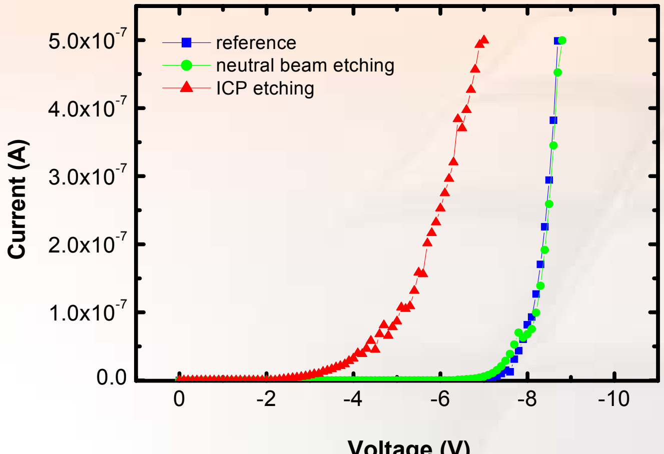


Treatment

- **ICP plasma**
  power: 500 W, bias voltage: -100 V,
  gas: O_2, time: 2 min
- **Neutral beam**
  power: 500 W, acceleration voltage: 400V,
  extraction voltage: -100V
  gas: O_2, time: 30 min, distance: 5 cm



<small dot: 100um x 100um>



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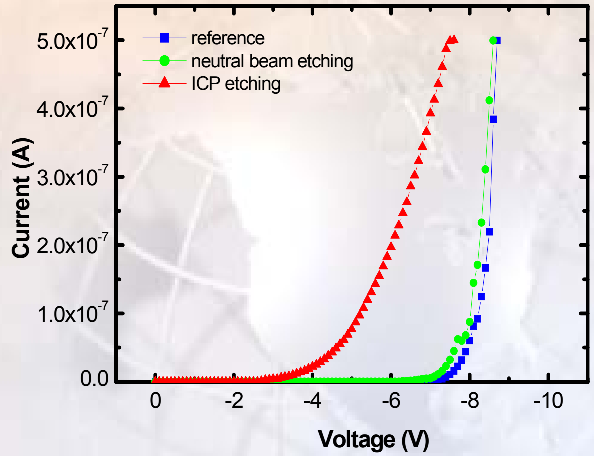
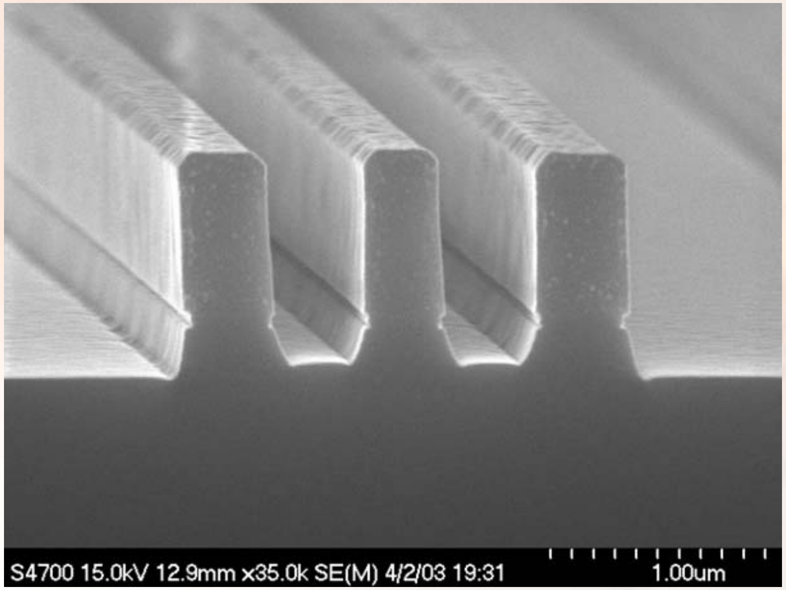


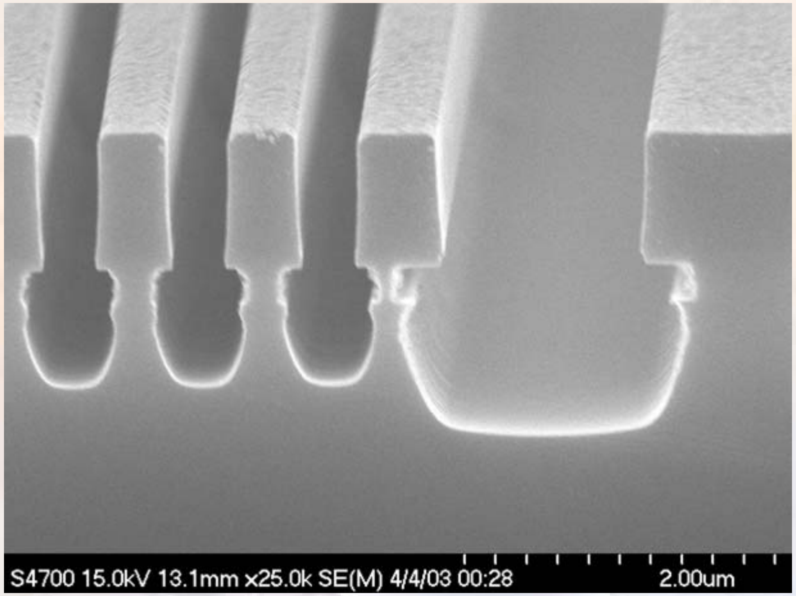
<Big dot: 300um x 300 um >

SEM Micrograph of Poly-Si and Poly-Si/SiO_2 Etch Profiles (ICP Etching)

- condition : rf power: 700W, Bias voltage: -75V pure SF_6 5 mTorr,



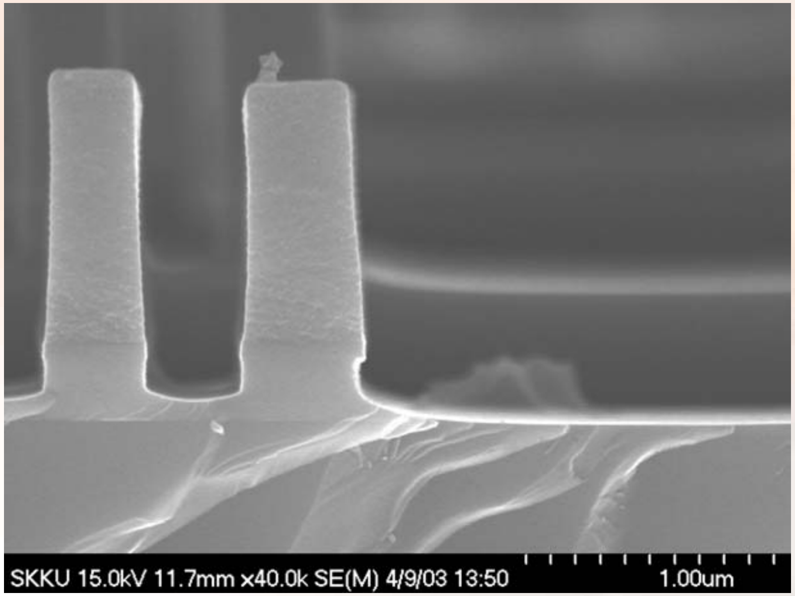
(Poly-Si)



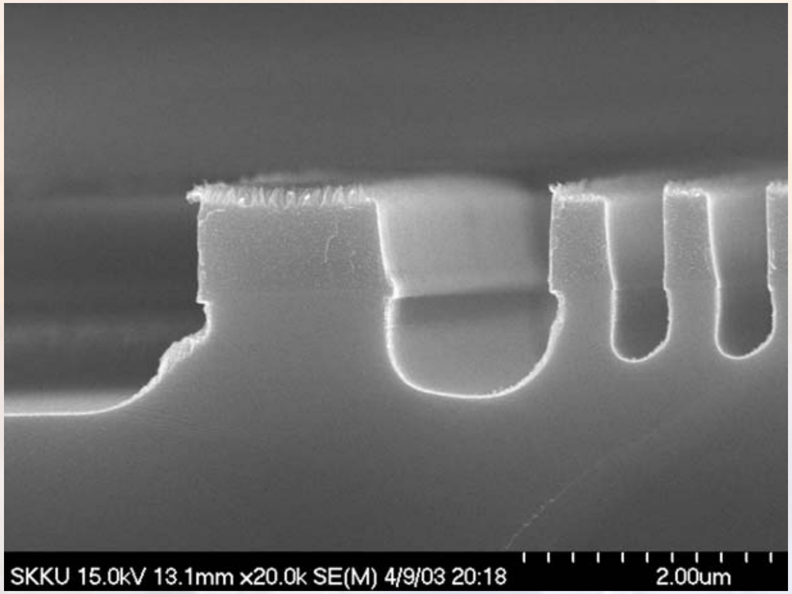
(Poly-Si/SiO_2)

SEM Micrograph of Poly-Si and Poly-Si/SiO_2 Etch Profiles (Ion Beam Etching)

- condition : SF_6 2.5 sccm(0.3 mTorr), rf power: 400W , Ve: -100V, Va: 400V, etch mask: Cr



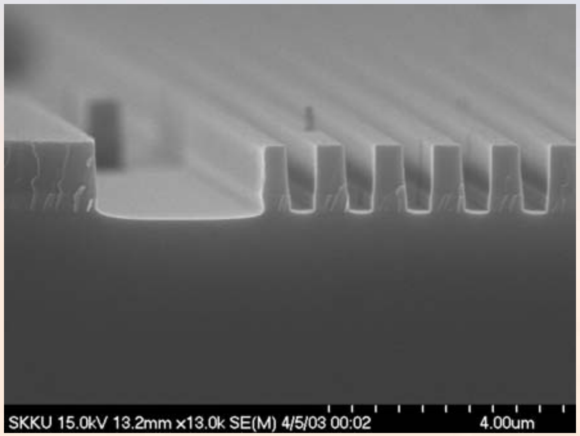
(Poly-Si)

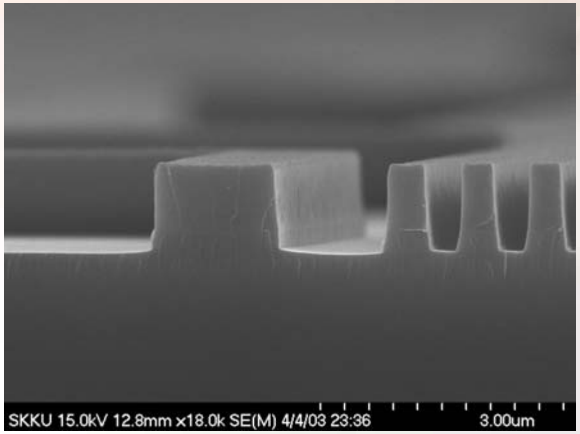


(Poly-Si/SiO_2)

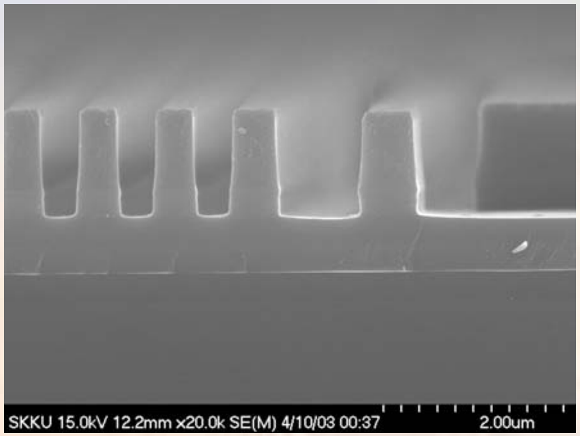
SEM Micrograph of poly-Si and SiO_2 Etch Profiles (Neutral Beam Etching)

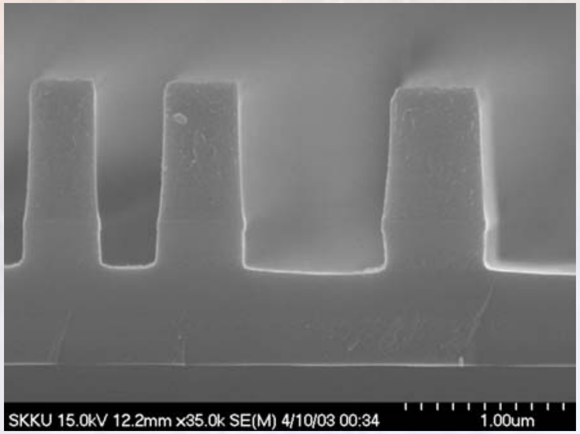
- condition : reflector angle: 5˚, SF_6 2.5 sccm(0.3 mTorr), rf power: 400W , Ve: -100V, Va: 400V





(Poly-Si)



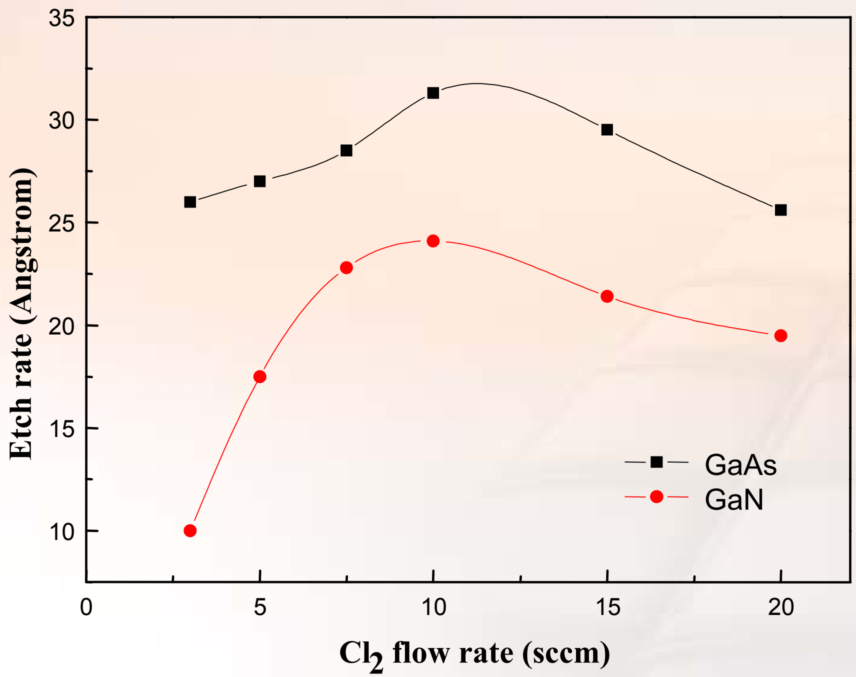


(Poly-Si/SiO_2)

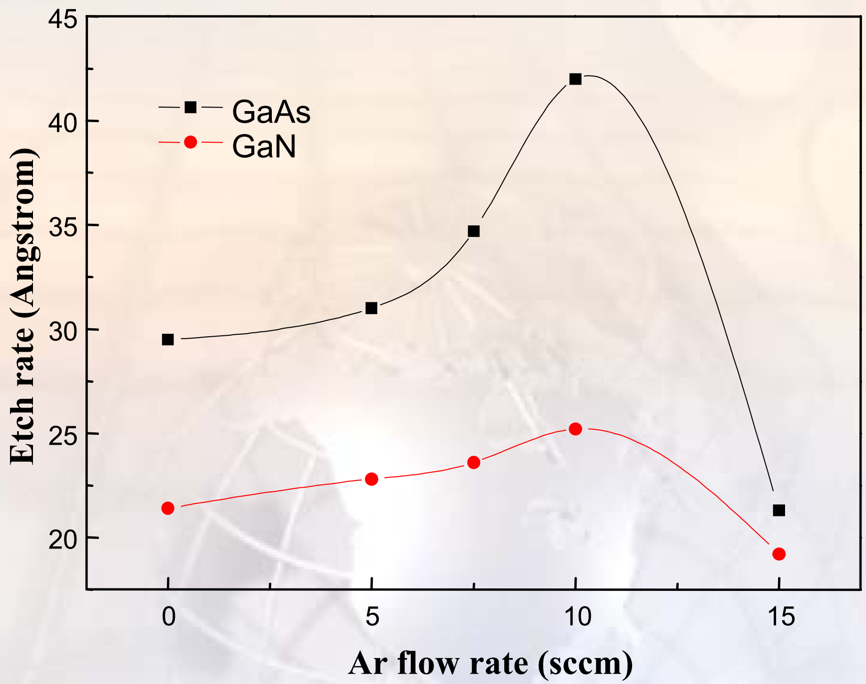
GaN and GaAs Etching as a Function of Flow rate, Additive Gas

Process conditions

Fixed power : 400W, Fixed acceleration voltage : 400V



<Cl_2 Flow rate>



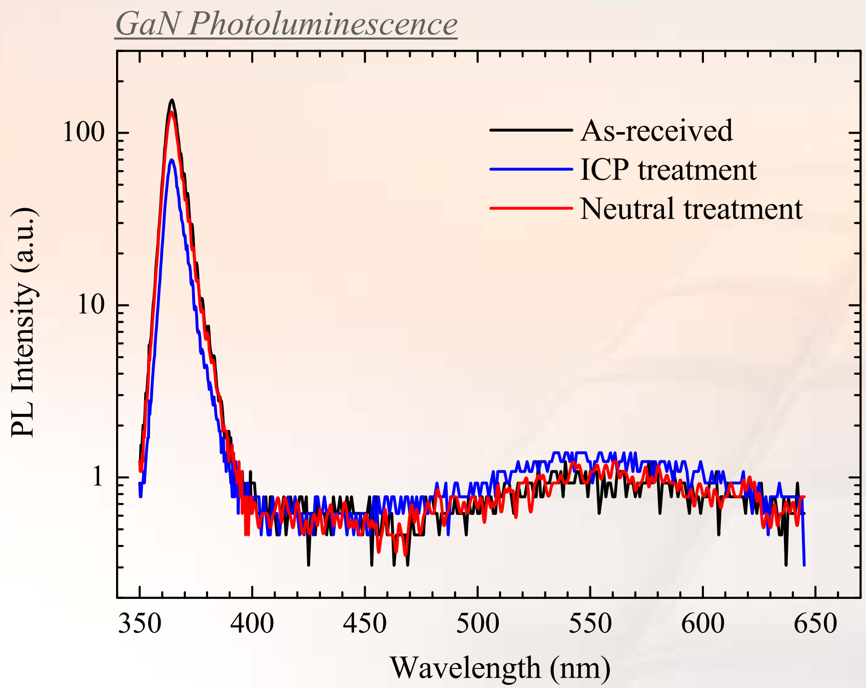
<Cl_2+Ar Flow rate>

Total flow rate : 15sccm

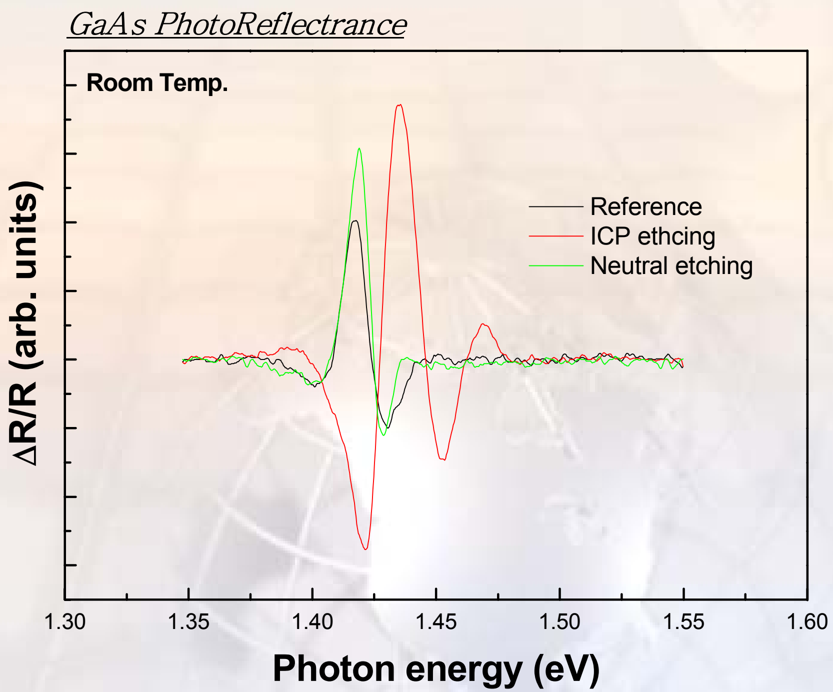
Damage Analysis Etched n-GaN, GaAs

Process conditions

Fixed acceleration voltage : 400V, pure Cl_2, Gas flow rate : 3sccm,



<GaN PL>

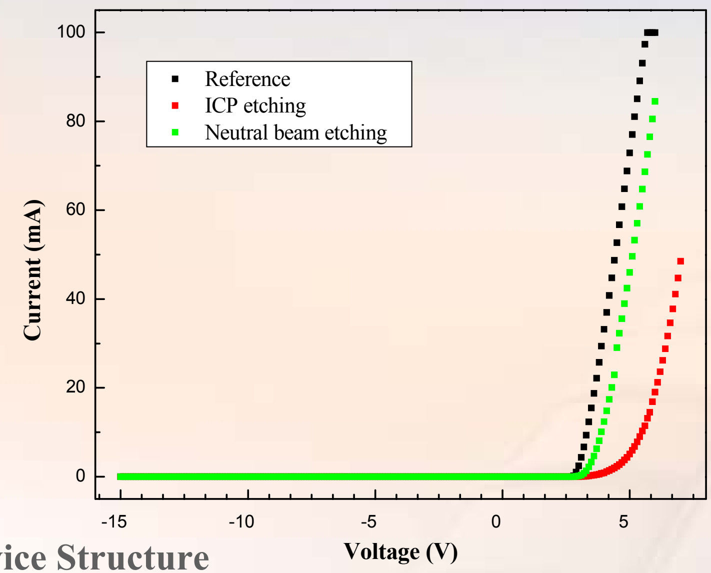


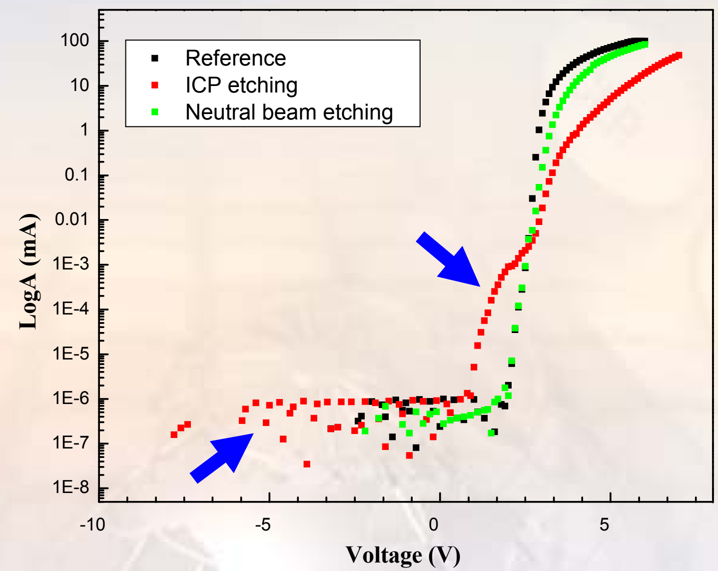
<GaAs PRS>

I-V Characteristics of GaN LEDs after Neutral Beam Etching of p-GaN

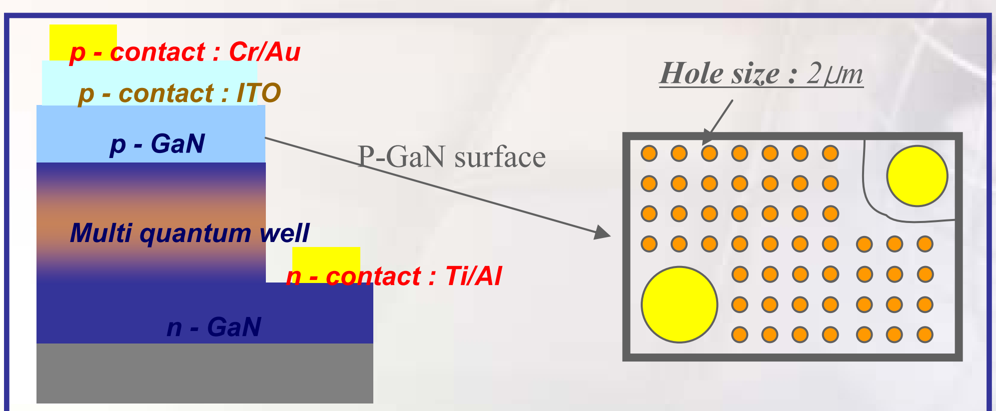
✓ **Condition**

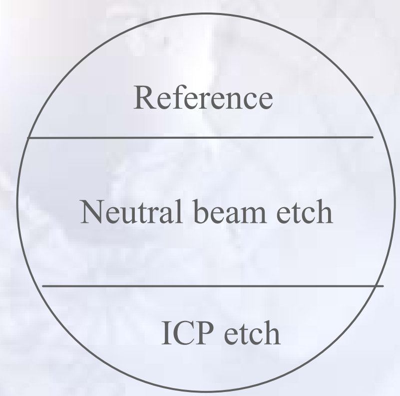
- Neutral beam etching : Power 400W / Bias +400V / CF_4 15sccm / 40min / thickness 600-650Å
- ICP etching : Power 400W / Bias -400V / CF_4 15sccm / 15sec / thickness 750-800Å





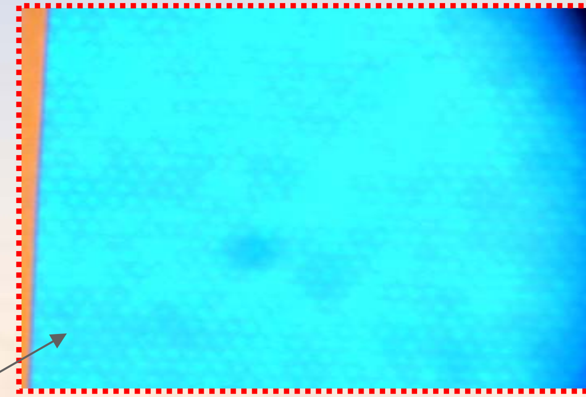
✓ **Device Structure**





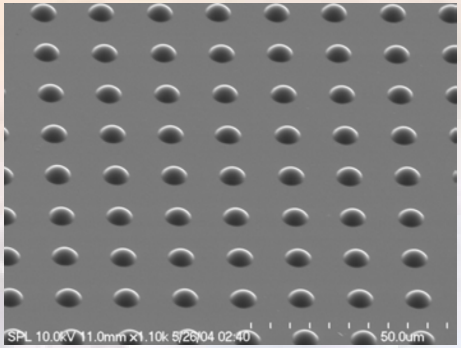
GaN Device Efficiency after Neutral Beam Etching of p-GaN

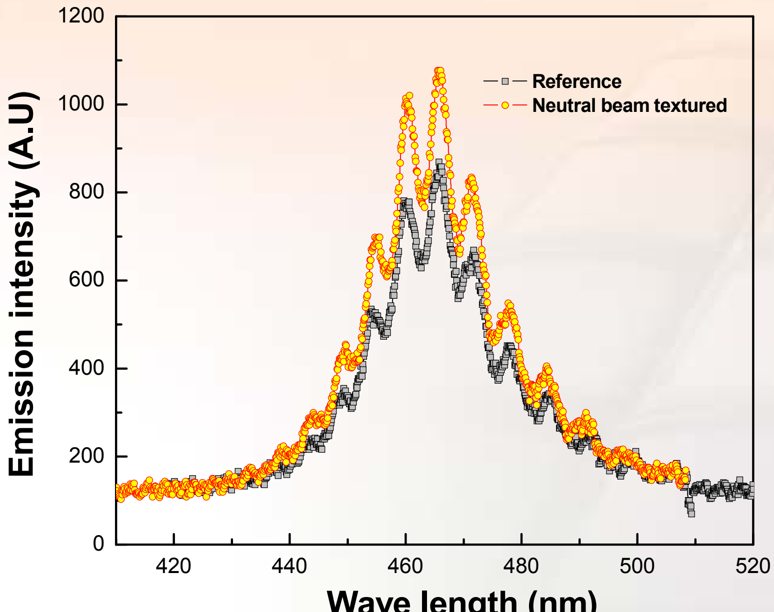
<Reference (No pattern)>



Hole patterns

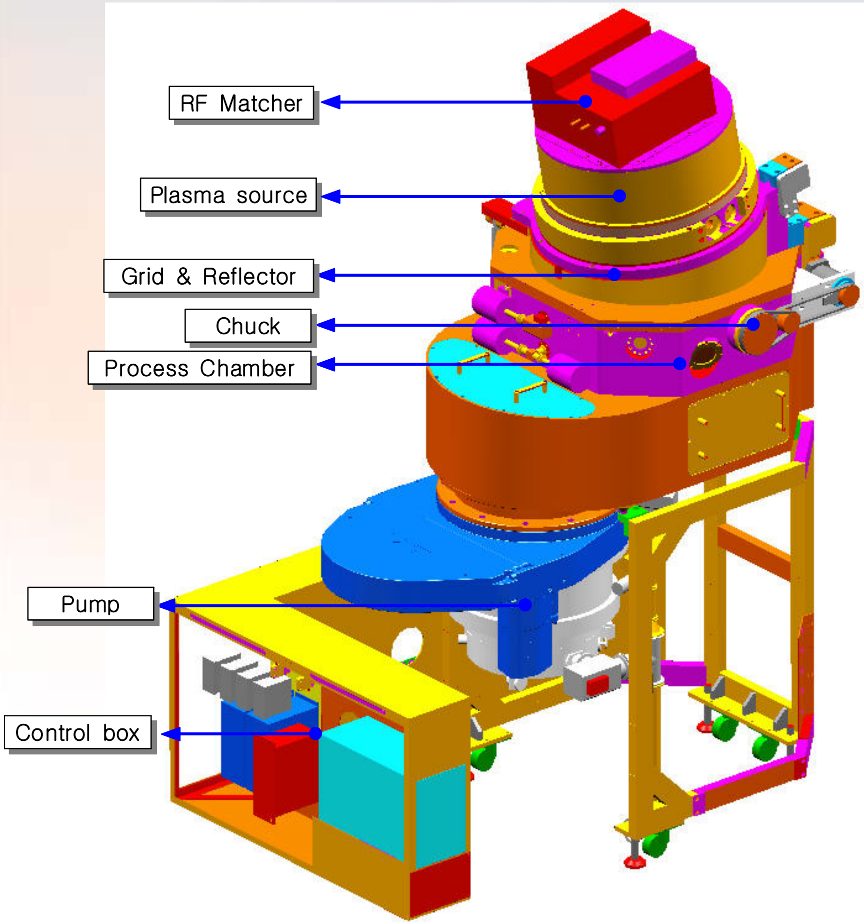
<Neutral beam etch (patterned)>



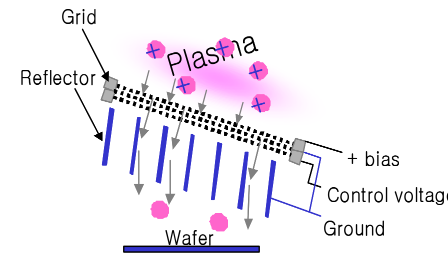


- ✓ Emission at 20mA
- ✓ Emission intensities were **increased about 22%** in neutral beam textured GaN LED (*OES analysis*)

Commercialization
Alpha Version – for 12inch Dia. Silicon Nano Processing



<설비 구성>

Item	사양
Ion source	- Source type : ICP - Power 3000W - Density : 5.5E+11(4mTorr, 2500W)
Grid & Reflector	 - Grid에 DC Bias 인가 - Grid hole size; 2, 3, 4mm - Grid gap; 2, 4, 6mm - Reflector angle; 3, 5, 7° - Chuck & reflector gap; 50, 100, 150mm - Grid material : Graphite
Chuck	- Tilting(Manual, 45°) & Rotating(Automatic, 15RPM) - Lift pin & Mechanical clamp - No Cooling & heating
Chamber & Vacuum system	- Vertical type - Chamber pressure : 0.3mTorr with Ar 40sccm - TMP 4200ℓ/s - Gate valve : ø400, Step motor Operation(Pressure control)
Gas	- Gas box type : IGS(1.25) - Gas line : 14 line

<설비 사양>

Summary

- Using a low energy reflection of reactive ion beam, directional reactive neutral beam for chargeless etching was successfully fabricated.
- By using the neutral beam, nanoscale etching of silicon and silicon oxide could be achieved.
- No charging damage was detected by the use of the neutral beam while the conventional ICP etching showed a significant damage such as leakage of gate oxide, RIE-lag, etc.
- It is believed that, neutral beam etching technique is benificial for the nanodevice processing not only for the top-down devices but also for the bottom-up devices