Low Energy Implantation for Medium Current Implanter with Molecular Ions

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Abstract. Ion implantation is now indispensable process for semiconductor device fabrication. One of the key issues for the next generation LSI device fabrication is the formation of ultra shallow junction using Boron implantation. Medium current ion implanter for LSI production use can dope ions to the device wafer with accurately controlled uniformity and incident angle at a variety of energy ranges. However, the productivity of LSI at sub-keV energy region with conventional atomic B⁺ implantation will quickly fall down due to the low beam current caused by the well-known space charge limitation. To achieve a high productivity in this energy region, Decaborane (B₁₀H₁₄⁺) implantation is supposed to be an appropriate solution. We are to review the technologies used for the commercial medium current ion implanter including Decaborane implantation for ultra shallow junction formation.

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INTRODUCTION

In order to fabricate ultra-shallow junctions in a transistor, doping atoms such as boron has to be implanted at low energy and high current. Table 1 shows the 2001 ITRS (International Technology Roadmap for Semiconductor), indicating that production on the 80nm technology node will be start at 2005, and PN junction depth will be 24-47nm. To fabricate PMOS transistor at such junction depth, boron ion energy has to be less than 200eV, because the annealing process after implantation causes the transient enhanced diffusion (TED). As the transistor size is miniaturized, the lateral distribution of ions becomes the problem. We think the best way to solve these demands is to improve the medium current implanter so that it can deliver much more sub-keV boron current by breaking through the well-known space charge problem at low energy high current beam transportation.

The junction depth depends on the energy of single atom. When we use molecular ions, the energy of each atom is assigned by the mass ratio. If we use decaborane (B₁₀H₁₄⁺) ion at 10keV, the each of the boron atom energy is roughly 1keV. Thus we can use 10keV decaborane ion for boron implantation at 1keV. The space charge is calculated by the beam current, the energy and the ion mass. To transport 1mA boron ion is equivalent in terms of boron atomic current to transport 0.1mA decaborane ion. The velocity of boron 10keV and decaborane 1keV is roughly the same, the space charge of decaborane is ten times lower than that of boron ion. Using decaborane ion is easier to transport than boron ion for low energy implantation.

<table>
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<tr>
<th>year</th>
<th>2001</th>
<th>2003</th>
<th>2005</th>
<th>2007</th>
<th>2010</th>
<th>2016</th>
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<tr>
<td>node (nm)</td>
<td>130</td>
<td>100</td>
<td>80</td>
<td>65</td>
<td>45</td>
<td>22</td>
</tr>
<tr>
<td>Gate oxide (nm)</td>
<td>1.3-1.6</td>
<td>1.1-1.6</td>
<td>0.8-1.3</td>
<td>0.6-1.1</td>
<td>0.5-0.8</td>
<td>0.4-0.5</td>
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<tr>
<td>PN junction depth (nm)</td>
<td>48-95</td>
<td>33-66</td>
<td>24-47</td>
<td>18-37</td>
<td>13-26</td>
<td>7-13</td>
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MEDIUM CURRENT IMPLANTER 
EXCEED2300

The EXCEED2300 is a medium current implanter for 300mm wafers. It has a hybrid scanning system, using horizontal magnetic scanning and vertical mechanical scanning. The schematic configuration of EXCEED2300 is shown in Fig. 1. The implanter consists of an ion source, an analyzing magnet (SAM) with a bending angle of 120(in the high voltage terminal), an acceleration column, final energy magnet (FEM), beam sweep magnet (BSM), collimator magnet and an end station chamber. The energy range of singly charged ion beam is from 3 to 250keV.

DECABORANE BEAM TEST

As described above, low energy implantation using Decaborane ions is one of the solutions to form the ultra shallow junction\(^1\). To apply this method to the process of semiconductor device production, the implanter has to meet a couple of requirements from semiconductor manufactures, such as sufficient beam current to keep a high productivity, stability of beam current, reliability of the ion source, and safety at the maintenance of ion source. From these points of view, we started the development of a Decaborane implantation system for industrial use. Here we show the present results of Decaborane beam extraction tests. A modified PIG (Penning Ion Gauge) ion source was installed in the NISSIN EX2300H and beam extraction test was carried out.

Ion Source For Decaborane

The schematic of the prototype ion source is shown in Fig. 2. This source is based on the NISSIN BEAR (Bernas Electron Active Reflection) source\(^2\). BEAR source is a kind of conventional PIG source, but an electron reflector beside a filament is added. Typically, large negative potential with compared to that of filament is applied to the reflector. This potential can reflect the electron from the filament effectively to the plasma, so that loss of the electron to the plasma chamber wall will be reduced. This improves efficiency of the plasma production and achieve long lifetime. In this prototype ion source, two gas inlets are provided. One is for Decaborane vapor, and the other is for a gas such as argon to maintain the arc discharge. The decaborane vapor is fed from a vaporizer through a small gate valve. The flow rate is controlled by adjusting temperature of the vaporizer.

Modification of ion source is carried out in the point of cooling the plasma production chamber. One of the important techniques to increase the Decaborane beam is to keep the temperature of an ion source low, because when Decaborane vapor passes through a high temperature region like a hot-cathode plasma chamber it can be easily dissociated. Alex S. Perel et al carried out the measurement of partial pressure of Decaborane as a function of temperature\(^3\),\(^4\), and showed that if the temperature of the plasma chamber wall exceeds over 350 degree centigrade, the partial pressure of Decaborane will quickly fall down. In this prototype ion source, the plasma chamber is directly cooled by temperature controlled water. In typical operation, the

![Figure 1: Schematic configuration of medium current implanter EXCEED2300.](image1)

![Figure 2: Schematic of ion source.](image2)
temperature of the plasma chamber without cooling goes up to 600 degree centigrade, but by applying the cooling, it goes down to nearly 50 degree. This low temperature will reduce the dissociation of Decaborane molecules.

**Beam Extraction Test**

Beam extraction test was carried out using the prototype ion source equipped in NISSIN EX2300H. A typical sample of measured mass spectrum is shown in Fig. 3. The main peak is 116 AMU, which corresponds to the molecule ion component of $^{11}\text{B}_{10}\text{H}_{6}^+$. Beside the main peak, many peaks which relates to the number of attached hydrogen and the presence of isotope $^{10}\text{B}$ are detected. In addition there can be seen the peaks are grouped in accordance with the number of boron.

![FIGURE 3. The mass spectrum of ionized Decaborane](image)

The beam current of $^{10}\text{B}_{10}\text{H}_{6}^+$ versus energy was measured and is shown in Fig. 4. The beam current was measured at the back faraday, which exists just on the downstream side of a wafer-scanning unit. Unfortunately, because the data at 20 and 40keV were not measured with optimized ion source parameters, this curve may not show the real energy dependence of beam current. However, we can say this dependence clearly differs from the well-known space charge behavior at low energy region. For example, the beam currents at 5 and 10keV are nearly the same though the measurement was done in the same operation parameters of the source plasma production. This is essentially caused by the small beam current with the value around 10 nA. In such beam current range, the effect of space charge is supposed to be not so significant, and beam current depends on the non-space charge beam optics of transport line. In fact, the nearly same beam currents as described above are achieved by selecting the appropriate extraction voltage and the voltage of focusing electrode in the accelerating column. In other words, the present beam current is mainly determined by the current from ion source. As a matter of fact, the present optimum arc current for Decaborane extraction is around 0.5A. This value is quite small with compared to the conventional atomic ion extraction at maximum beam current. This result implies that at the higher plasma density with the arc current above 0.5A, molecular decaborane ions can easily dissociate in the plasma chamber.

![FIGURE 4. The beam current as a function of the ion energy](image)

The measurement of beam transmission from the ion source to the FEM faraday, which is located just in the downstream of accelerating column, was carried out. The transmission ratio can be evaluated by dividing the total decaborane current at the FEM faraday by the extraction current. This value is also compared with that of $^{115}\text{In}^+$ at the same energy. The ions produced by the ionization of decaborane have a variety of mass number, but most of the major peaks are in the mass range over 90. So, if the beam optical parameters such as the extraction current, extraction voltage, the focusing voltage and so on are nearly the same in both conditions, at least the transmission ratio

<table>
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<tr>
<th>Parameters</th>
<th>Decaborane</th>
<th>Indium</th>
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<tbody>
<tr>
<td>Ext. Current (µA)</td>
<td>2850</td>
<td>3570</td>
</tr>
<tr>
<td>Total decaborane current at FEM Faraday (µA)</td>
<td>294</td>
<td>1479</td>
</tr>
<tr>
<td>Transmission</td>
<td>0.103</td>
<td>0.414</td>
</tr>
<tr>
<td>Gas pressure at SAM chamber (Pa)</td>
<td>3.2E-3</td>
<td>4.3E-5</td>
</tr>
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due to the beam optics are supposed to be the same. The summary of the results is shown in Table 2. It is shown that the transmission ratio of decaborane is almost a quarter as less as that of Indium. As for indium, the gas pressure of at SAM chamber is quite low, so that a beam loss in SAM chamber is negligible and the ratio of indium represents the characteristic of present normal beam optics. Therefore, this difference of transmission ratio indicates that nearly 75% of ions of decaborane ions are lost in the transmission line from ion source to the accelerating column. This is caused by the high gas pressure of SAM chamber and a large cross section relating to a charge exchange or dissociation. Taking account of the parameters in Table 2 and the transmission line length, we estimate that the cross section as described above has a value over 1E-14 (cm$^2$). This value is quite large with compared to the cross sections regarding to the atomic-atomic collision. In addition, the gas pressure of SAM chamber is not low compared to the beam extraction chamber with the other gas species. This is caused by the dissociation of decaborane due to the high temperature of the filament in the ion source. The gas pressure of SAM chamber is compared among three ion source conditions and is shown in Fig.5. The first condition is that only the gate valve for decaborane gas feeding is opened. The second is that the power is fed to the filament up to 170A without establishing plasma. It is clear that the vacuum pressure goes up by the factor of 4. The third condition is that beam is extracted. Under the latter two conditions, the gas pressure is almost the same.

As described above, to increase the decaborane beam current, not only the source optimization by improving the production ratio of decaborane ion but also keeping low gas pressure in beam transport line is necessary.

**CONCLUSION**

We have developed the decaborane ion source for medium current implanter EXCEED2300. Mass separated decaborane ion beam was measured, and found that many peaks related to the number of boron and hydrogen atoms are observed. The decaborane ion current at changing the ion energy was also measured, and found that the beam current is roughly constant over the 5keV. We got the equivalent boron current 110puA at 500eV.

**ACKNOWLEDGMENTS**

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**REFERENCES**


**FIGURE 5.** The gas pressure of SAM chamber