

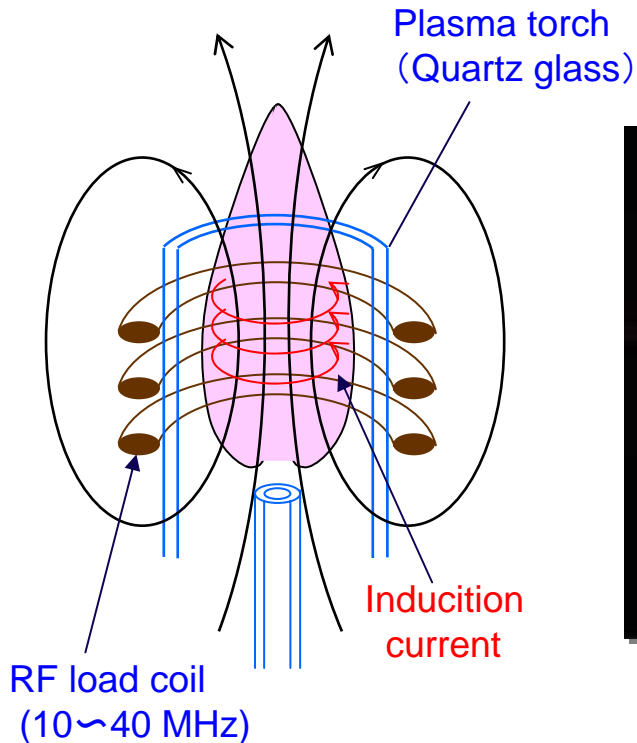
Application to Semiconductor Cleaning Process of Atmospheric ICP

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Principle of Atmospheric ICP

Plasma temperature: 3000~8000 K

Electron number density: 10^{15} cm^{-3}



High reactivity

2. Electrode less plasma:

High purity

Maintenance free

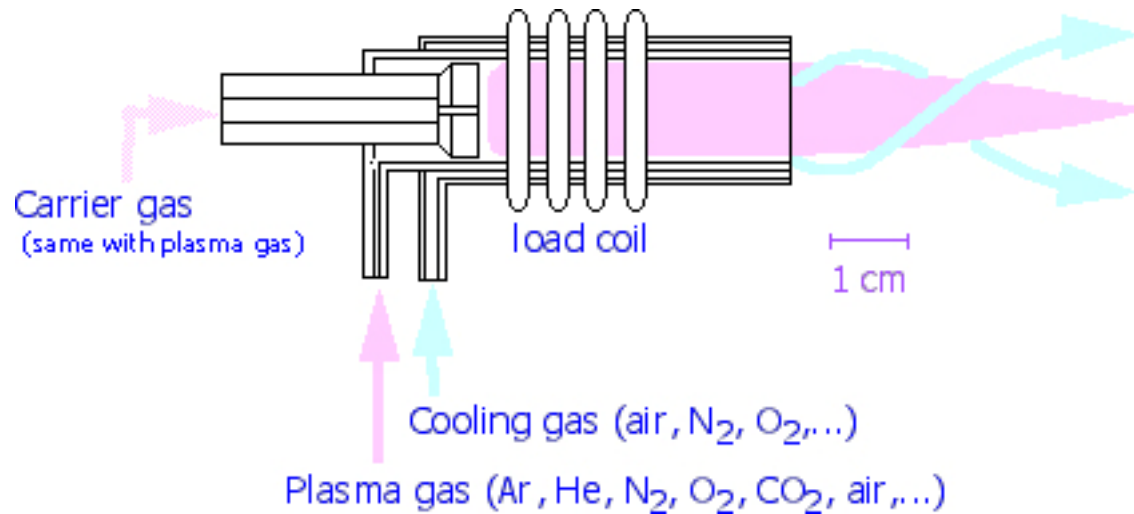
3. Large plasma:

High processing rate

But, usual ICP source can generate only Argon plasma.

(High power device (>10 kW) can generate Nitrogen or other plasma)

Multi-gas ICP source

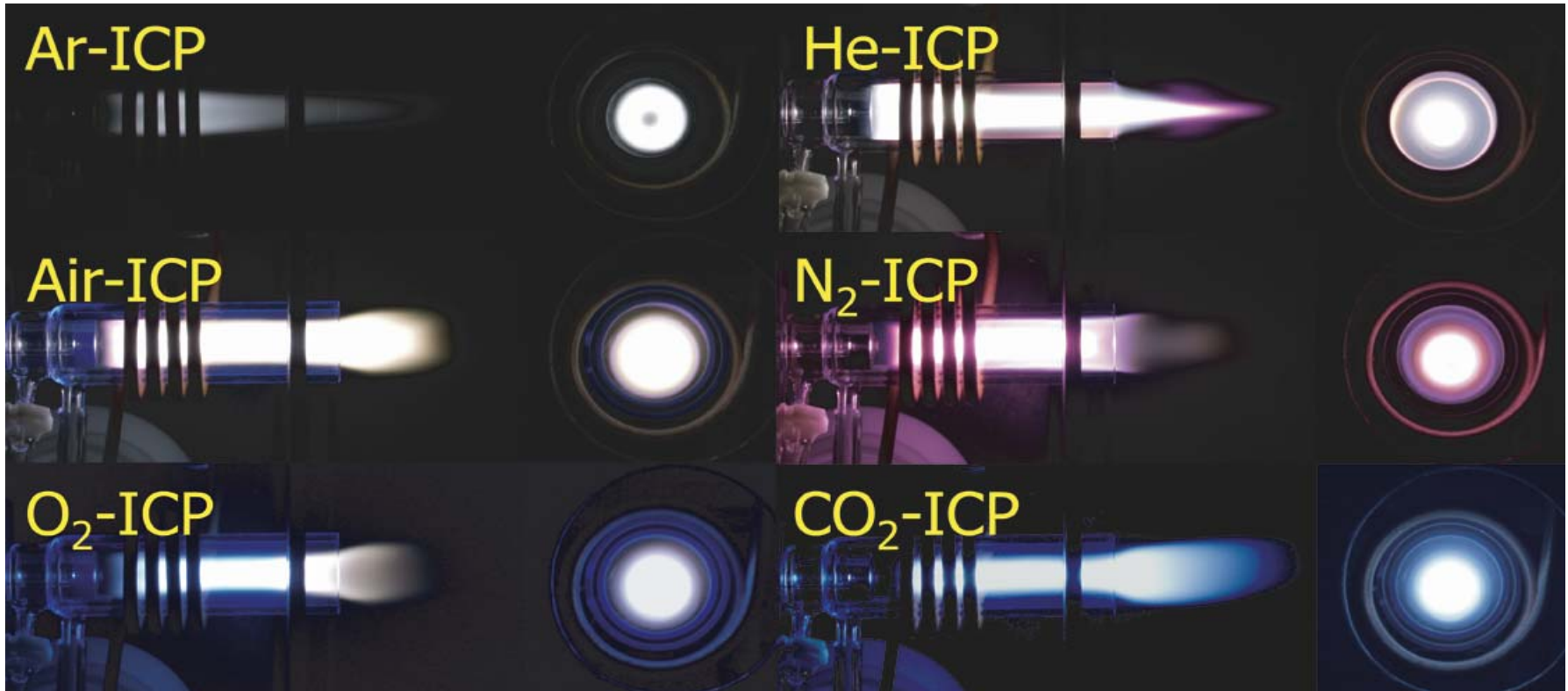


We designed and manufactured a multi-gas ICP source. The multi-gas plasma torch has coaxial three quartz glass tubes and the cooling gas, the plasma gas and the carrier gas are flowed between the tubes.

To generate adequate plasma gas tangential (vortex) flow:
smaller gas inlet, short torch configuration, etc.

To generate molecular gas plasma:
gas cooling system, smaller gas inlet, etc.

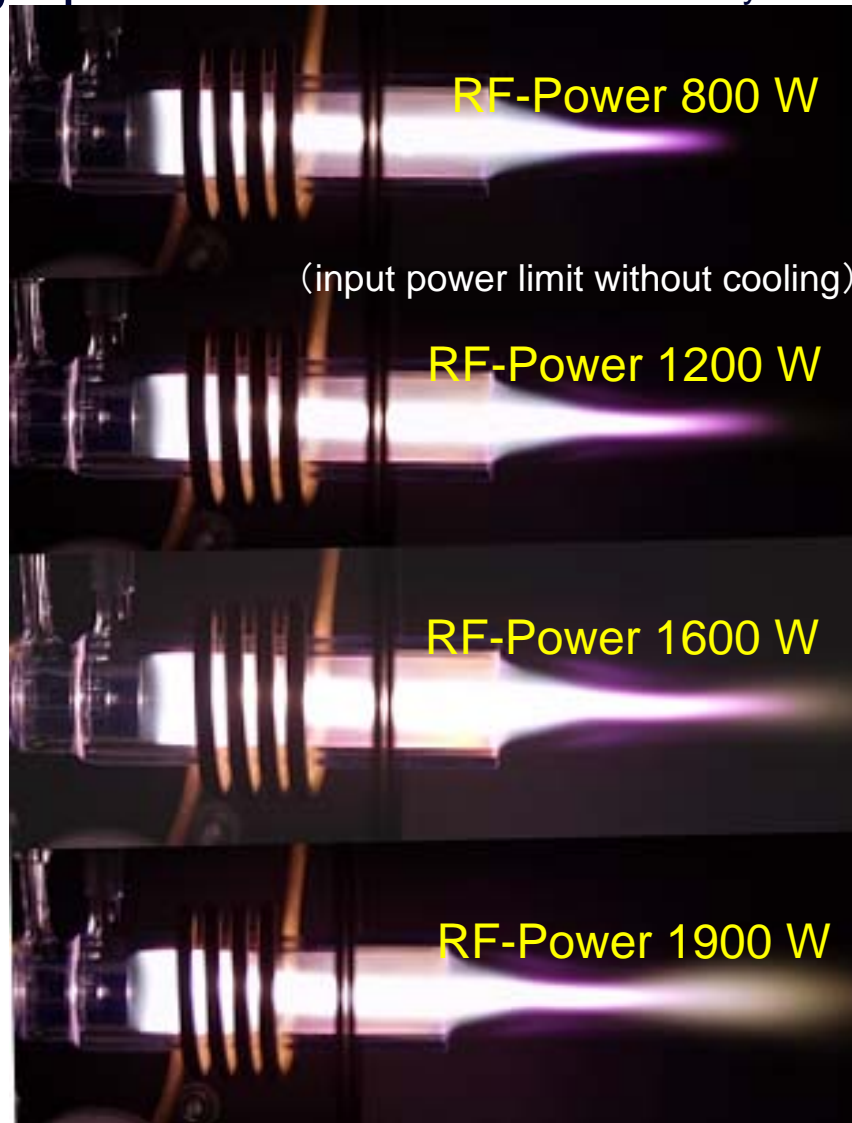
Photograph of multi-gas ICP (Data by TIT)



It is able to generate not only argon but helium, N₂, O₂, CO₂, air and their mixture gas plasma in the pressure from few to 760 Torr.

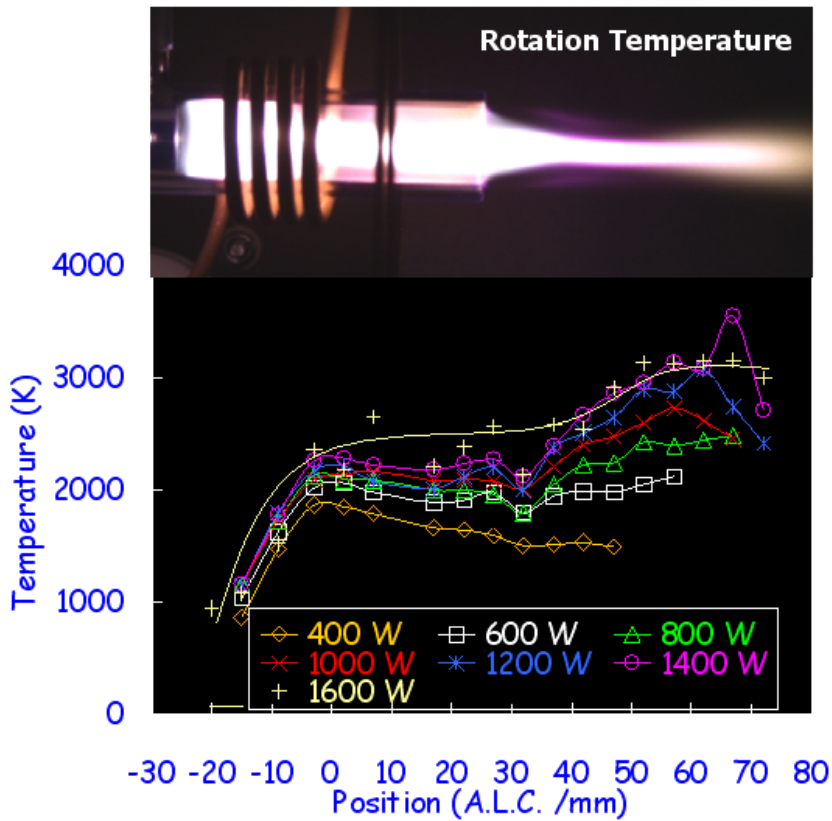
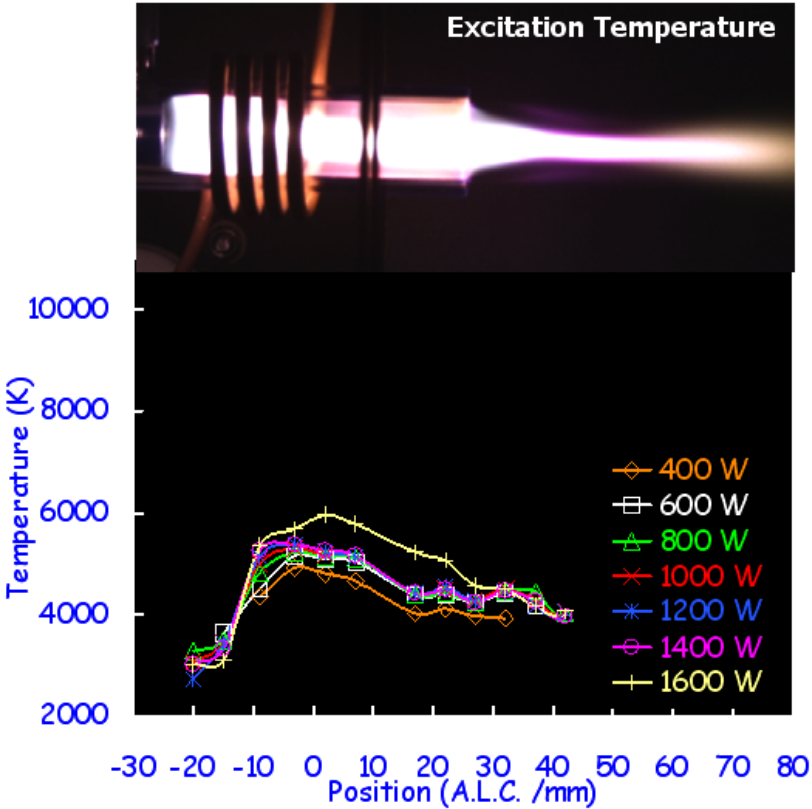
H₂ mixed plasma also can be generated.

High power ICP source (Data by TIT)



With pulse operation, RF power limit enhanced to 3500 W.

Plasma properties of high power helium ICP (Data by TIT)

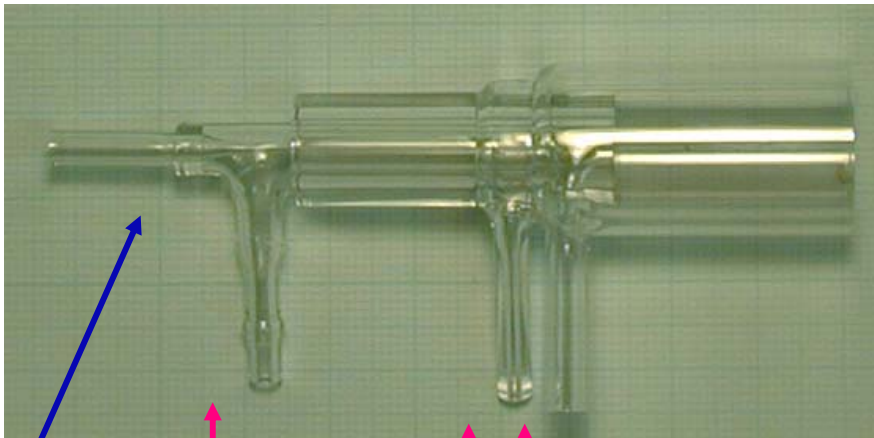


With high power drive excitation and rotational (= gas) temperature of helium ICP enhanced about 1500 K and 1000 K, respectively.

Direct injection multi-gas ICP source

Aqueous solutions are spray into the plasma by nebulizer.

Aqueous solutions



Ar ICP

He ICP

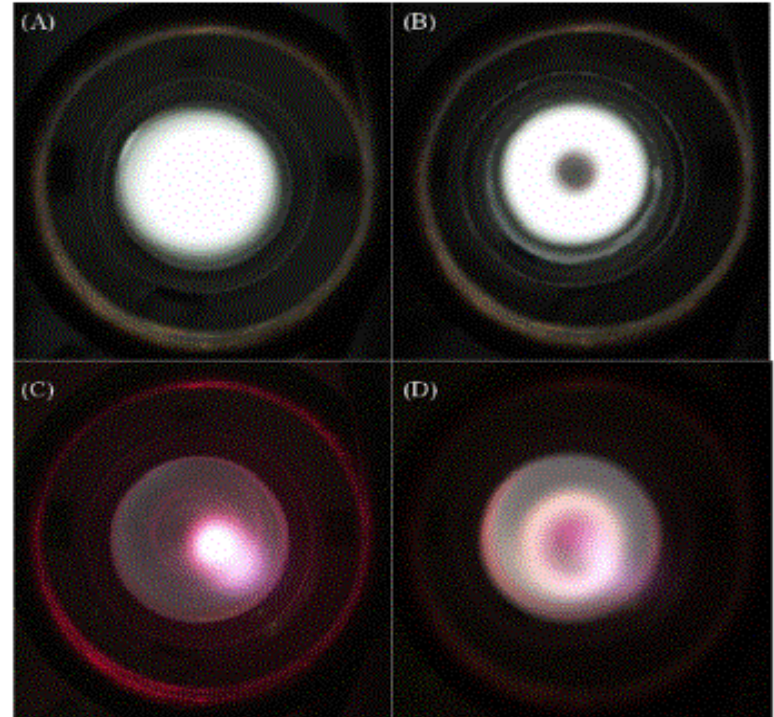
Carrier gas

Cooling gas

Plasma gas

prototype

improved



Aqueous solutions can be directly introduced into multi-gas plasma.

Introduction efficiency is 100%.

Advantage of Atmospheric ICP

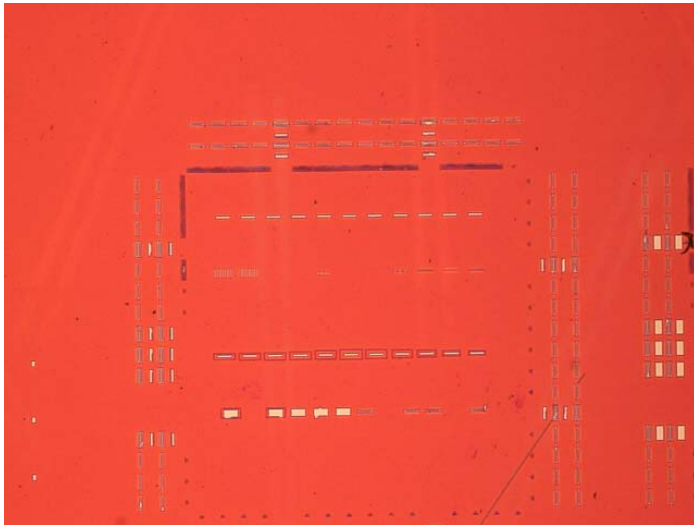
- Clean without metal contamination
- High Density Plasma
- Multi-gas process
- Easy scanning for single wafer process
- Merged process with dry & wet cleaning

Wet Cleaning merged Atmospheric ICP

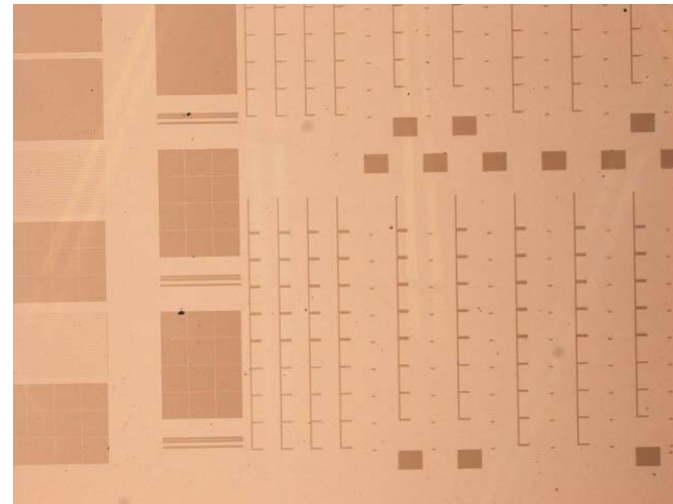
- Hydrogen radical would be effective for Si process
FEOL as well as BEOL
- Hydrogen radical effect **BEOL**
 - decrease of interface level density
 - improvement of material defect for interconnect
- Hydrogen radical effect **FEOL**
 - Cleaning solution of Resist Removal
 - APM+DHF solution
 - low k ?

Effect of Atmospheric ICP

- Oxygen radical



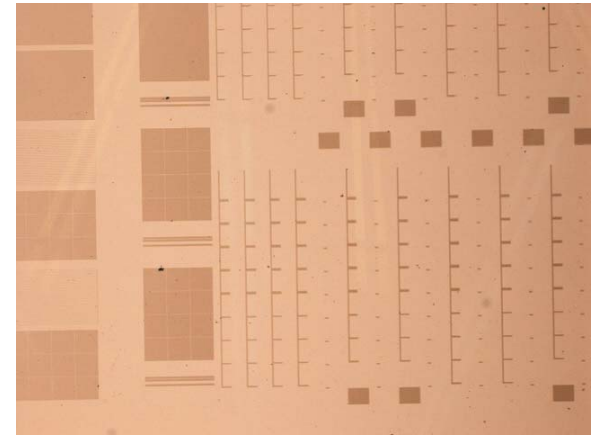
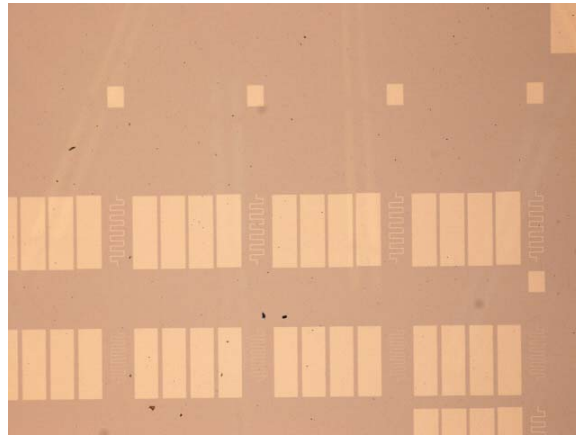
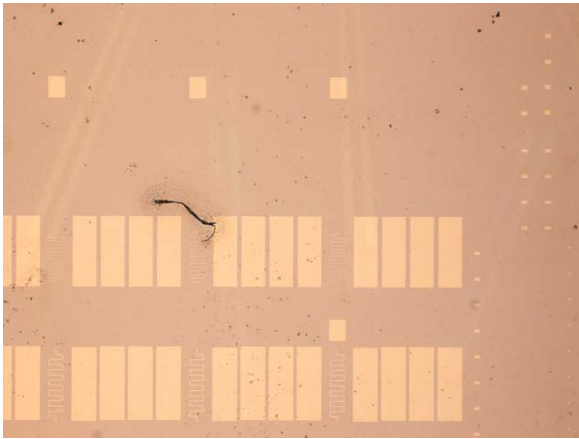
Before Stripping



After Stripping by Oxygen Plasma
Distance (X): 2cm
Process Time: 1 sec.

Resist was removed completely by irradiating oxygen radical only for 1 second.

Effect of AICP

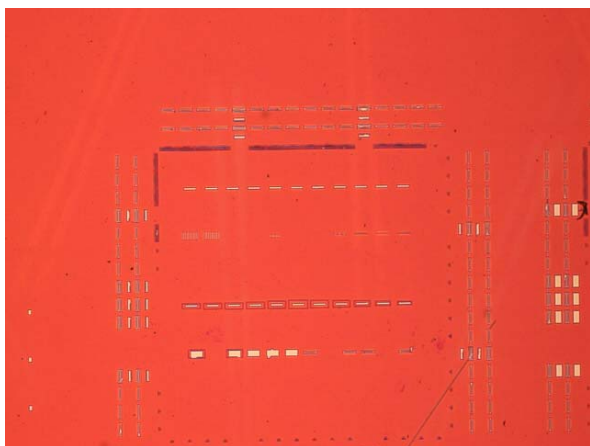


Gas: **Ar/O₂**
Distance (X): 2 cm
Irradiation Time: 8 sec.

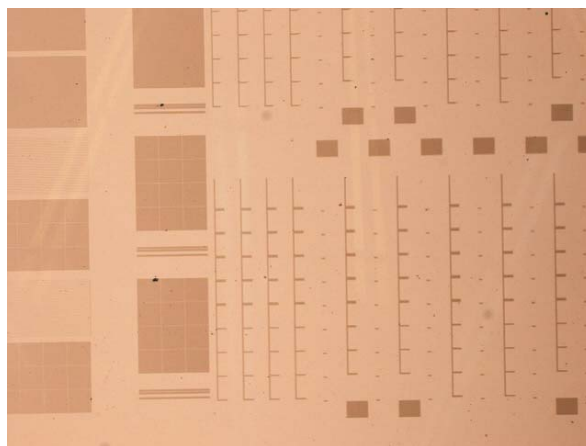
Gas: **He/O₂**
Distance (X): 2 cm
Irradiation Time : 5 sec.

Gas: **O₂**
Distance (X): 2 cm
Irradiation Time: 1 sec.

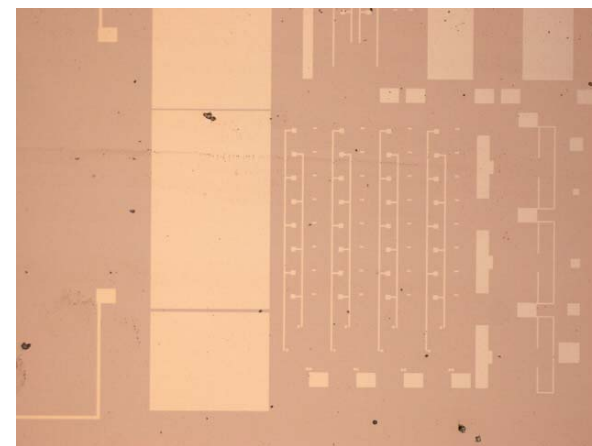
Resist Removal



Before Stripping



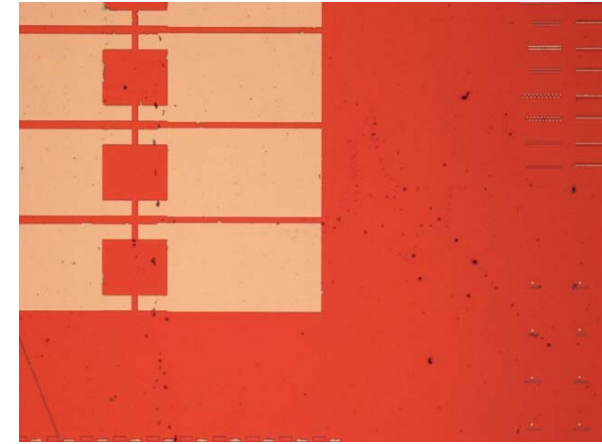
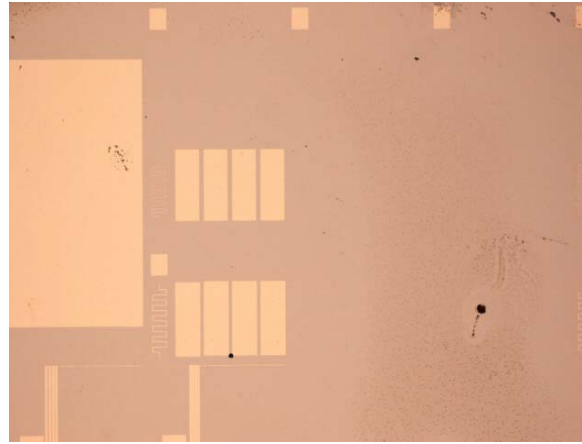
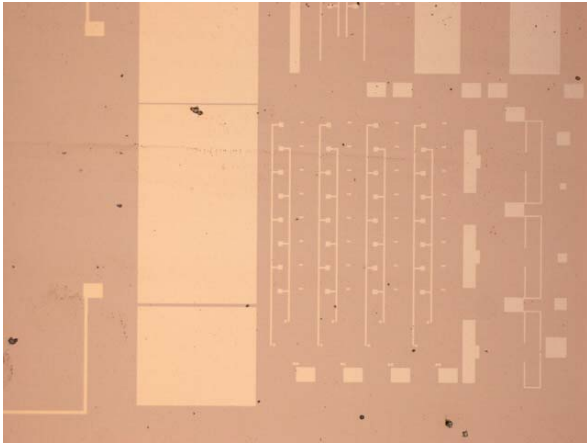
**After Stripping
by Oxygen Radical
Distance (X): 2cm
Process Time: 1 sec.**



**After Stripping
by **Hydrogen Radical**
Distance (X): 3cm
Process Time: 10 sec.**

Resist was removed completely by even irradiating hydrogen radical only 10 seconds as well as by oxygen radical.

Resist Removal



Gas: **He/H₂**
Distance (X): 3 cm
Irradiation Time: 10 sec.

Gas: **He/H₂**
Distance (X): 5 cm
Irradiation Time : 30 sec.

- Gas: He/H₂
- Distance (X): 7 cm
- Irradiation Time: 30 sec.

It is possible to control the stripping rate by irradiation conditions.

Semiconductor Cleaning Process

Major Cleaning steps

- APM + DHF + Dry
- APM + DHF + HPM + Dry
- FPM + APM + DHF + Dry

APM; $\text{NH}_4\text{OH}/\text{H}_2\text{O}_2/\text{H}_2\text{O}$ 60~80°C

HPM; $\text{HCl}/\text{H}_2\text{O}_2/\text{H}_2\text{O}$ 60~80°C

FPM; $\text{HF}/\text{H}_2\text{O}_2/\text{H}_2\text{O}$

DHF: $\text{HF}/\text{H}_2\text{O}$

Semiconductor Cleaning Solution

- Case of “APM + DHF + Dry” process,

APM + DHF + Dry is changed to

NH₄OH /H₂O₂ + Hydrogen radical irradiation/DI rinse

After NH₄OH /(H₂O₂) , surface is covered by Si-OH bond, this OH is very effective for particle removals.

Hydrogen radical irradiation change the Si surface from OH to H.

Finally, surface is kept inactive.

Precise cleaning is performed by 1 chamber.

Mechanism of Watermark generation

1) **O₂ Diffusion** to Si surface

2) **Oxidation of Si surface**



3) **Hydration of SiO₂**



4) **Dissolution of H₂SiO₃**



Surface is protected by Hydrogen atoms termination

M.Watanabe et al, Materials Science and Engineering, B4, p401(1989)