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
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2. Recent SiC applications

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4. Large bow issue of 6” SiC wafers

5. Summary
1-1, A brief introduction to Nissin Ion Equipment

Worldwide Operation (Support center)

- **Kyoto, Japan**: 242 employees
- **Shiga, Japan**: 35 employees
- **S. Korea**: 35 employees
- **Taiwan**: 46 employees
- **Shanghai**: 23 employees
- **Singapore**: 3 employees
- **Texas**: 10 employees

:*Number of employees in Japan
:*Number of employees of local stuff
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.

<table>
<thead>
<tr>
<th>Products</th>
<th>Ion Implanter (Semiconductor)</th>
<th>Ion Doping (FPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install Base</td>
<td>991</td>
<td>187</td>
</tr>
<tr>
<td>Market Share</td>
<td>WW 30% M/C Segment</td>
<td>WW 95% G4/G5/G6</td>
</tr>
</tbody>
</table>
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 \( \times \) higher beam current
- Precise beam control
- Low particle level & energy contamination

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B_{18}H_{22}  

C_{16}H_{10}
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°C Implantation system
- Al ion beam
2-1, Recent SiC applications

- Image of Smart Society

Energy systems, living environment and transportation systems are linked through a new information network and environmentally friendly town planning aiming at improved comfort and energy savings.
2-2, Recent SiC applications

Electricity consumption in US:

Electricity consumption in US: 3725 Billion KWh in 2013
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
  - Lower On-resistance
  - Lower Switching loss
  - Higher Temperature operation
  - Lower Power loss
  - High-speed Operation
  - Smaller size and Higher performance
2-4, Recent SiC applications

- Major application areas of power devices
2-5, Recent SiC applications

- SiC Market

- 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%)

SiC Power module

Cooling fin
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**

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

  PCU 24module  PCU 14module

  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.

H=3301mm

W=3500 mm

W=3200 mm

L=6967 mm
3-4, General specifications of IMPHEAT

- High Current Al Ion Beam - Ion Source -

**Beam current and stability**
- $\text{Al}^+$ beam current over 2.0mA
- Beam stability $\leq \pm 10\% / \text{hour}$

**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

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**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
3-6. General specifications of IMPHEAT

- Platen for heated ion implantation
  - Electrostatic chuck with heater

**Thermocouple**
Temperature is monitored by TC

- **Si or SiC Wafer**
- **Ion beams (Scanned horizontally)**
- **Electrostatic chuck with heater**
- **Thermal shield**

**High Temperature Platen**

- **Platen body**
  - 720 °C

- **4 inch wafer**
  - 543 °C

- **Graphite wafer holder**

- **ESC with heater**
- **Wafer size**
  - 6, 4inch
- **Graphite wafer holders are used for smaller samples**
3-7 General specifications of IMPHEAT

- 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.

![Pyrometer Diagram]

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<th>Wavelength [μm]</th>
<th>Transmissivity (%)</th>
<th>Emissivity (%)</th>
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<tr>
<td>2.5</td>
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<tr>
<td>6.5</td>
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<td>10.5</td>
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<td>14.5</td>
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<td>18.5</td>
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The infrared rays characteristic of SiC

The wafer temperature measurement system
3-8. General specifications of IMPHEAT

- Temperature characteristic of wafer
  - Average temperature: 495.6 degC, Tmax - Tmin: 21.8°C

![Temperature uniformity on 6" wafer](image)

- Temperature uniformity on 6" wafer
  - 6" Si wafer with TC sensor on
  - ESC setup temperature: 530°C

"[Graph showing temperature uniformity on a 6" wafer]"
3-9 General specifications of IMPHEAT

- 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.

Charge up effect on the depth profiles

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

Depth profiles With / without PFG
Al⁺ 10keV 5E14/cm² 200uA at room temperature
3-10, General specifications of IMPHEAT

- Rs with heated ion implantation after several annealing conditions

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

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

- A wafer handling video
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**

<table>
<thead>
<tr>
<th>Ion Type</th>
<th>H</th>
<th>Li</th>
<th>Be</th>
<th>B</th>
<th>C</th>
<th>N</th>
<th>O</th>
<th>F</th>
<th>Ne</th>
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<tr>
<th>Ion Type</th>
<th>Na</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cl</th>
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<tr>
<th>Ion Type</th>
<th>Ti</th>
<th>V</th>
<th>Cr</th>
<th>Mn</th>
<th>Fe</th>
<th>Co</th>
<th>Ni</th>
<th>Cu</th>
<th>Zn</th>
<th>Ga</th>
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| Ion Type | Rb | Sr | Y  | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te |
|----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

| Ion Type | Cs | Ba | La | Hf | Ta | W  | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po |
|----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

**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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