NISSIN ION EQUIPMENT CO.,LTD.

Heated ion implantation system for SiC power devices

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Outline

1. Introduction
2. Implant process for SiC
3. Feature of IMPHEAT
4. Requirements for SiC device manufacturing
5. Summary

IMPHEAT

Heated ion implantation system

Growing market of power devices

Robotic suit kick off
in world cup 2014

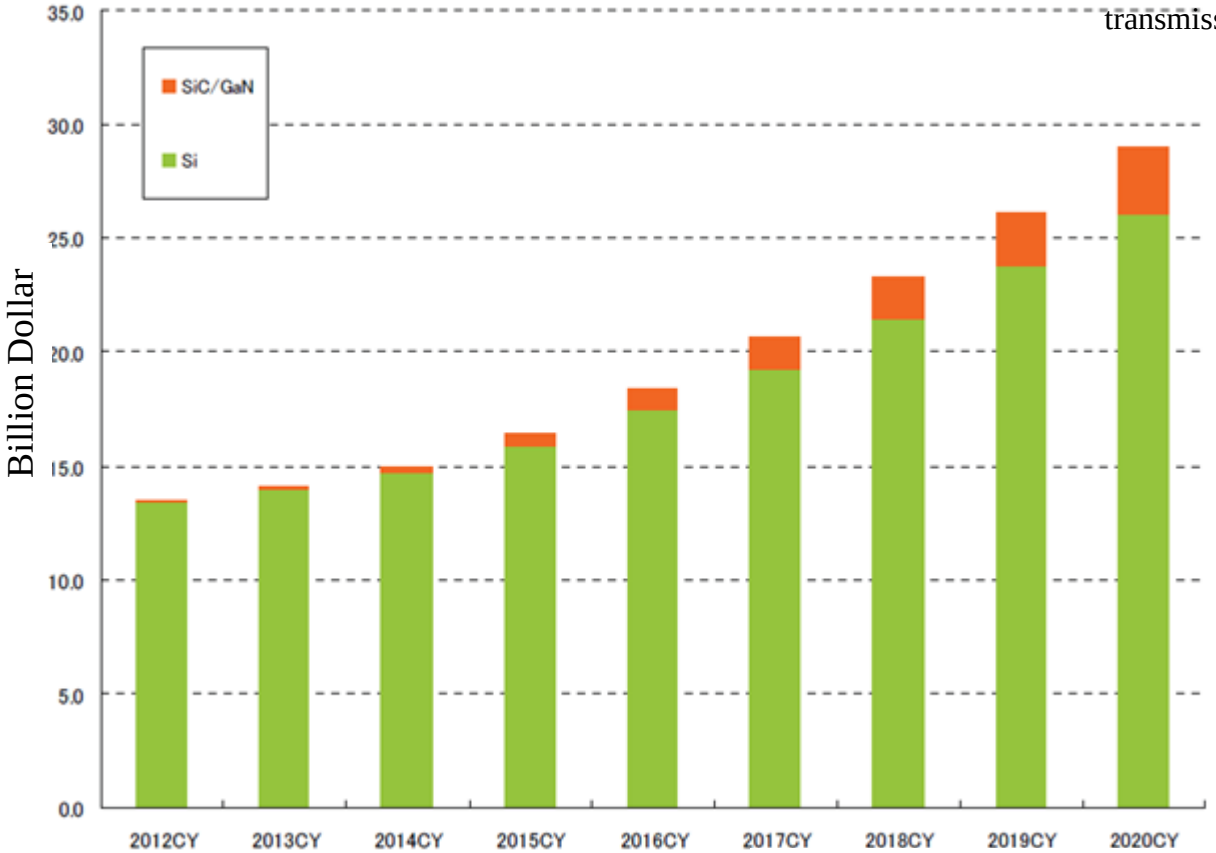
Bullet train

Air conditioner

Inverter for power transmission

Electric Vehicle

Projected market growth of power devices



Source: Yano Research Institute Ltd. (2013)

Advantages of SiC power devices

	Si	4H-SiC
Band gap (eV)	1.12	3.26 (x 3)
Electron mobility (cm2/Vs)	1400	1000 (x 0.8)
Electric breakdown field (MV/cm)	0.30	2.5 (x 8)
Electron saturation voltage (cm/s)	1.0E7	2.2E7 (x 2)
Thermal conductivity (W/cmK)	1.5	4.9 (x 3)

Smaller size and higher power density

Lower power loss and higher efficiency

Higher frequency and higher performance

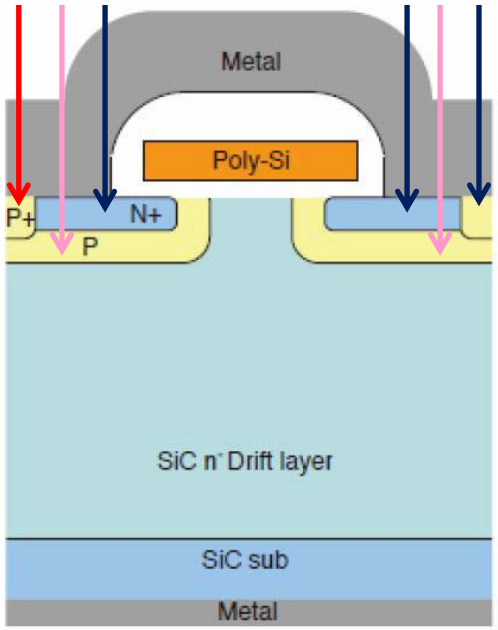
Higher heat resistance

Ion implant process for SiC devices

- ☻ Hard to re-crystalize SiC
- ☻ Low dopant activation
- ☺ Small diffusion of dopant

Heated ion implantation

	5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999
	13 Al 26.982	14 Si 28.085	15 P 30.974	16 S 32.06
30 Zn 65.38	31 Ga 69.723	32 Ge 72.63	33 As 74.922	34 Se 78.96
48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60



Beam Energy
10 ~ 960keV

Dosage
5E11 ~ 1E16 /cm²

Dopant
Al, P, B, N

Wafer Temperature
Up to 500 ºC

Wafer Size
100mm, 150mm

Challenging with SiC substrate

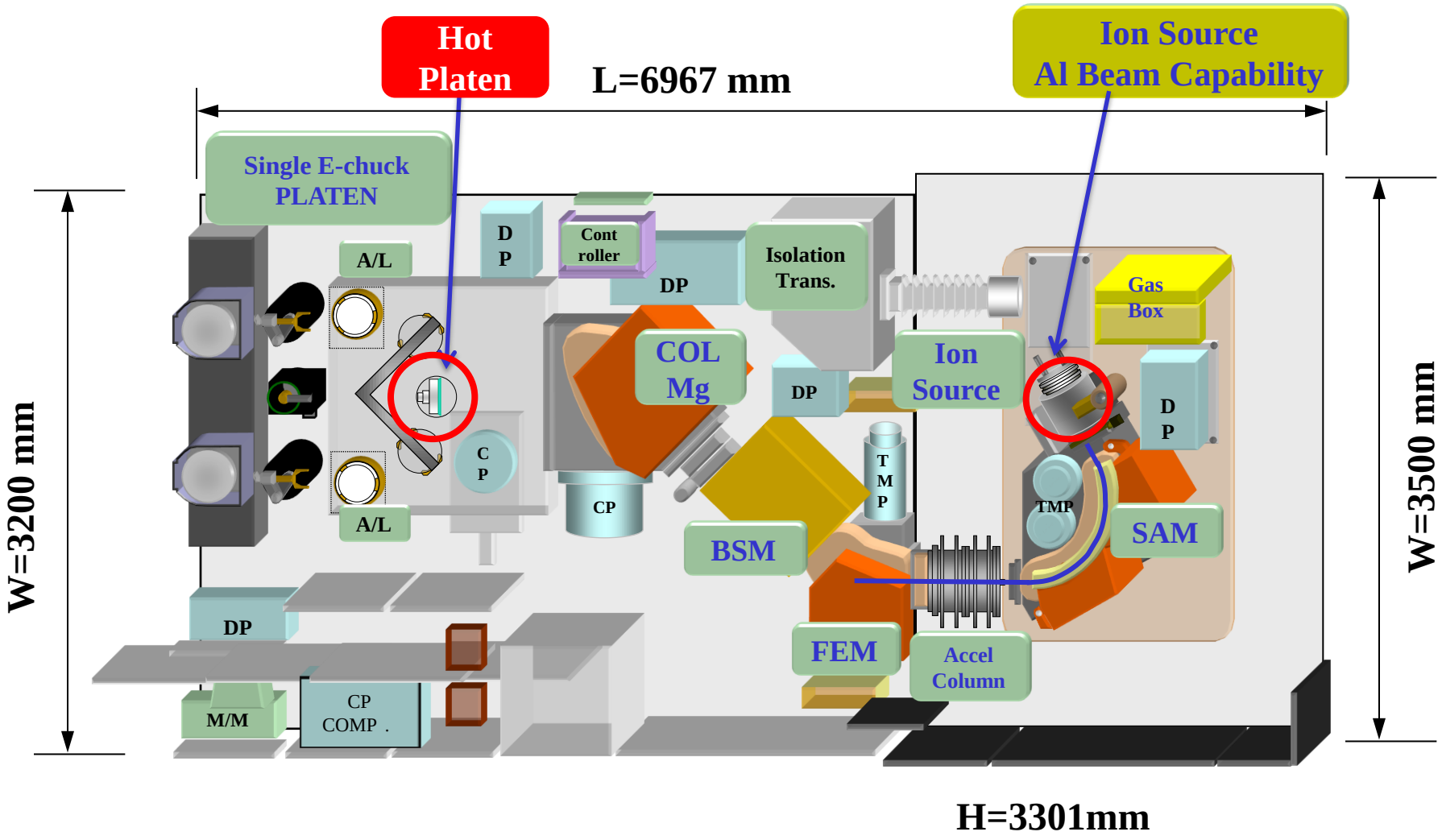
- Crystallinity
- Dopant activation
- Measurement of substrate temperature
- Electro-static chucking of SiC
- Charging up with high resistivity substrate

NISSIN heated ion implant system "IMPHEAT"

- **Based on EXCEED series which are our field-proven M/C tools**
- **High Current Al ion beam**
- **Heated implant capability up to 500°C**
- **Automatic wafer transportation system for 6 or 4inch SiC wafer**

The only tool for high-temperature implant used in mass production lines for power devices

Tool Layout


Hot Platen
L=6967 mm
Ion Source Al Beam Capability
Single E-chuck PLATEN
W=3200 mm
W=3500 mm
H=3301mm
A/L
D P
Cont roller
DP
Isolation Trans.
Gas Box
COL Mg
Ion Source
DP
D P
C P
CP
T M P
TMP
SAM
BSM
DP
FEM
Accel Column
M/M
CP COMP .
A/L

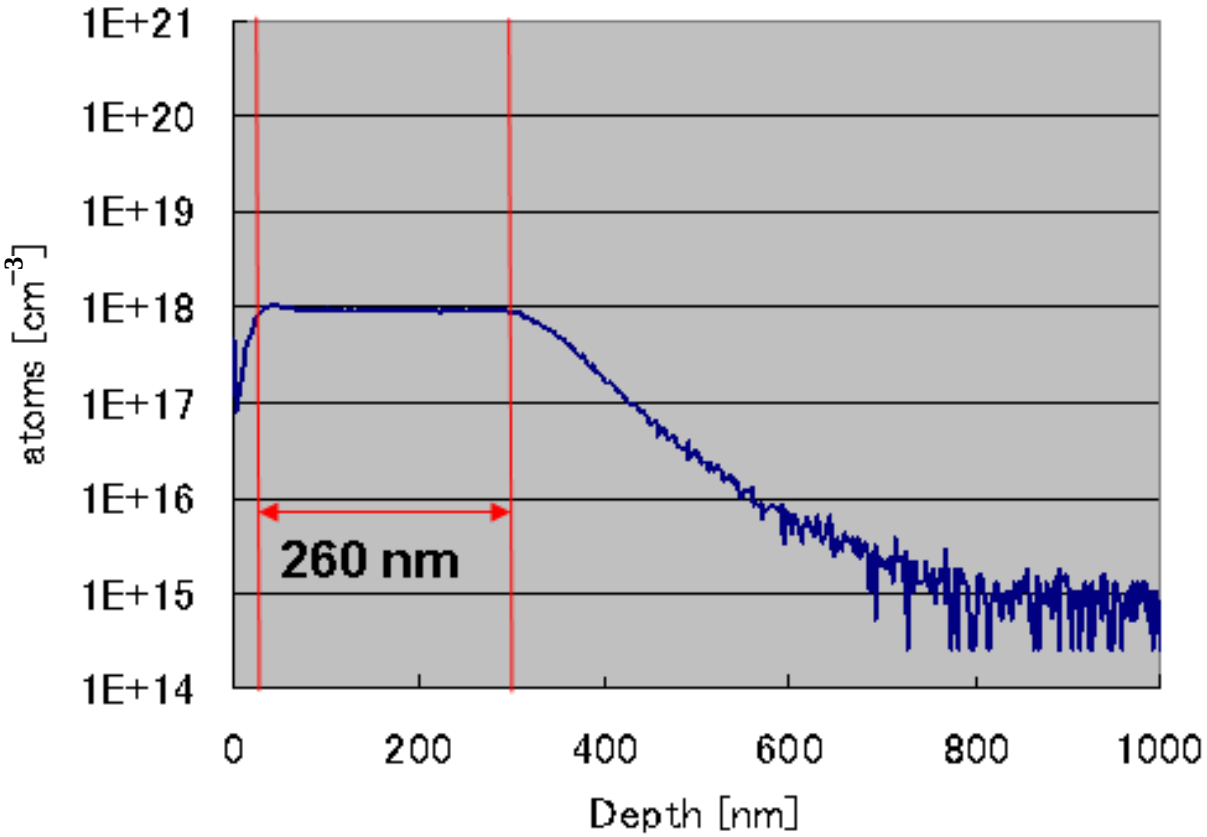
High Current Al Ion Beam - Ion Source -

- **Beam current and stability**
  - **Al^+ beam current up to 2.0mA**
  - **Beam stability < ±10 % / hour**

- **Lifetime of Al source**
  - **Lifetime of more than 300 hours was confirmed**

Box Profile Implantation

Al^+, BOX Imp (Target Density : $1E18cm^{-3}$)



BOX Implantation

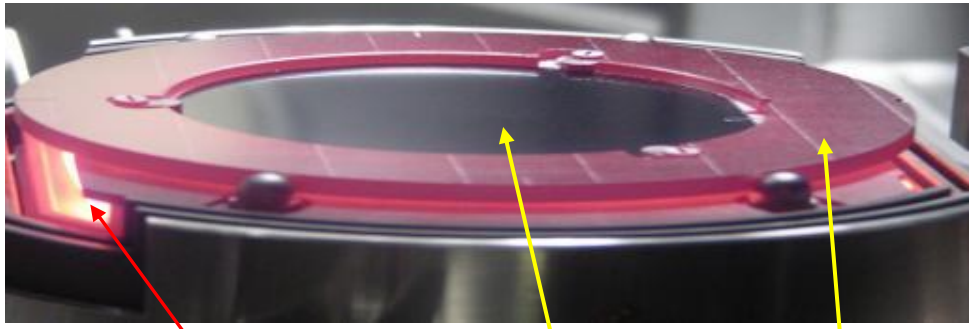
250keV	$1.6E+13cm^{-2}$
150keV	$8.0E+12cm^{-2}$
90keV	$5.5E+12cm^{-2}$
50keV	$3.0E+12cm^{-2}$
30keV	$2.0E+12cm^{-2}$
Total	$3.45E+13cm^{-2}$

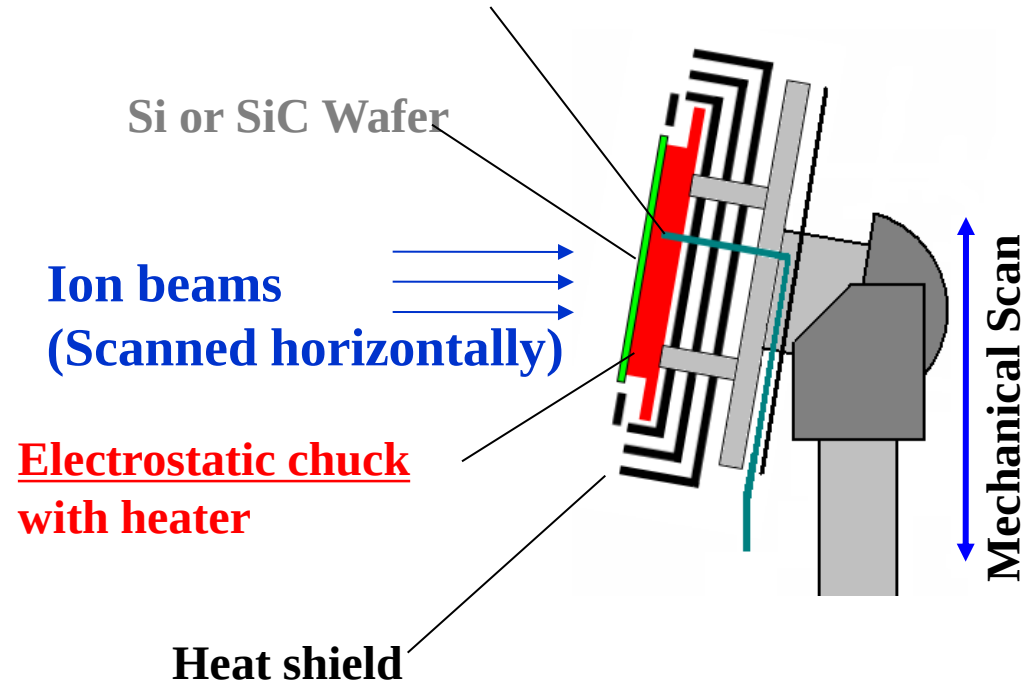
SIMS Profile of BOX Implantation

High beam current in wide energy range is required.

Platen for heated ion implantation

- Electrostatic chuck with heater-

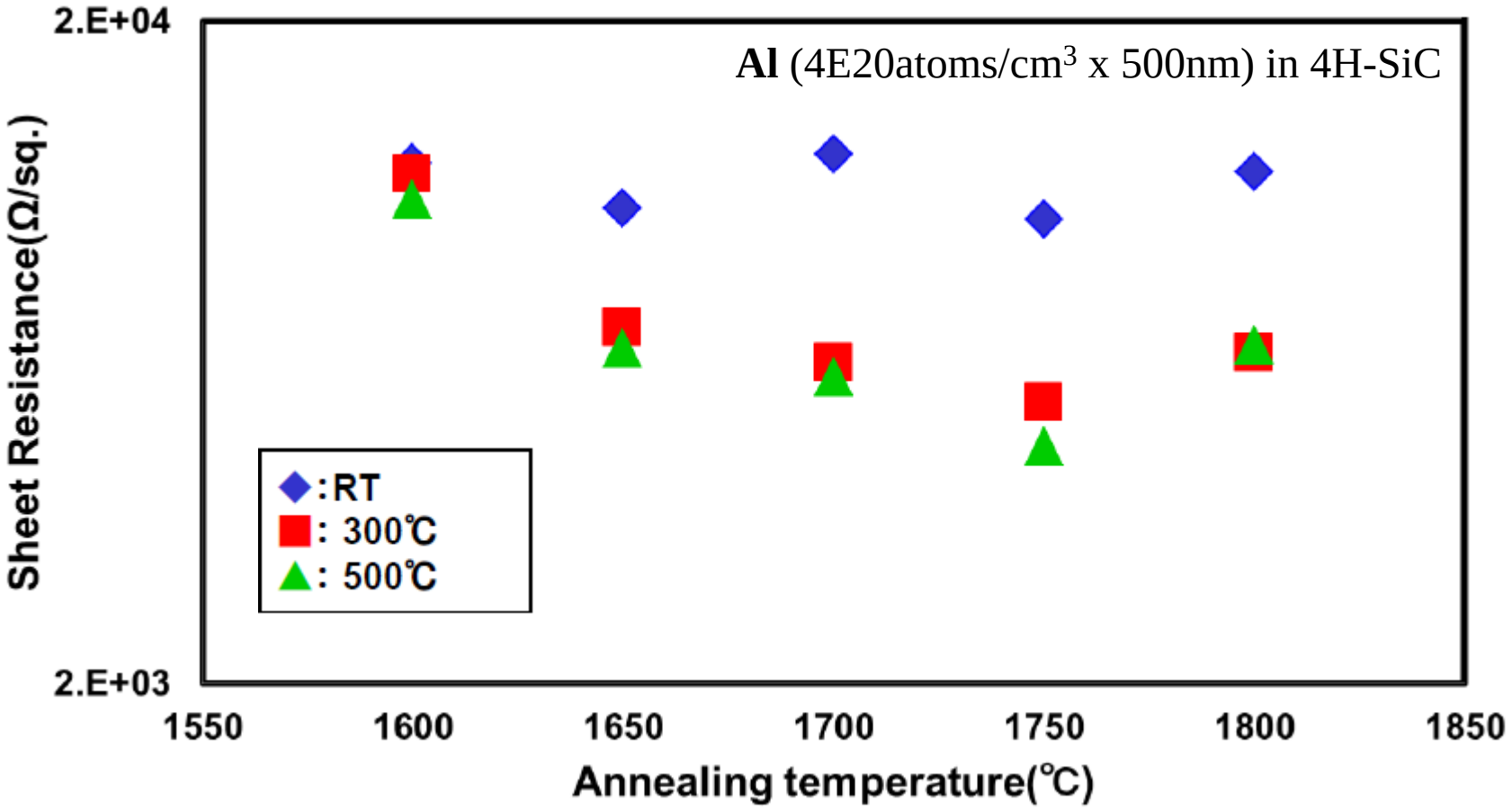




- **ESC with heater**
- **Wafer size**
  - **6, 4inch or smaller**
  - **Graphite wafer holders are used for small samples**

High Temperature Platen

Rs with heated ion implantation



Collaboration work with TOYO TANSO and EpiQuest

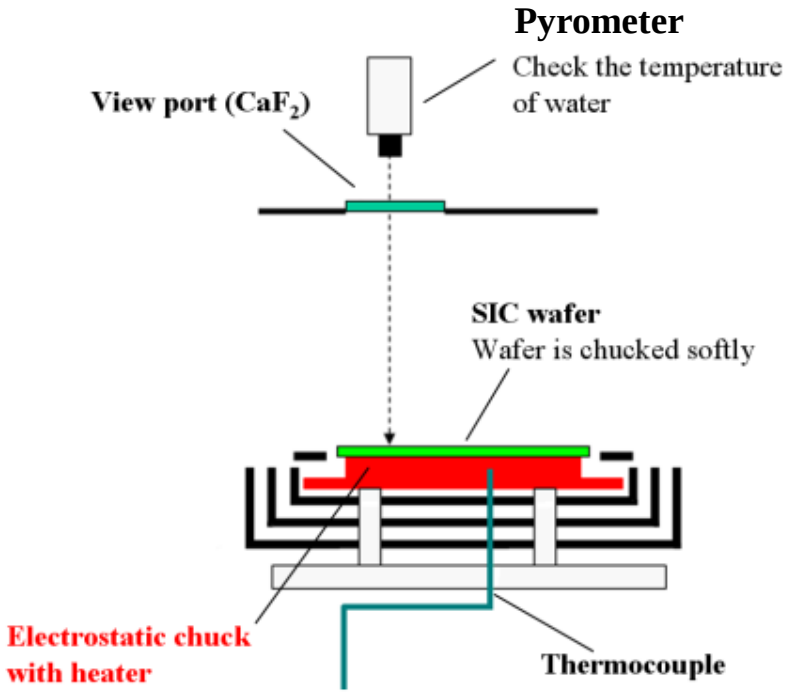
Lower Rs with higher substrate temperature

Monitoring system of wafer temperature

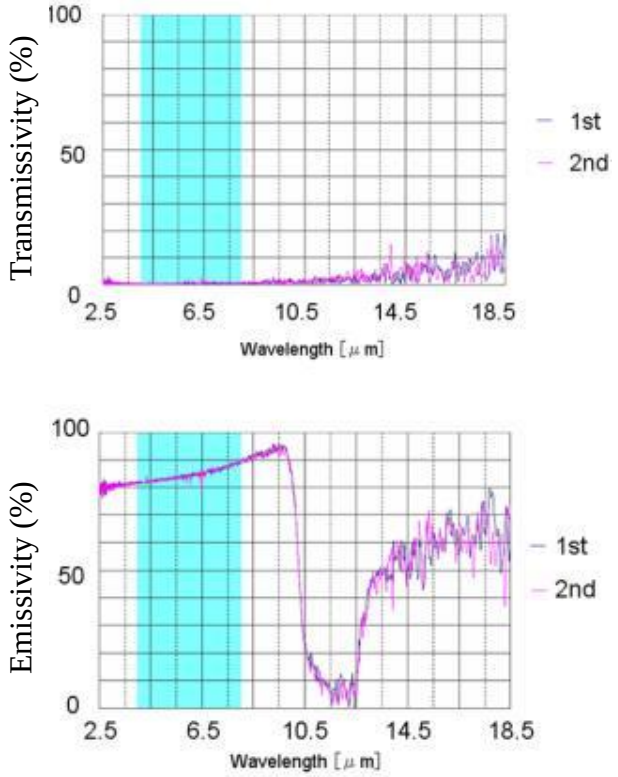
Pyrometer

Pyrometer is adopted to measure the temperature of SiC 4H-N single crystal wafer directly,

- **4-7μm is the best wavelength to measure the temperature.**
- **CaF2 was selected as the material of the view port window.**



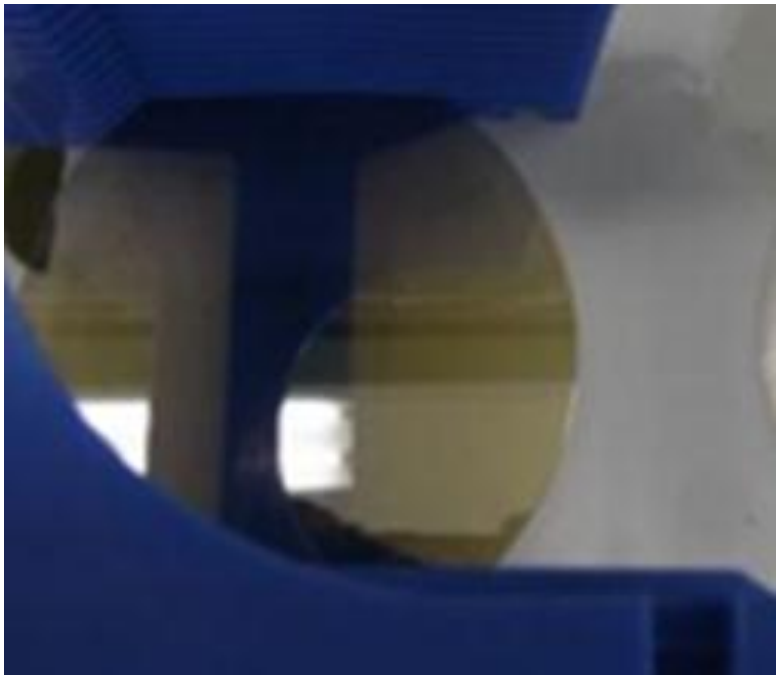
The wafer temperature measurement system



The infrared rays characteristic of SiC

High Purity Semi-Insulated Silicon Carbide (HPSI-SiC)

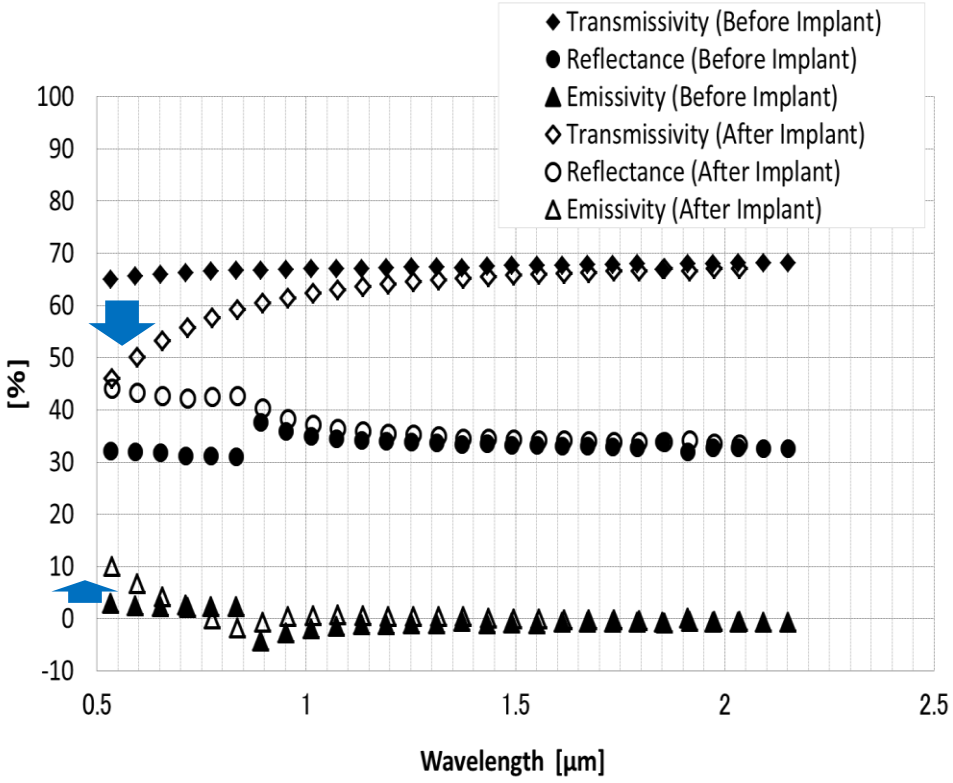
Before implantation

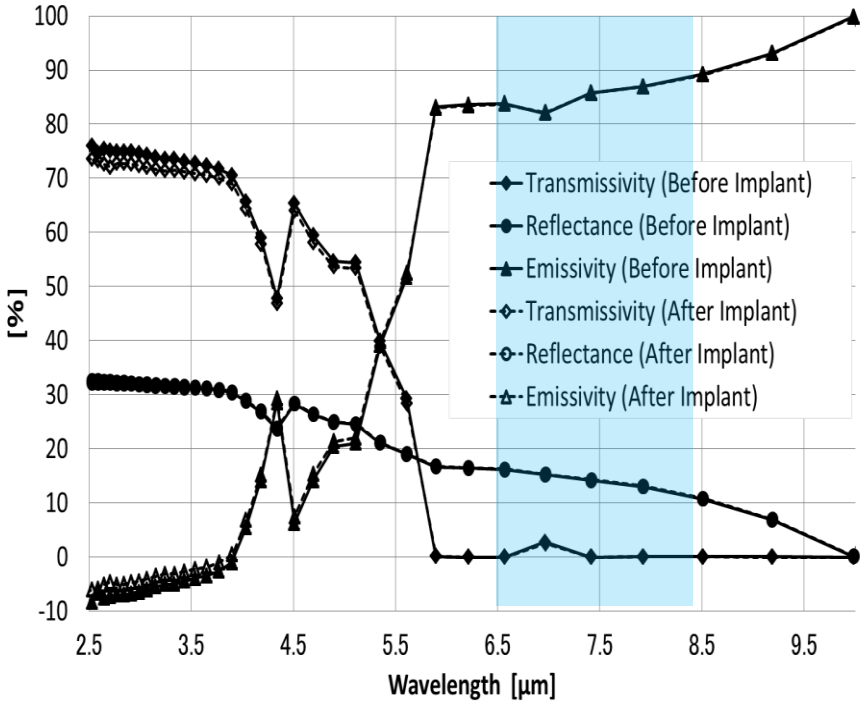


After implantation
Ar^{+} 100keV 2E14/cm^{2} 1mA 300 ºC

Wafer transmissivity changes after ion implantation

Spectroscopic characteristics of HPSI-SiC

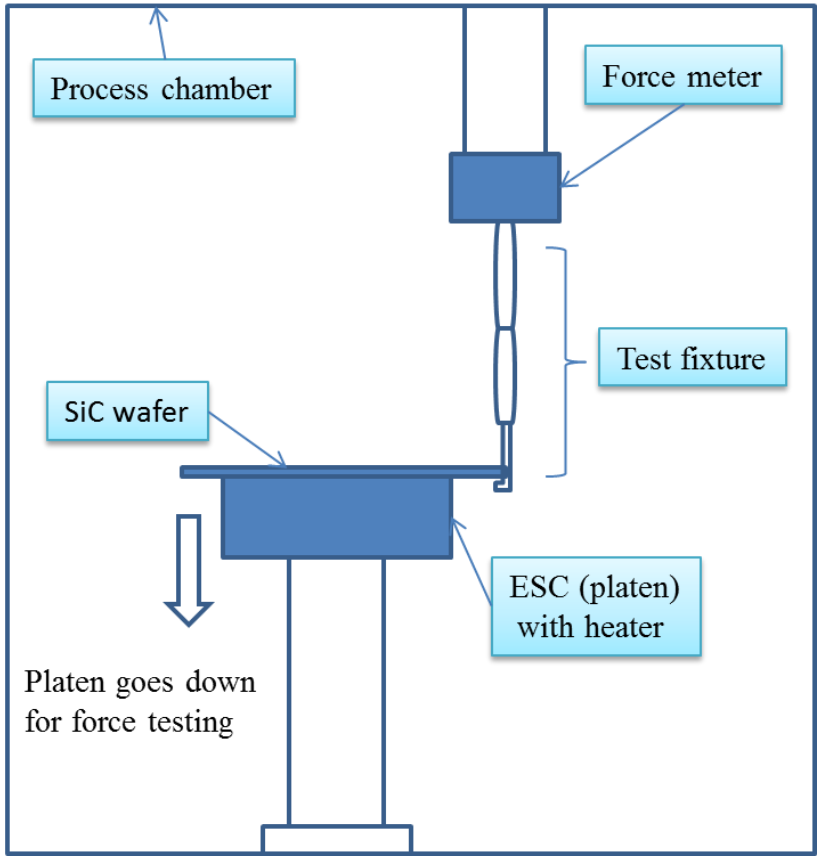


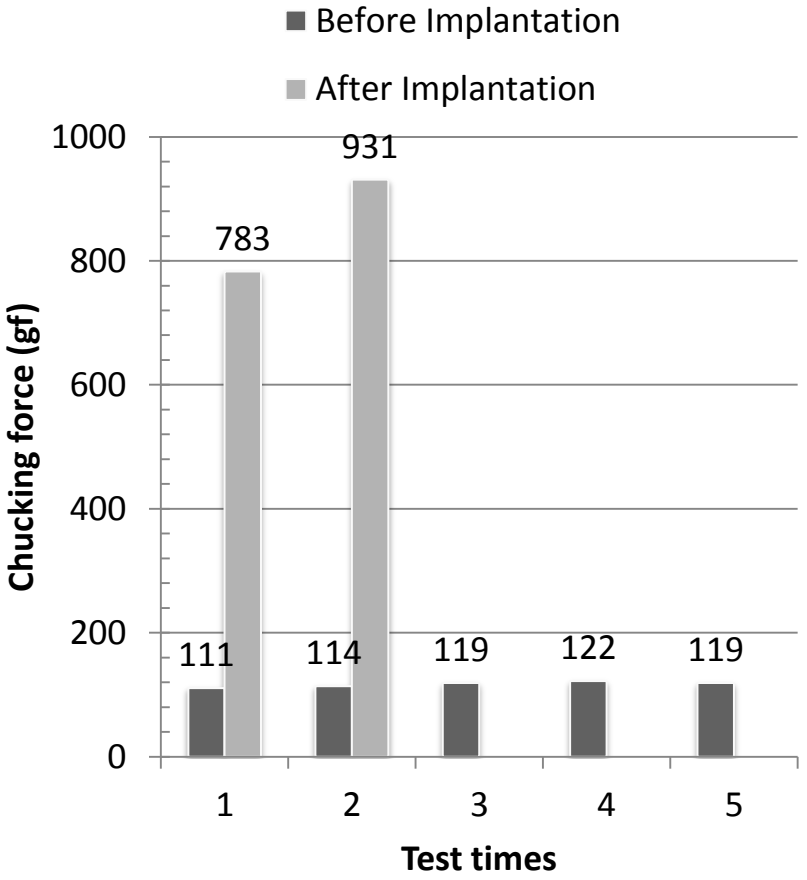


W. Zhao et al. IIT2014

Transmissivity and emissivity changes after ion implantation in low wavelength region.
Suitable wavelength for temperature observation changes depend on the substrate.

Chucking force observation for HPSI-SiC before and after implantation





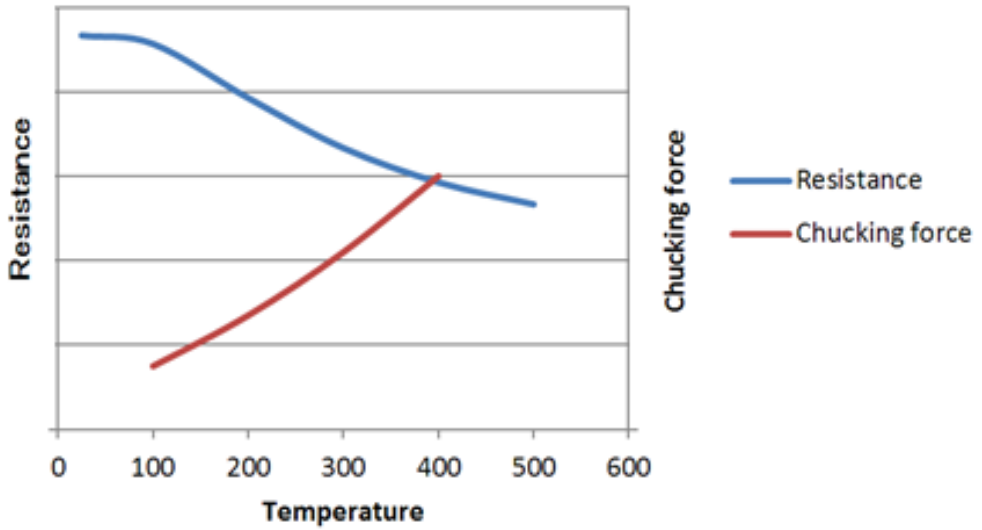
Chucking force increases during implant.
Soft tearing off is required not to break the wafer.

Temperature dependence of the Chucking force

Difficulty of implanting both at RT and HT in one configuration

ESC changes its electrical property as a function of temperature.

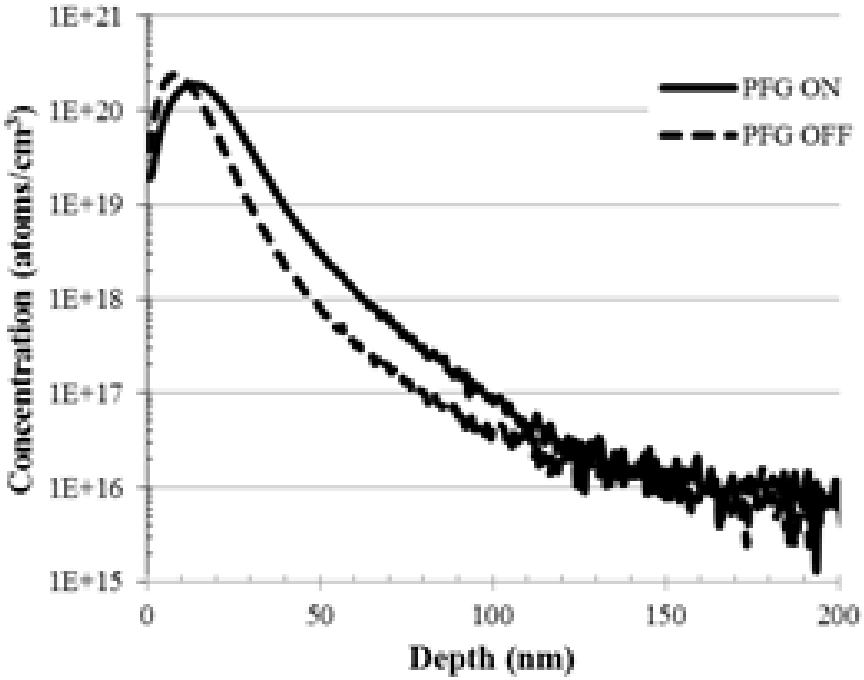
HT implant requires thermal insulation for heating, and RT implant requires thermal conductance for cooling.

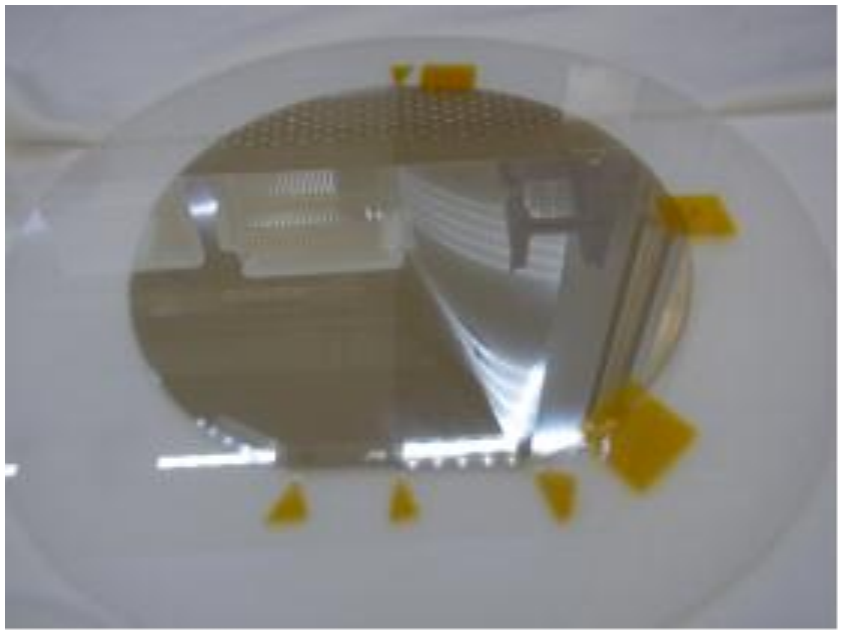


Wide range of chucking force capability is required.
Our expertise for chucking force control and ESC design has enabled both RT and HT implant in one configuration!

Charge up effect on the depth profiles in HPSI-SiC

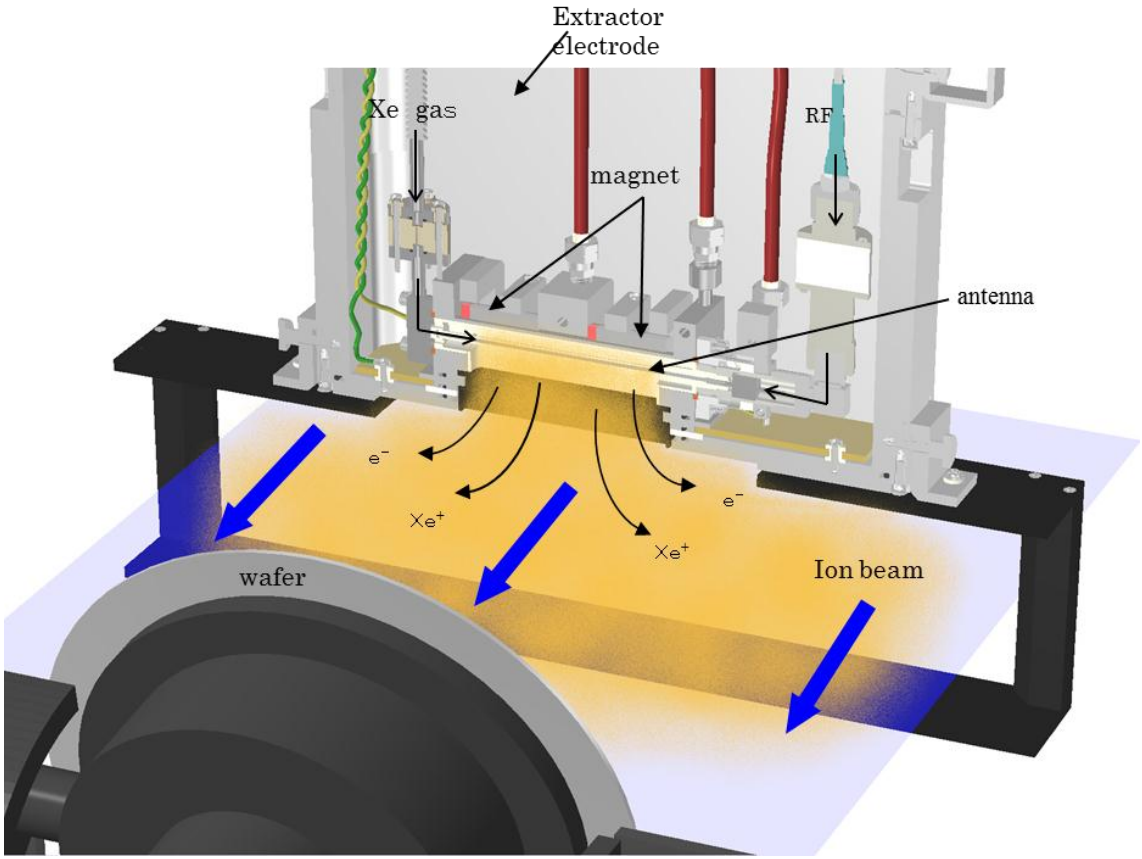
Al^+ 10keV 5E14/cm^2 200uA 0/90 at room temperature





Charging up is sometimes critical for dopant profiles with high resistance substrate

Plasma Flood Gun (PFG) of IMPHEAT®



Our powerful PFG helps to get designed dopant profiles supplying low energy electrons to neutralize the charges on wafers.

Summary

- SiC is one of the promising candidates for next generation high performance power devices
- Heated ion implantation is required for higher activation and better re-crystallization
- Heated ion implanter “IMPHEAT” was developed based on the EXCEED series which are proven tools in mass production lines for silicon devices
- High-current aluminum beam
- Heated ion implantation capability up to 500^{o}C
- Expertized technologies against the difficulties of SiC substrate