High Performance High Temperature Ion Implanter (IMPHEAT) for Manufacturing SiC Power Devices

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NISSIN ION EQUIPMENT CO.,LTD
Ion Beam Equipment Business Department

Contents

1. A brief introduction to Nissin Ion Equipment

2. Recent SiC applications

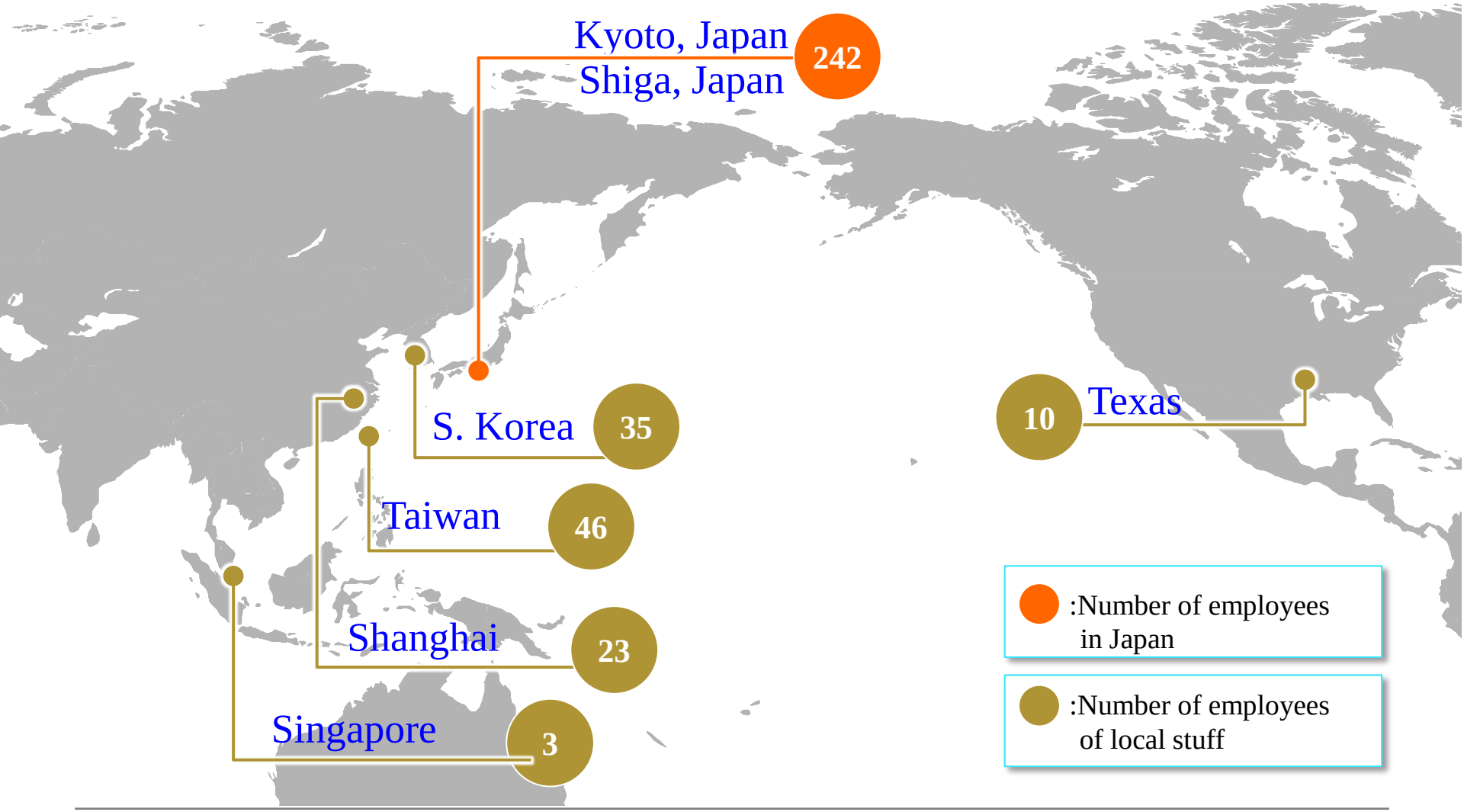
3. General specifications of IMPHEAT

4. Large bow issue of 6” SiC wafers

5. Summary

1-1, A brief introduction to Nissin Ion Equipment

Worldwide Operation (Support center)



1-2, A brief introduction to Nissin Ion Equipment

Worldwide Operation (Manufacturing and R&D)

Kyoto Plant

Head office and R&D function

Shiga Plant

Mass production for implanters for semiconductor and Flat Panel Display

Yangzhou Factory

Local assembly of implanters for semiconductor and Flat Panel Display and components/parts manufacturing.

R&D Center in Massachusetts

Development of most advanced implanter technologies and marketing of new business

1-3, A brief introduction to Nissin Ion Equipment

Company Business Data

- Established in 1973 as a division of Nissin Electric whose business history continues over 100 years.
- Nissin Ion Equipment was found in 1999.
- 2 products serving 2 markets.

Products	Ion Implanter (Semiconductor)	Ion Doping (FPD)
Install Base	991	187
Market Share	WW 30% M/C Segment	WW 95% G4/G5/G6

1-4, A brief introduction to Nissin Ion Equipment

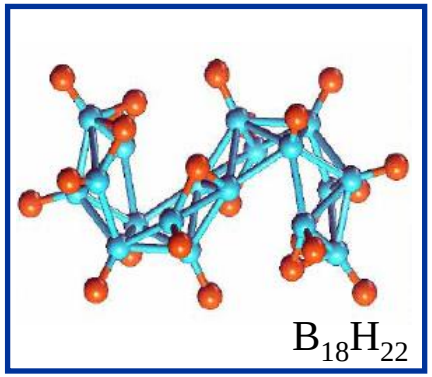
- Ion Implanters (for semiconductor) and their applications

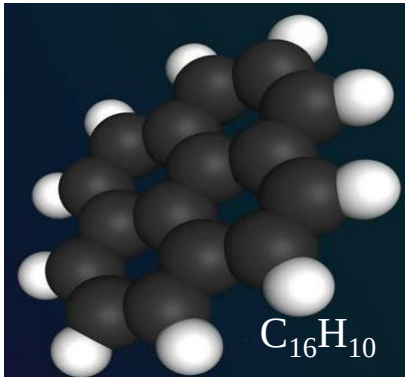
High Current Implanters

Cluster ion implantation

CLARIS

- Ultra shallow junction formation
- Getting-layer formation
- Trench implant
- Damage engineering

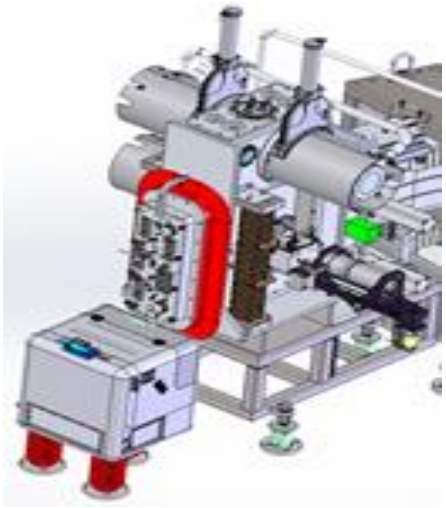




Vertical sheet beam

LUXiON

- 60keV
- 1.5 × higher beam current
- Precise beam control
- Low particle level & energy contamination



1-5, A brief introduction to Nissin Ion Equipment

◻ Ion Implanters (for semiconductor) and their applications

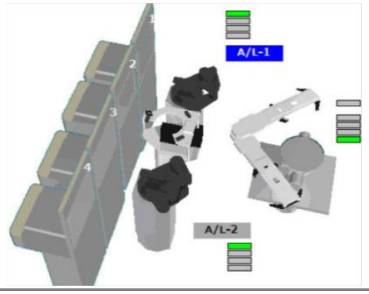
Medium Current Implanters

EXCEED3000AH/9600A -Ev, -Evo, -Evo2

The Most Advanced Model

BeyEX

- 250keV & 320keV (BeyEX-H)
- 500WPH-E/S
- Higher productivity
- Precise angle control system
- Minimum CoC



Customized tool for 8 inch legacy users

EXCEED 3000AH-8C

- 250keV
- 430WPH-E/S,
- Field proven performance
- Same parts as latest model

High Temperature tool for SiC devices

IMPHEAT

- 320kV
- Higher productivity
- 500℃ Implantation system
- Al ion beam

2-1, Recent SiC applications

Image of Smart Society

2-2, Recent SiC applications

- Electricity consumption in US

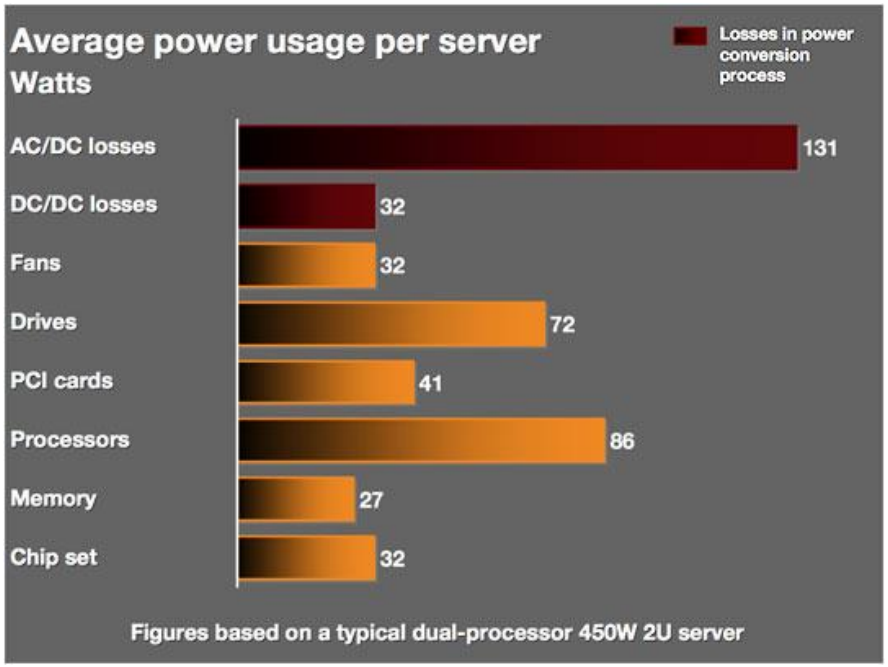
Electricity consumption in US : 3725 Billion KWh

Data centers 91 Billion KWh in 2013

140 Billion KWh in 2020

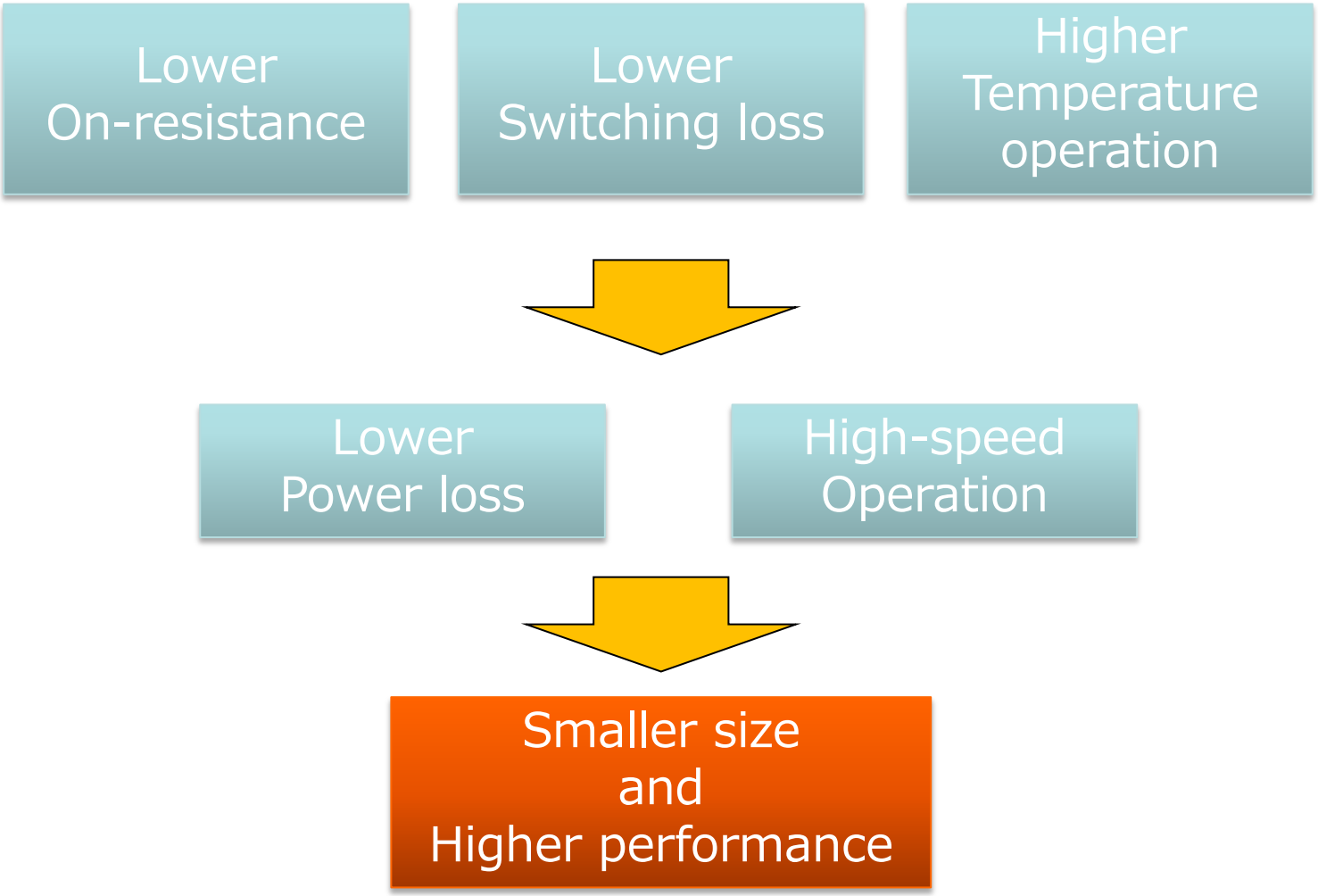
Losses in power conversion process are major factor

Reduction of power loss in power devices is strongly required



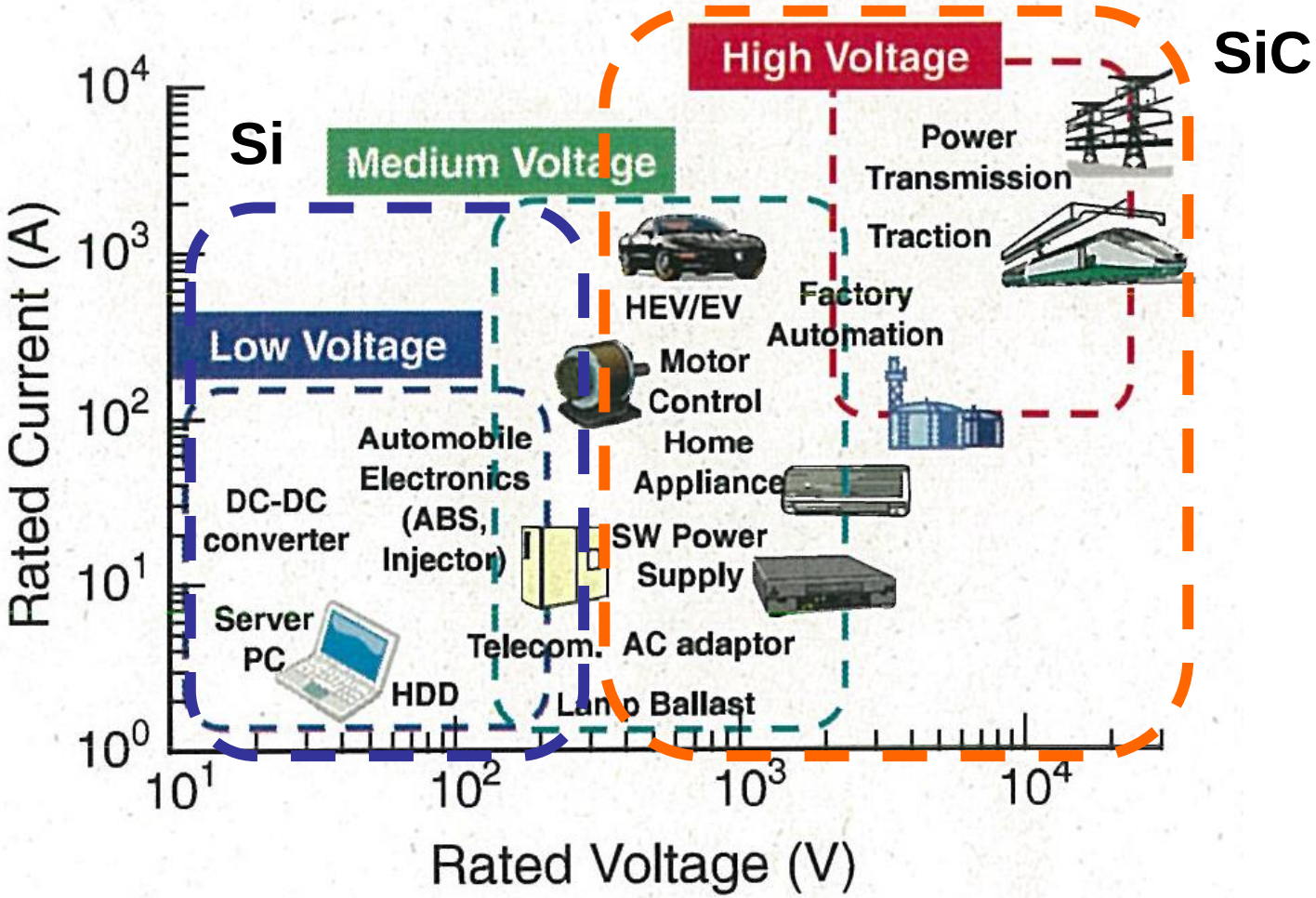
2-3, Recent SiC applications

- Advantages of SiC power devices



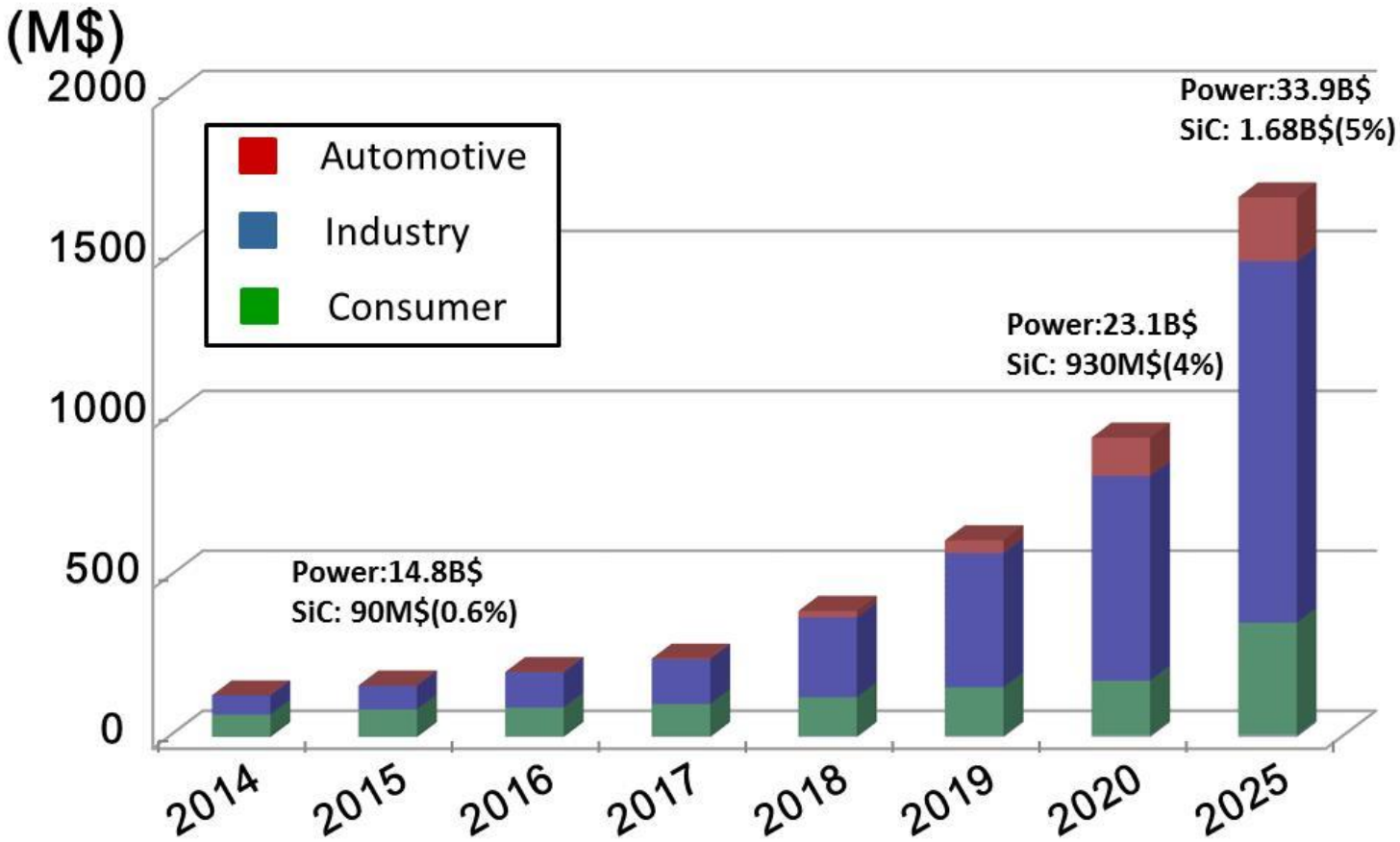
2-4, Recent SiC applications

- Major application areas of power devices



2-5, Recent SiC applications

◻ SiC Market



Source: Yano research 2016 edition.

- **Market driver is the industry use**
- **Automotive use will really stand up after 2020**

2-6, Recent SiC applications

Railcar Traction Inverter

Tokyo metro subway Ginza-line
2013
SiC diode (Mitsubishi Electric)
1.7kV, for 600V catenaries
Power loss reduction at regeneration breaking

Power consumption :30% reduction

Odakyu Railway, JR Yamanote-line, Hankyu Railway
2014 Dec.
All-SiC module (Mitsubishi Electric)
3.3kV,1500A for 1500V catenaries

Power consumption 36% reduction

2-7, Recent SiC applications

◻ Shinkansen Bullet Trains

2016 test run start
2020 Release

Input 2500V AC
SiC : 3.3kV 1500A

Joint project: JR, Mitsubishi, Hitachi, Toshiba, Fuji

Power consumption :7% reduction

Motor driving system

Weight:1000kg (△30%)

2-8, Recent SiC applications

◻ Automotive application

Toyota Motor Corp started test run of a hybrid vehicle (HEV) equipped with SIC on a public road from 2015.

5% Fuel Efficiency Improvement With SiC

PCU 24module

PCU 14module

Motor Voltage is stepped up to 650V from 200V by PCU

Toyota Motor Corp also started test run of Fuel Cell Bus with SIC power device on a public road from 2015.

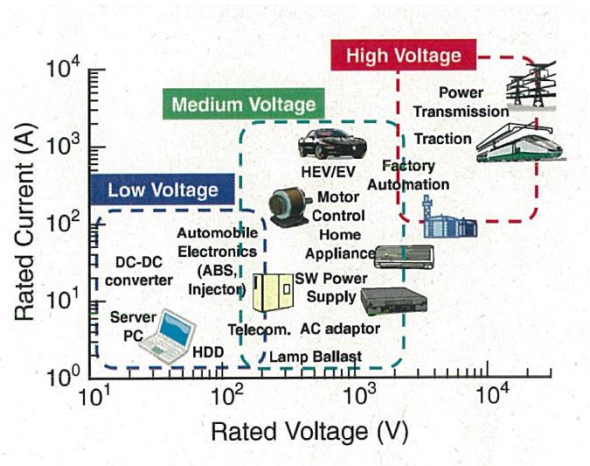
2-8, Recent SiC applications

- Automotive application

Honda began to sell a fuel cell powered vehicle using SiC power device for the first time in the world at 2016.

2-9, Recent SiC applications

- Current issues in SiC business



SiC device penetrates into high Voltage area which is effectively applied the advantage of SiC.
However TAM of this area is small

Sustaining of SiC process line becomes serious issue because of small product volume

Adoption in the high volume zone is strongly required !!
But Automotive: Full introduction will be after 2025
Yield issue (Big die is requested)
Consumer products : cost issue, Only used for flagship
air-conditioner, refrigerator

Current targets of Japanese SiC suppliers are Industry use (Factory automation, robot, and elevator) and over 6kV MOS for R&D

3-1,General specifications of IMPHEAT

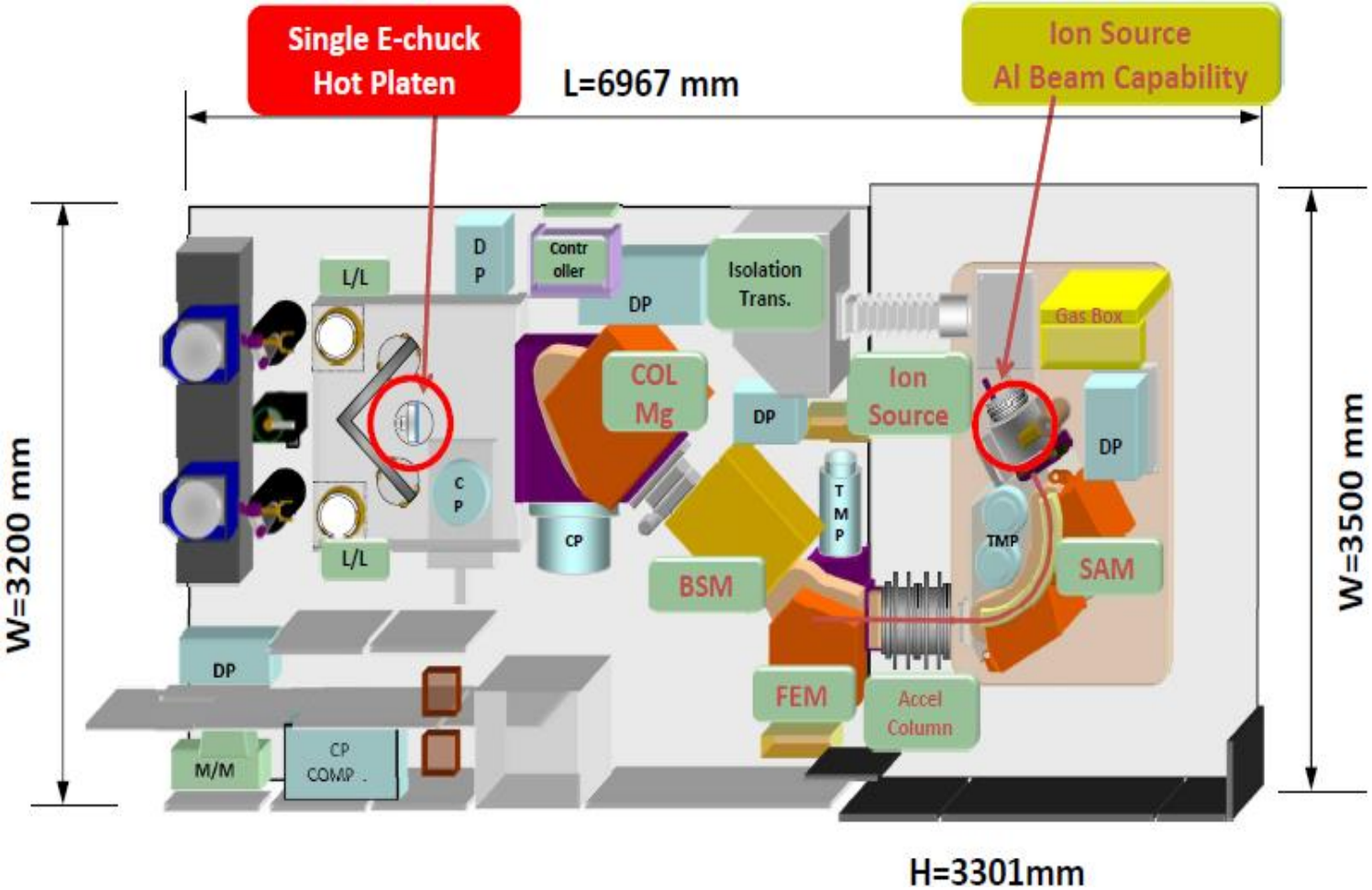
- “IMPHEAT®”

- **Based on EXCEED® series which are our field-proven M/C tools**
- **High Current Al ion beam**
- **Heated implant capability up to 650°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

3-2,General specifications of IMPHEAT

◻ Tool Layout of IMPHEAT



A very stable beam line and high quality beam which has hundreds of shipment recorder.

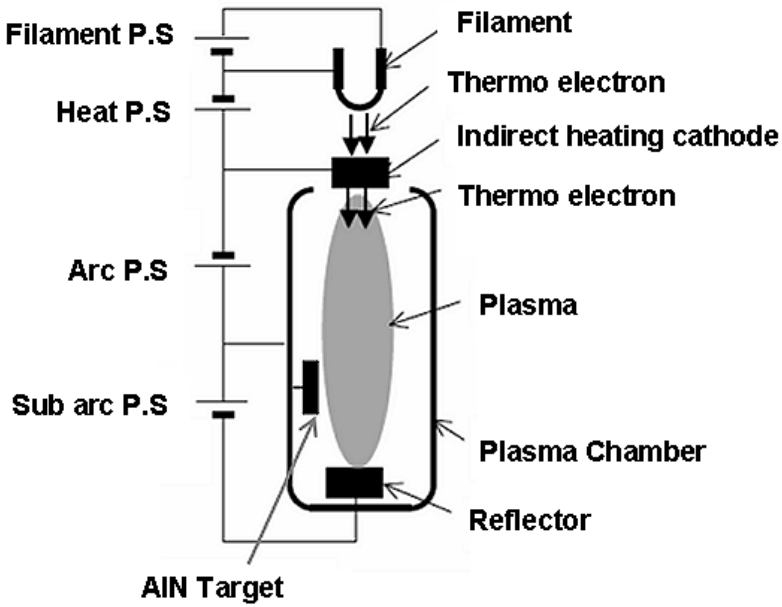
◻ High Current Al Ion Beam - Ion Source -

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

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

IHC-R Ion source

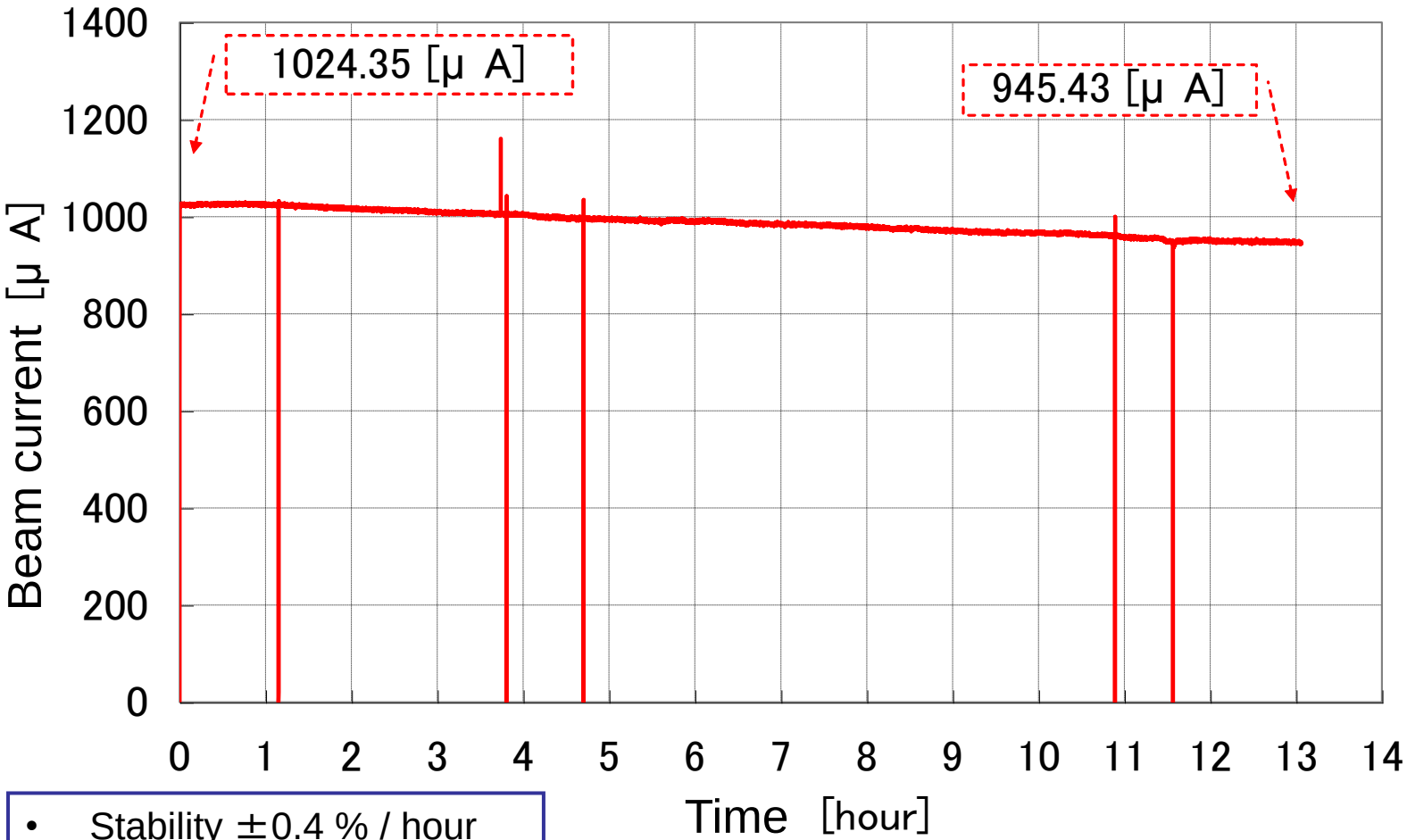
•Generating Al ion by chemical sputtering from AlN target



Schematic diagram of ion source

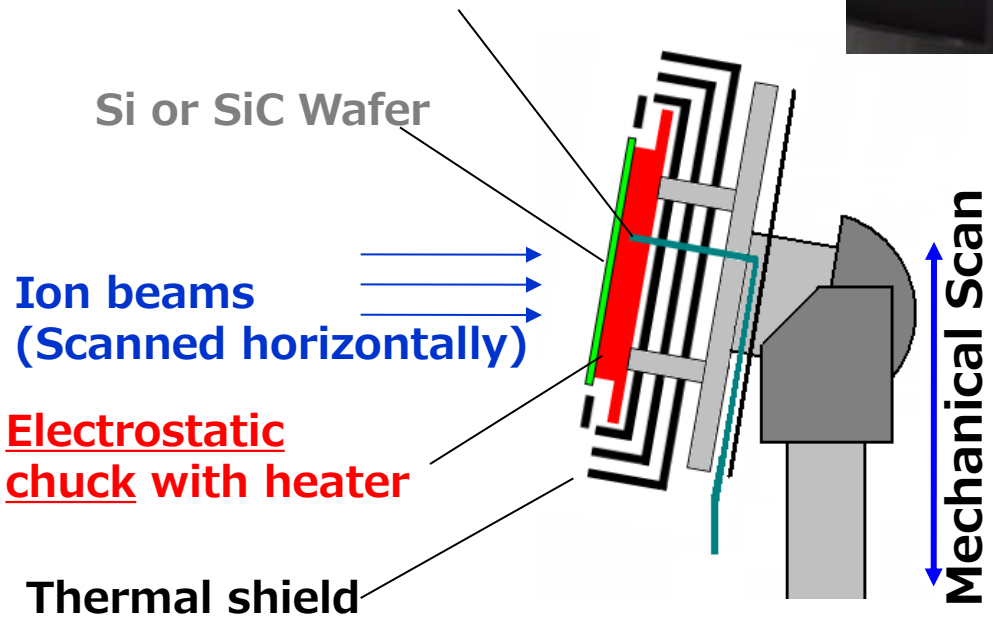
3-5,General specifications of IMPHEAT

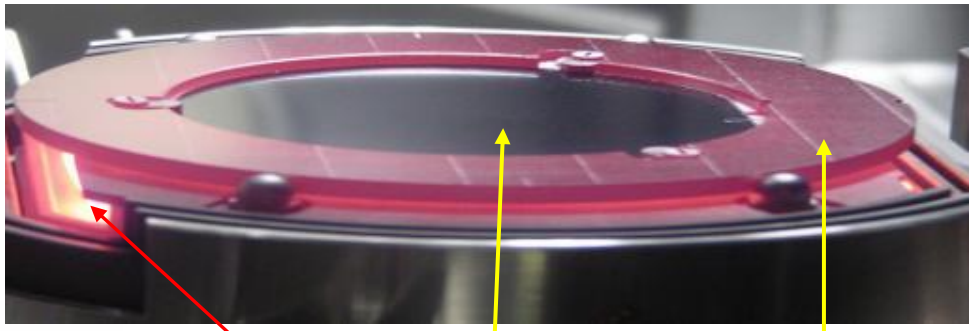
◻ High Current Al Beam -Al^+ beam Stability-



- Stability ±0.4 % / hour
- Glitch 6 times@13 hours

◻ Platen for heated ion implantation - Electrostatic chuck with heater-



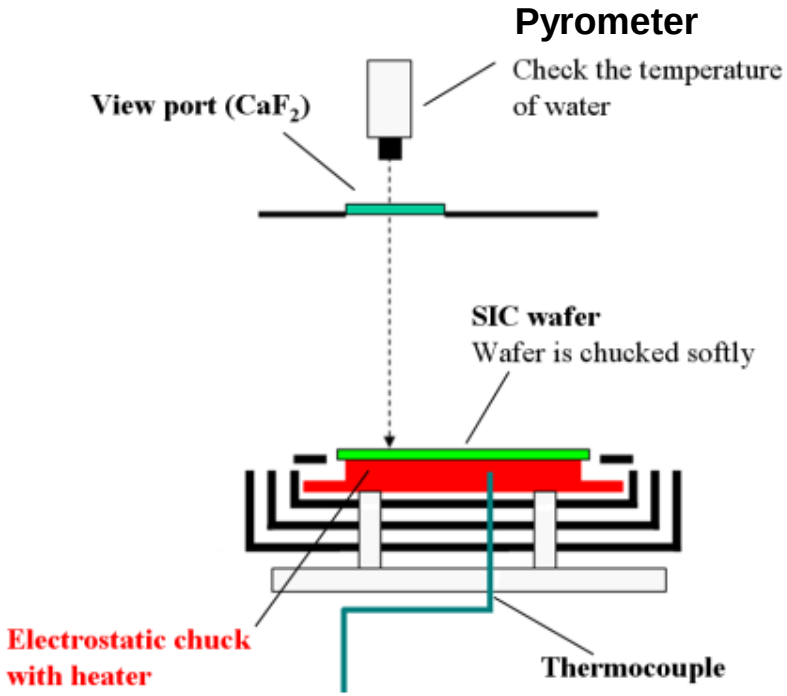


High Temperature Platen

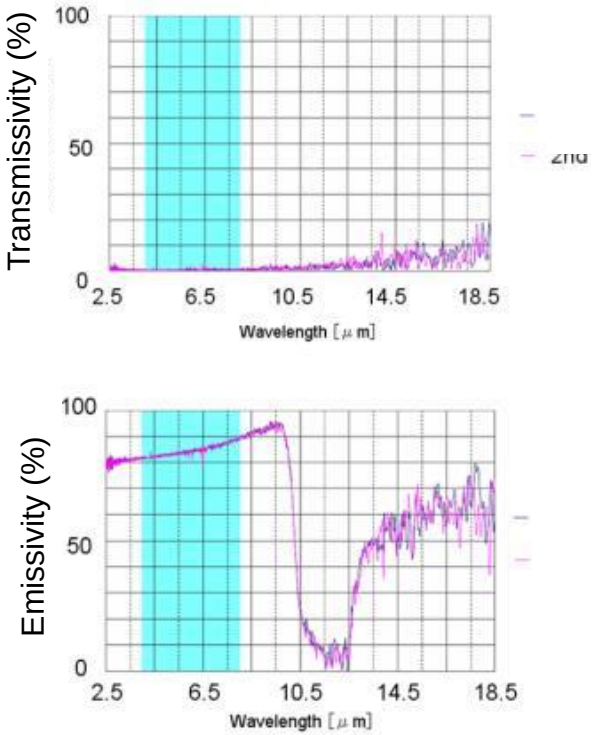
- **ESC with heater**
- **Wafer size**
  - **6, 4inch**
  - **Graphite wafer holders are used for smaller samples**

Monitoring system of wafer temperature

- Wafer temperature is measured by a pyrometer before implantation.
- We observed the wavelength dependence of the transmissivity and emissivity.
- Low transmissivity and high emissivity is suitable for its measurement.
- So we usually use around 5um for SiC.



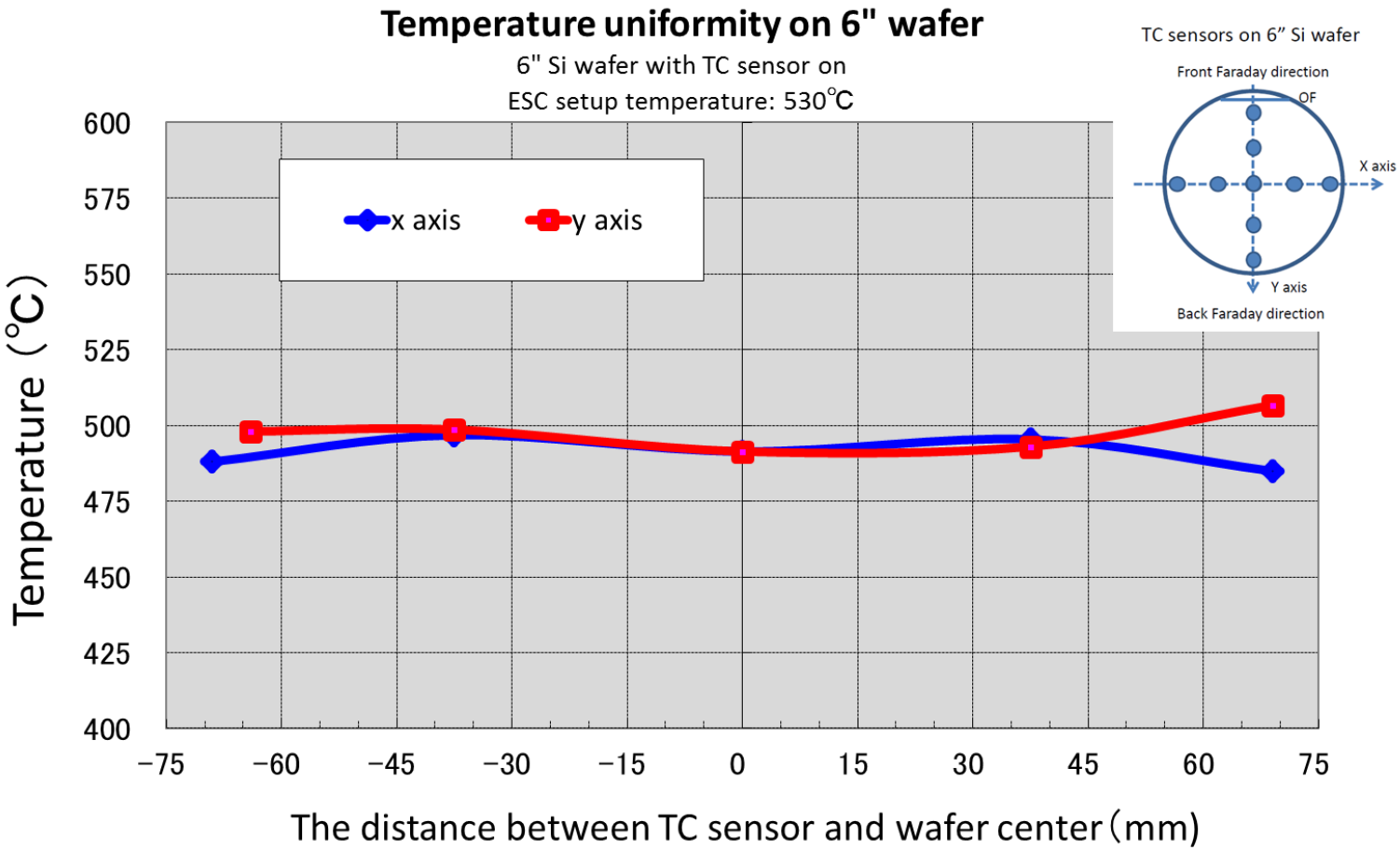
The wafer temperature measurement system



The infrared rays characteristic of SiC

3-8,General specifications of IMPHEAT

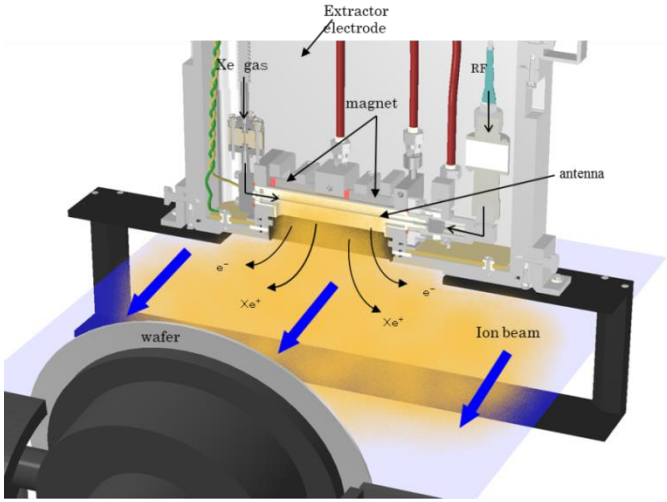
- Temperature characteristic of wafer
  - average temperature: 495.6 degC, Tmax-Tmin: 21.8℃



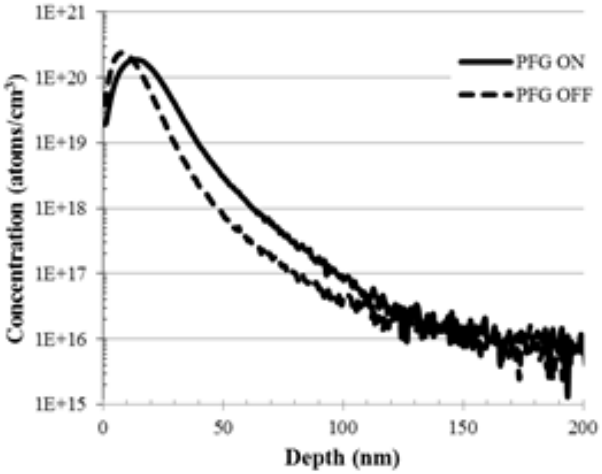
Plasma Flood Gun (PFG)

- Semi-insulated or insulated wafers must be charged up and had a positive potential.
- Then Al ions were decelerated before implant.
- Plasma flood gun is a neutralizer to neutralize the charge on the wafer during implantation.

Overview of PFG



Charge up effect on the depth profiles



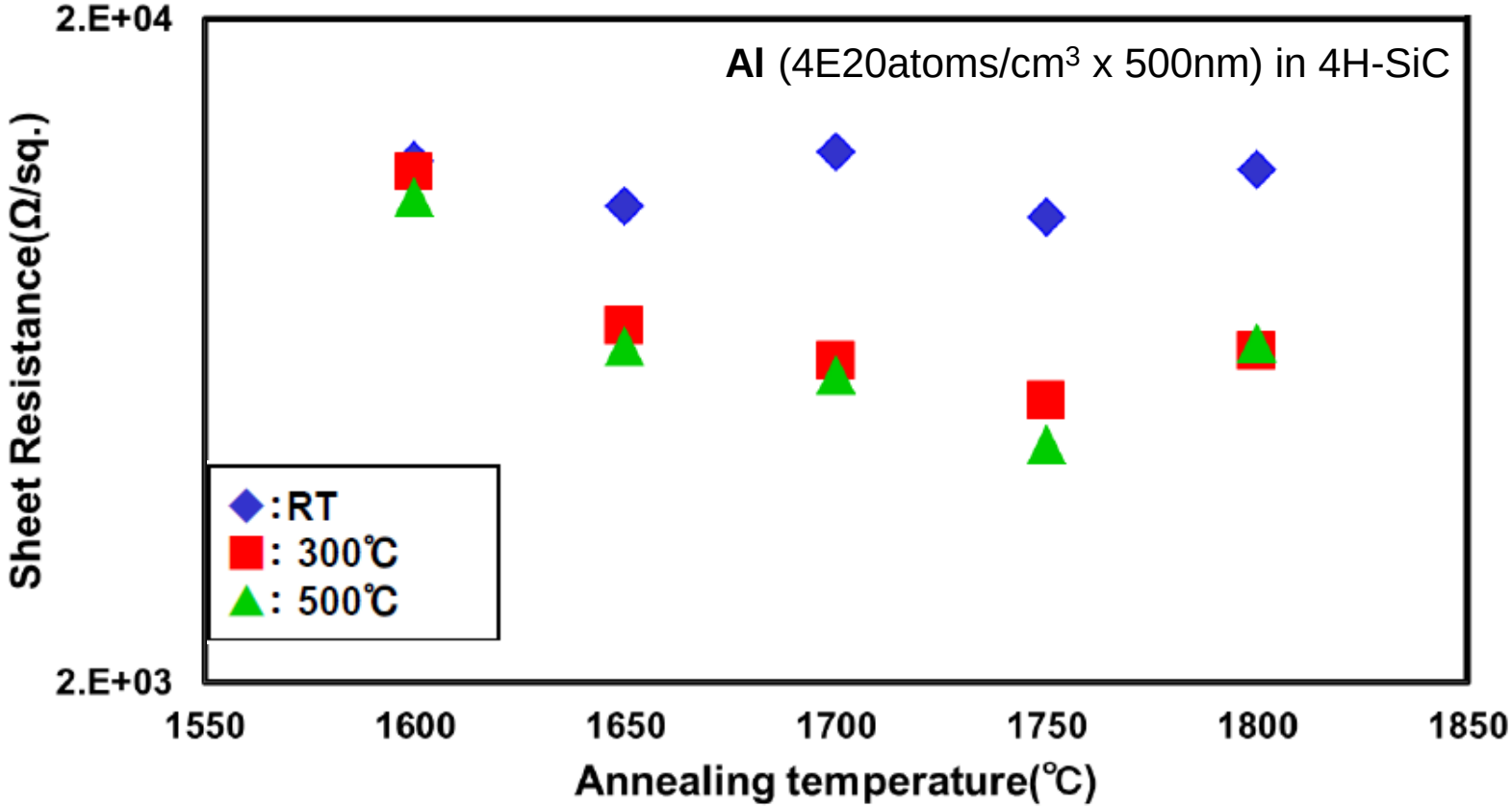
Depth profiles With / without PFG

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

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

3-10,General specifications of IMPHEAT

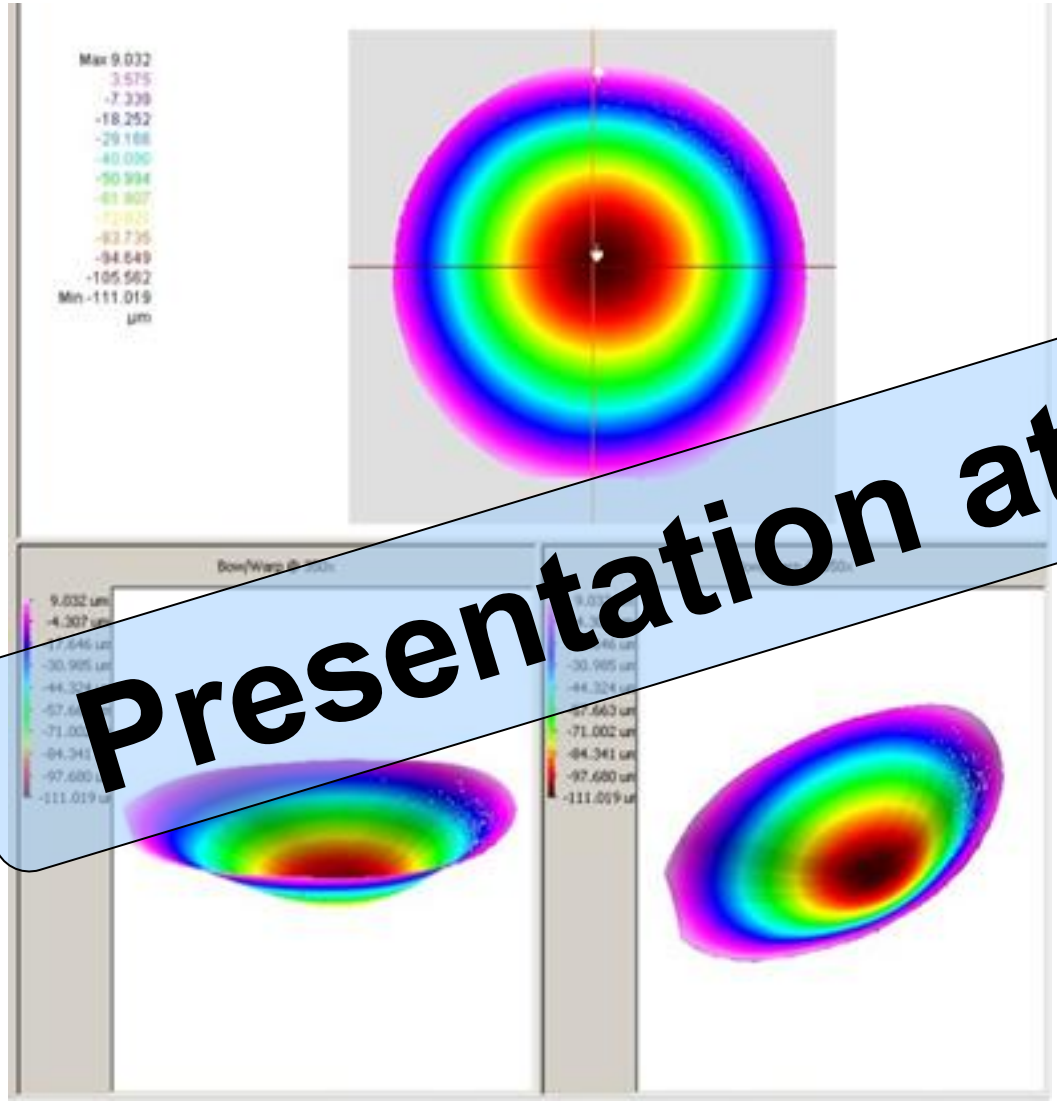
- Rs with heated ion implantation after several annealing conditions



Collaboration work with TOYO TANSO and EpiQuest
Si-vapor ambient anneal without carbon capping

We got lower Rs with higher substrate temperature at higher annealing temperature over 1650 ºC.

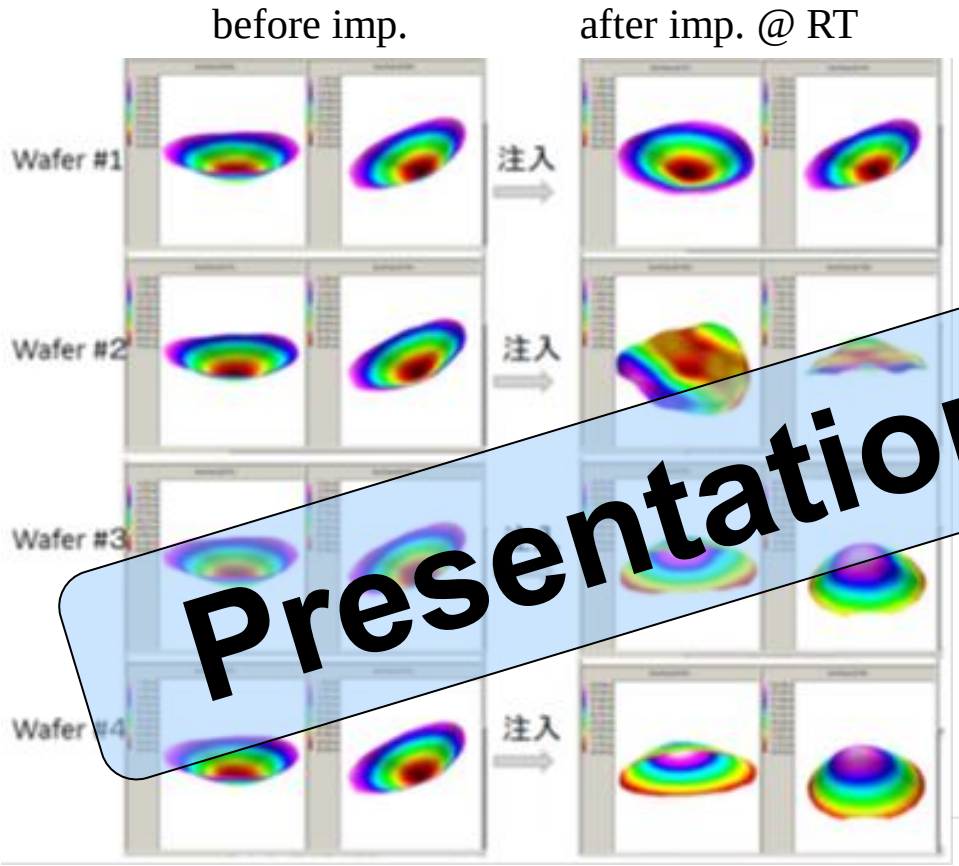
4-1,Large bow issue of 6” SiC wafers

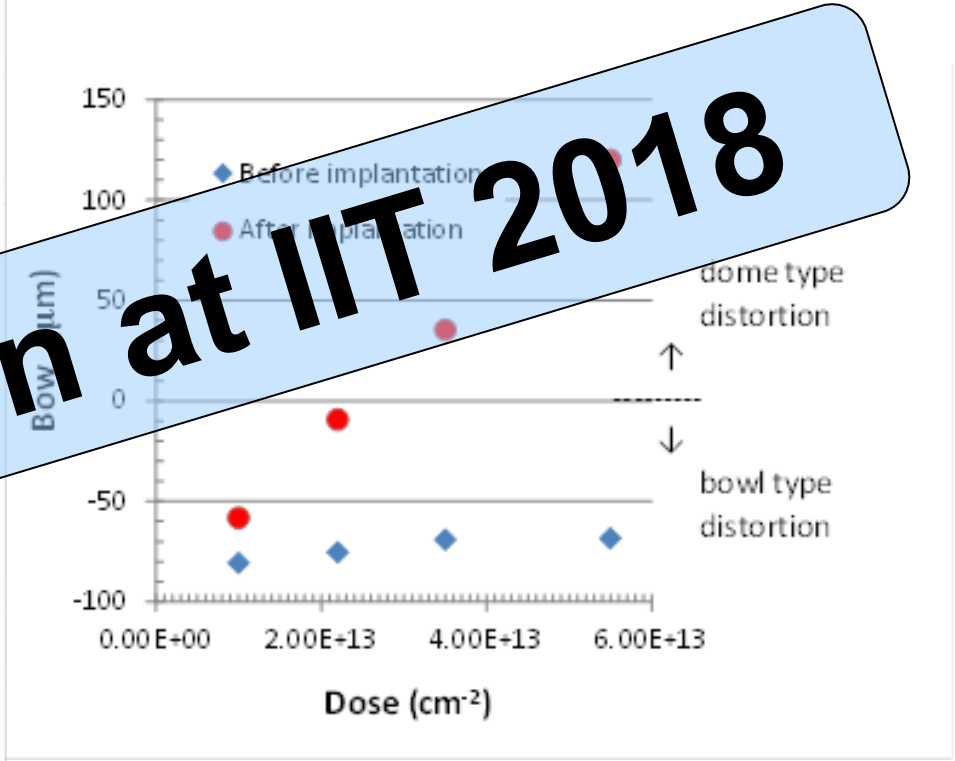


A distorted 6” SiC wafer (t 350 µm production grade) having a bow of -110.1 µm.

4-2,Large bow issue of 6” SiC wafers

- Bow VS implant Dose @ RT Al+ imp



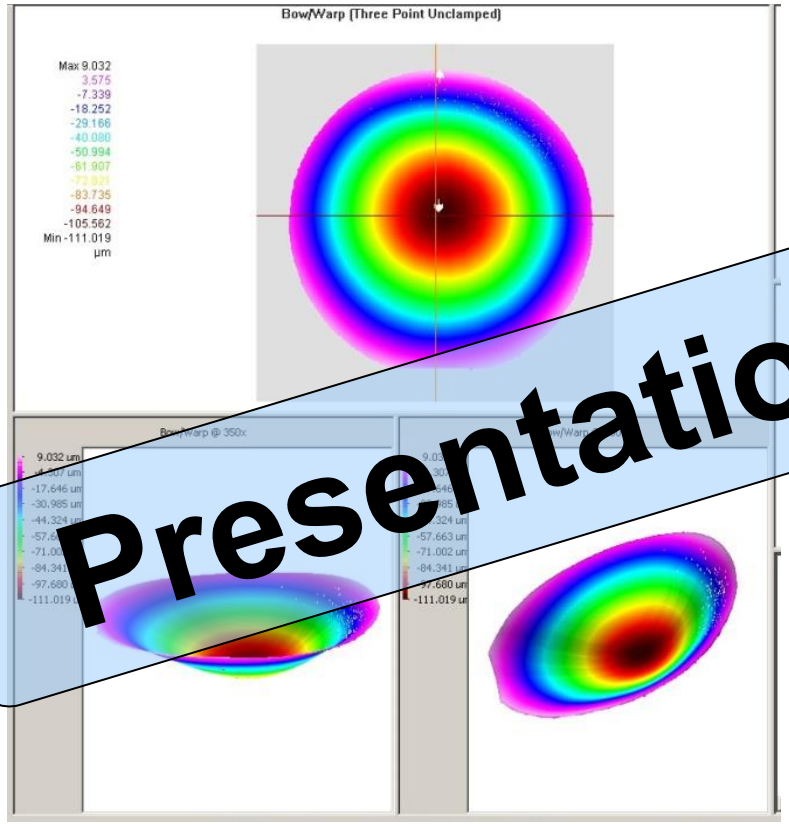


Wafer bow changes from bowl type to dome type even after **a room temperature** implant.

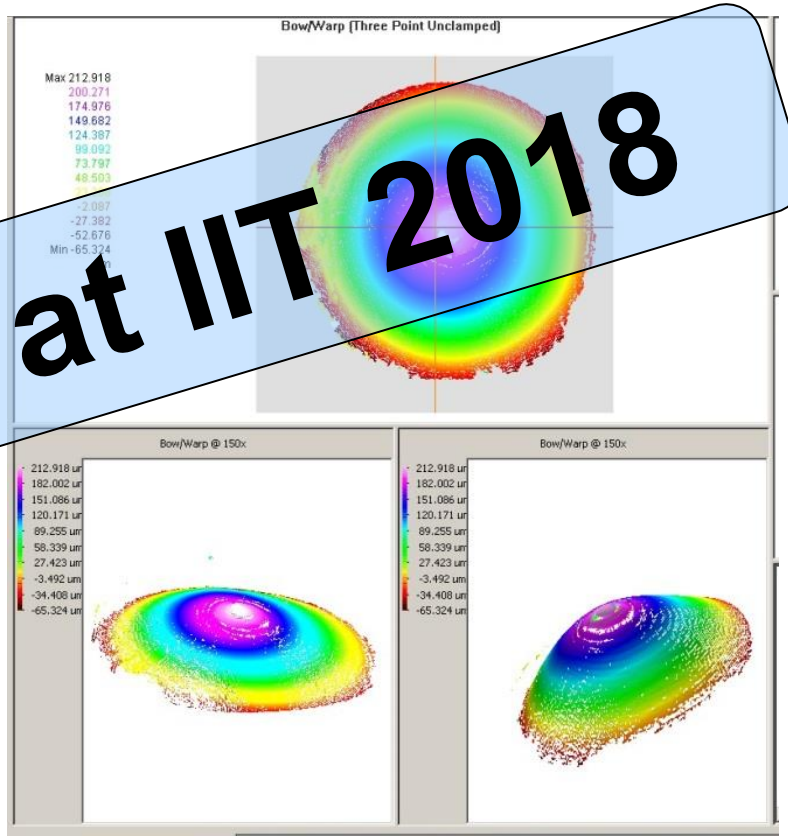
4-3,Large bow issue of 6” SiC wafers

- Shape changing after implant @ HT

before imp



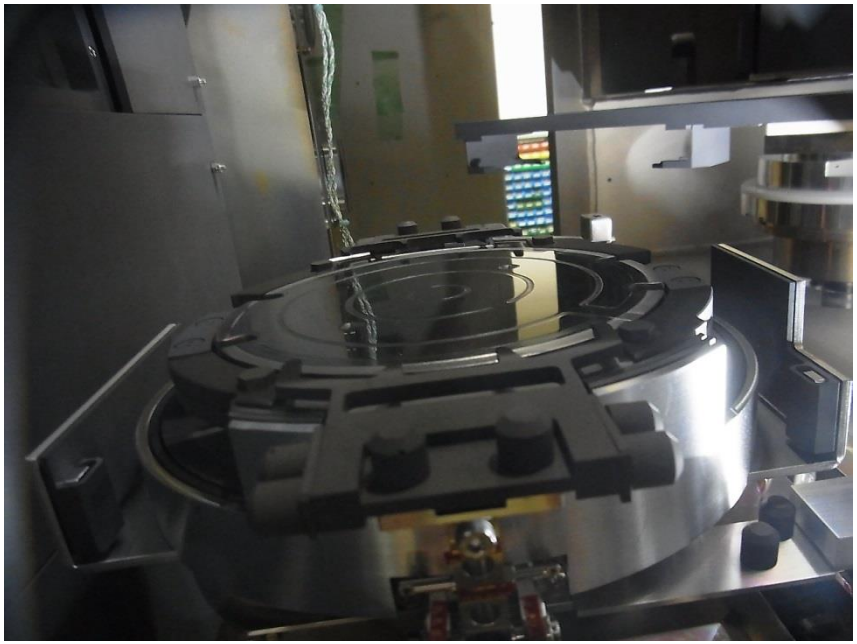
after imp (Al^+ 6E14 500degC)



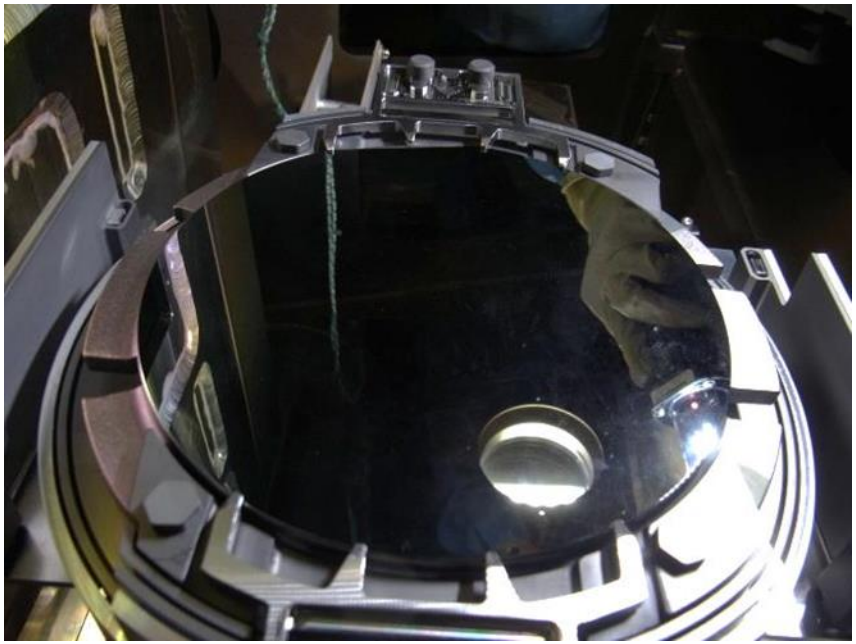
Bow: **-110.1** µm $\xrightarrow{\text{imp}}$ **+211.5** µm

4-4,Large bow issue of 6” SiC wafers

- The way IMPHEAT deals with bowed SiC wafers
  - A mechanical clamp and ESC system



An ESC with clamp



A wafer chucked and clamped by ESC and the Clamp

  - **<u>A wafer handling video</u>**

5, Summary

- SiC is one of the promising candidates for next generation high performance power devices.
- Heated ion implanter “IMPHEAT” was developed based on the EXCEED series which are proven tools in mass production lines for silicon devices.
- IMPHEAT has high stability beam line and high quality beam.
- Heated ion implantation capability up to 650°C and good temperature uniformity.
- IMPHEAT can handle largely bowed SiC wafer, such as a bow of more than 200 μm.

6, Ion implant service

Class 1 clean room

Ion Type

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn

Energy and Dose

0.2keV to 900keV , 5e10～5e17/cm2

Wafer Size , Material and Temp.

From small sample to 300mm wafer

Si, SiC, GaN etc. Cover from RT to 500deg C

Application

Si LSI device (B18H, B10H, B, P, As etc.)

SiC power device (Al, N, P etc. with hot chuck)

GaN power device and LED (Mg, Si, H etc.)

Tools

IMPHEAT (100mm, 150mm, Al, B, 500deg C)

CLARIS（300mm, B18H）

EXCEED3000AH (300mm, B, P, As)

EXCEED2300 (300mm, Mg, W, Fe, etc.)

EXCEED2000A (200mm, B, P, As, H)

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