B$_{10}$H$_{14}$ Implantation

for 45nm Node USJ Doping

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Outline

I Introduction

II Equipment Development
   beam current of present configuration

III Implantation Characteristics
   3keV equivalent energy implantation
   500eV equivalent energy implantation

IV Summary
Requirement for 45nm node I/I

Tilt Angle (0, 30, 45deg) & Step Rotation (1, 2, 4, 8, 12 step)

Halo/Pocket:
High Tilt, Step Rotation

SDE Implant:
0Tilt, Tilted, Step Rotation

Well:
0Tilt

Accurate Dose, Precise Control of Beam Angle & Size
## Low Energy Implantation Technologies

<table>
<thead>
<tr>
<th></th>
<th>Advantage</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I/I System with Decel. Mode</td>
<td>Traditional System</td>
</tr>
<tr>
<td>2</td>
<td>Molecular (Cluster) Ion Implantation</td>
<td>Low Space Charge Effect. Good angle control.</td>
</tr>
<tr>
<td>3</td>
<td>Plasma Immersion Ion implantation</td>
<td>Ultra Low Energy</td>
</tr>
<tr>
<td>4</td>
<td>Gas Cluster Ion Doping</td>
<td>Ultra Low Energy</td>
</tr>
</tbody>
</table>

There are many candidates!
I. Introduction

Space Charge Effect at Ultra Low Energy

\[ \rho = \frac{I_i}{\pi R^2 v_i} \]  
Neutralization: 0%

Beam will be blown-up with decreasing energy

Beam diverges easily and is difficult to transport.

\[ z = 2 \frac{R}{K} \int_0^{\ln(R/r)} e^{u^2} du \]

\[ K^2 = \frac{I_i}{(2V)^{\frac{1}{2}}} \frac{1}{\pi\varepsilon_0} \left( \frac{m_i}{e} \right)^{\frac{1}{2}} \]
I. Introduction

Molecular Decaborane ($B_{10}H_x^+$) Ion Implantation

1/10 times lower beam current ($J$), 10 times higher energy ($V$) can be applied with the equivalent boron monomer implantation.

\[ S \propto J \sqrt[3]{\frac{M}{eV}} \]

For example

- $B_{10}H_x^+$: 5keV: 100\(\mu\)A
  (Equivalent $B^+$: 0.5keV: 1000\(\mu\)A)

\[ = \quad B^+: 0.5\text{keV: }10\mu\text{A} \]

1/100 times smaller space charge force

Small beam divergence, easy to control the beam angle for across the wafer.
I. Introduction

Decaborane characteristics

Material properties

Solid @ Room temperature
Melting point: 99.6ºC
Boiling point: 213ºC
Vapour pressure: 6.7Pa @ 25ºC
Ionization Potential: 9.56eV
Toxic vapor
I. Introduction

Decaborane Characteristics

Typical mass spectrum

Many neighboring peaks
*the number of attached hydrogens
*the number of boron isotope $^{11}$B, $^{10}$B
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II. Equipment development

Overview of EXCEED2300H Beam Line

Decaborane Ion Source

SAM (Source Analyzing Magnet)

Acceleration Column

FEM (Final Energy Magnet)

BSM (Beam Sweep Magnet)

Collimator Magnet

Front Faraday (Multi-cups)

FEM Faraday
(FEM faraday current)

Back Faraday (Multi-cups)
(Back faraday current)

Energy contaminants are removed by the FEM
II. Equipment development

Improve beam current I: Larger ion source slit size

Ion Source slit size 30*3mm $\rightarrow$ 30*6mm

Beam current $\rightarrow$ FEM Faraday 300uA $\rightarrow$ 520uA $\rightarrow$ almost doubly improved

Larger slit size increases FEM Faraday beam current. But Back Faraday beam current not so much.
II. Equipment development

Improve beam current II, multi peak acceleration

By widening the mass resolving slit, i.e. 10 peaks can be introduced to the beam line

Beam current increases.

*Profiles of SIMS are completely the same.

Multi peak acceleration is acceptable but cross-contamination is a future problem.
II. Equipment development

Improve beam current III, Wide slit + multi peak acceleration

Beam current (10 peak input)

1900uA@500eV (FEM)
620uA@500eV (Back Faraday)

Focusing element is added in the beam line. It means beam optics should be optimizing.
II. Equipment development

Beam divergence measurement

Comparing the beam width (FWHM) to measure the beam divergence.
II. Equipment development

Beam divergence measurement

Beam diameter and divergence at a wafer (equivalent energy 500 eV)

The diameter of 10peak is 6 times as large as that of 2 peak.

The divergences are less than 0.4deg in both cases.

The parallelism is less than 0.5deg in both cases.

In 2peak case and 10peak case, the beam divergence is both less than 0.4deg.
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III. Implantation Characteristics

3keV equivalent energy implantation

TW value comparison

At lower dose condition, both TW values are almost same, but at higher dose condition, TW of decaborane is relatively high.

At decaborane higher dose, the crystalline damage is increased.
III. Implantation Characteristics

3 keV equivalent energy implantation

TEM images comparison (as-implanted, Dose rate: 1E15/cm²)

Amorphous layer by decaborane implantation is observed. Thickness of a amorphous layer is 9nm, which corresponds to the Rp of decaborane.
III. Implantation Characteristics

3keV equivalent energy implantation

SIMS profile comparison (Dose rate: 1E15/cm²)

As-implantation, both profiles are not so much different with Rp 9 - 10nm. After-anneal, the profile of decaborane is divided at around Rp.

Anneal ‖RTP1000 °C

For decaborane annealing, boron diffuses with different speed in the amorphous layer and crystalline layer.
III. Implantation Characteristics

500eV equivalent energy implantation (as-implanted)

TEM images comparison (as-implanted, Dose rate: 1E15/cm2)

Thin amorphous layer (3 nm) is observed.
III. Implantation Characteristics

500eV equivalent energy implantation (as-implanted)

As-implantation SIMS comparison (Dose rate: 1E15/cm²)

Without PAI
Decaborane tail is Shallower and Steeper

With Ge-PAI
Both almost same up to 13nm
III. Implantation Characteristics

500eV equivalent energy implantation (after annealing)

TEM image comparison after RTA

RTA 1000 °C, Dose: 1E15/cm²

No significant residual defects are observed.
III. Implantation Characteristics

500eV equivalent energy implantation (after annealing)

RS VS Xj

RTA Temp. 900 - 1050 °C

Dose: $10^{15}$ atoms/cm²

$X_j@ 1 \times 10^{18}$/cm³

Decaborane ->
Shallower $X_j$ with same Rs
Low Rs with same $X_j$

Better activation!
IV. Summary

Ion source and beam line development

1. Wide source slit and 10-peak acceleration makes improve beam current with 1900uA @FEM and 600uA @Back Faraday.
2. The beam divergence of less than 0.4deg is achieved.

Implantation characteristics

3. For Decaborane implantation amorphous layer is formed at higher dose.
4. Amorphous layer suppresses the channeling and changing the anneal process to improve the activation.

Decaborane implantation is a promising process for beyond 45nm USJ doping.
<Acknowledgment>

Takayuki Aoyama, Masatoshi Fukuda and Yasuo Nara; Fujitsu Lab. are highly appreciated for the process development.

This work was supported by the New Energy and Industrial Technology Development Organization (NEDO) and Japan Science and the Technology Agency (JST).

Thank you for your attention!