Electrical Properties of Ultra Shallow p Junction on n type Si Wafer Using Decaborane Ion Implantation

Jae-Hoon Song, Duck-Kyun Choi, Min-Seok Oh, and Won-Kook Choi
Thin Film Technology Research Center, Korea Institute of Science and Technology
P.O. Box 131, Cheongryang, Seoul 130-650, Korea
1Department of Inorganic Materials Engineering, Hanyang University
17 Haengdang-dong, Seongdong-Gu, Seoul, 133-791, Korea

ABSTRACT

The junction depth should be less than 0.05 microns to fabricate sub 0.1 micron devices. This requires implanting boron with energy of less than 1 keV. One drawback in a low energy ion source is low throughput due to low ion beam current. At present, boron known for a major p-type dopant for PMOSFET has problem to easily diffuse into Si wafer even in rapid thermal processing by high diffusivity. To resolve this problem, decaborane (B\textsubscript{10}H\textsubscript{14}) molecules are implanted to make p+/n junction on n-type Si wafers for low-energy boron dopant source. Ionized decaborane is accelerated at 1~10 kV and implanted up to dosages from 1x10\textsuperscript{12}/cm\textsuperscript{2} to 5x10\textsuperscript{13}/cm\textsuperscript{2}. Afterwards, Decaborane implanted Si wafers were post-annealed for 10 sec at 800, 900 and 1000\degree C, respectively. From RBS results on as-implanted n-type Si wafer implanted at 5 kV, it is observed there are amorphous Si layers with 4 nm in depth and boron ions are implanted up to 1~5 nm in depth from SIMS analysis. The electrical properties of these p-n junctions are 127~130 \textOmega/sq. as sheet resistance, +0.3 V turn-on voltage and –1.1 V breakdown voltage obtained from I-V measurement.

INTRODUCTION

Evolving into sub 0.1 \mu m device for the improved performance and greater density, the CMOS technology requires the junctions for source and drain extensions to be below 100 nm [1,2]. However, especially for PMOSFET, there are difficulties to overcome in low-energy implantation of boron ions for source/drain extensions and suppression of boron diffusion during
annealing process for dopant activation. To overcome these obstacles: the drastic reduction in boron ion beam current with the acceleration voltage and the transient-enhanced diffusion and thermal diffusion for boron ions, recently an alternative approach using decaborane molecules as boron clusters has been recently proposed [3-6]. When the boron clusters impact the solid surfaces, the constituents share the kinetic energy of clusters. Thus the boron ions have one-tenth lower implantation energy than that of decaborane (B₁₀H₁₄), which enables to implant boron ions shallowly with a suitable beam current and high ion dosage. In this paper, p-type junctions were fabricated successfully on n-type Si with this technique.

EXPERIMENTAL PROCEDURES

A vertical type accelerator, which could be accelerated up to 30 kV, was assembled and assessed. A turbomolecular pump used for pumping and keeping a main chamber under 1x10⁻⁶ Torr as basal pressure and 1~5x10⁻⁵ Torr as working pressure. A stainless steel vessel for sublimating decaborane was attached to the main chamber via a needle valve. Electrons emitted from a circular tungsten filament ionized the sublimated decaborane vapors. Ionization voltage for the thermoelectrons and the emission current were 200 V and 100 mA, respectively. Moreover, a Si wafer was cut as large as 20 x 20 mm² and was cleaned using tetrachloroethylene, acetone, methanol, and ethanol in sequence for each 10 minutes to remove residual organic materials and dilute hydrofluoric acid solution for 10 minutes to etch native oxides. To investigate the effect of decaborane implantation on Si wafer, the acceleration voltage and the dosage were varied from 1 kV to 15 kV and from 1x10¹²/cm² to 5x10¹³/cm², respectively. The ion beam current was measured by a Faraday cup connected to a picoammeter. Afterwards, the implanted specimens were annealed under nitrogen environment at 800, 900 and 1000°C for 10 seconds using a halogen lamp rapid thermal annealing system with ramping rate of 50°C /s. In addition, to measure sheet resistance, carrier concentration and I-V curve, Au dots with 300 µm in diameter were deposited on the specimens by thermal evaporation method. For precise I-V measurement, the specimens were etched by MESA etching method using deionized water (20ml), nitric acid (35ml) and HF (10ml) solution. Transmission electron microscope (TEM) and Rutherford backscattering spectrometry (RBS) for investigating the implantation-induced damage of the as-implanted specimen were performed.
DISCUSSION

Figure 1 shows the trajectories of boron ions and decaborane ions on Si surface at 5 kV simulated using TRIM code. The projectile range ($R_p$) of boron atoms is 23 nm, which is eight times deeper than that of decaborane, 3.2 nm.

![Simulated trajectories of boron and decaborane ions on Si surface at 5 kV](image)

**Figure 1.** Simulated trajectories of boron and decaborane ions on Si surface at 5 kV

Figure 2 shows RBS channeling spectra of bare n-type Si and as-implanted Si at 5 kV and a dosage of $5 \times 10^{13}$/cm$^2$. From the inset, it is observed that normalized yield and width of as-implanted specimen are higher and wider than bare n-type Si and the damaged layer thickness is about 4 nm which is similar to the simulated data. This means that decaborane ion implantation does not induce much defects.

Figure 3 shows high resolution cross sectional TEM image of as-implanted specimen at 10 kV and a dosage of $1 \times 10^{13}$/cm$^2$. The measured thickness of amorphous layer is about 4-5 nm and which is consistent with the results from RBS and TRIM code simulation [7].

Table 1 shows the electrical properties of annealed specimens at 800, 900 and 1000 °C for 10 seconds. Annealed specimens have lower sheet resistance than previously reported [1]. To calculate carrier concentration and resistivity, the value of 4 nm obtained from TEM, RBS and TRIM was used as the base implantation depth. As shown in Table 1, all specimens show very similar carrier concentration in spite of different dosages. Charge integration system should be prepared later and calibrated by $^{11}$B(p,$\alpha$)$^8$Be nuclear reaction analysis (NRA). However, it is confirmed that the decaborane is good candidate to make shallow boron implantation dopant.
Figure 2. RBS channeling spectra at bare n-type Si and as-implanted Si at 5 kV and a dosage of $5 \times 10^{13}$/cm$^2$.

Figure 3. High resolution cross sectional TEM image of as-implanted specimen at 10kv and a dosage of $1 \times 10^{13}$/cm$^2$. 

A3.5.4
Figure 4 shows I-V measurement results of post-annealed specimens. In case of a specimen implanted at 1 kV and a dosage of $1 \times 10^{12}$/cm$^2$ and annealed at 900°C for 10 seconds, the turn-on voltage and breakdown voltage was 0.3 V and −1.1 V, respectively.

**CONCLUSIONS**

Decaborane ions up to dosages from $1 \times 10^{12}$/cm$^2$ to $5 \times 10^{13}$/cm$^2$ at 1–10 kV are implanted on n-type Si wafer. The implanted specimens are annealed under nitrogen atmosphere for 10 seconds at 800, 900 and 1000°C, respectively. In the as-implanted n-type Si wafer at the acceleration voltage of 5 kV, the formation of an amorphous Si layers with the thickness of about 4-5 nm is confirmed by high resolution cross sectional TEM image and RBS channeling. The sheet resistance of these p-n junctions shows the low value as much as 117–130 Ω/sq. In particular, the specimen implanted at 1 kV, the dosage of $1 \times 10^{12}$/cm$^2$, and annealed at 900°C shows +0.3 V turn-on voltage and −1.1 V breakdown voltage. Consequently, it is confirmed that decaborane implantation at the lower voltage of 1–10 kV is an alternatively promising technique to achieve ultra shallow junction with the thickness below a few tens nm. For the investigation of

A3.5.5
transient enhanced diffusion behavior of implanted boron dopant, the development of an analysis technique having sub nm scale resolution to accurately determine a boron concentration with depth is mostly demanded in near future.

REFERENCES


<table>
<thead>
<tr>
<th>Acceleration Voltage</th>
<th>Ion Dose</th>
<th>Annealing Temperature</th>
<th>Carrier Concentration</th>
<th>Sheet Resistance</th>
<th>Resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kV</td>
<td>1x10^{12}</td>
<td>800°C</td>
<td>9.3x10^{19}</td>
<td>119.3</td>
<td>4.77x10^{-5}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>900°C</td>
<td>9.0x10^{19}</td>
<td>116.9</td>
<td>4.67x10^{-5}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000°C</td>
<td>1.3x10^{20}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 kV</td>
<td>5x10^{12}</td>
<td>800°C</td>
<td>9.0x10^{19}</td>
<td>126.5</td>
<td>5.06x10^{-5}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>900°C</td>
<td>9.5x10^{19}</td>
<td>129.6</td>
<td>5.2x10^{-5}</td>
</tr>
<tr>
<td>10 kV</td>
<td>1x10^{13}</td>
<td>1000°C</td>
<td>1.2x10^{20}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Electrical Properties of annealed specimens at 800, 900 and 1000°C for 10 seconds