Investigation of Converted p^+ poly-Si Gate Formed by $B_{18}H_X^+$ Cluster Ion Implantation

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Abstract. Conventional B^+ or BF_2^+implantation has a limitation in terms of throughput and energy contamination. Boron cluster implantation is one alternative to solve this problem.We have investigated the characteristics of $B_{18}H_X^+$ cluster ion implantation using p^+ poly-Si gated MOS capacitors. The $B_{18}H_X^+$ cluster was implanted to n^+ poly-Si in order to convert to p^+ poly-Si with energy of 2.5keV and dose of 1.6E16 ~ 2.0E16 ions/cm^2 The improvement in the inversion capacitance (more then 3%) was observed in the case of cluster ion implantation. This result indicates less poly-silicon depletion effect. It was verified by TDS and SIMS that the hydrogen level of the by p^+ poly-Si gate implanted by the cluster ions, and then annealed, was similar to that of a sample implanted by conventional B^+ ions.Thus, boron cluster implantation was proven to be more beneficial than the conventional B^+ implantation for the capacitor performance.

Keywords : $B_{18}H_X^+$, Cluster Boron, P^+ poly
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Introduction

Boron ion implantation at low energies has been traditionally used for the formation of dual poly gate in pMOSFETs. However, the increase of implantation dose brings about a low throughput issue. Although deceleration mode implantation is more effective to increase beam current, it can cause energy contamination problems with high energy ions.

Plasma doping is one of the very attractive technique to overcome above issues [1]. Another approach is boron cluster implantation [2-3]. Boron cluster implantation, regaining extraction and transportation of ion beams at much higher energies than the desired implant energy, has been proposed as a solution for the both throughput and energy contamination issues. Boron cluster implantation has been investigated using source materials such as $B_{10}H_{14}$ (decaborane) for many years. Recently, the beam current of novel $B_{18}H_x^+$ cluster ions from $B_{18}H_{22}$ has been substantially improved using the SemEquip ClusterIon® Source and becomes more practical for use for the formation of p^+ poly-Si gates.

In this work we used $B_{18}H_X^+$ implantation to fabricate the p^+ poly-Si gated MOS capacitors. The beams were generated in an Axcelis GSD200 ion implanter modified with a SemEquip ClusterIon® Source and vaporizer. We compared results of $B_{18}H_X^+$ and B^+ from the viewpoint of capacitor performance. The hydrogen ion issue, one of the concerns for cluster implantation, was also investigated. In fact, a large amount of hydrogen ions can degrade device performances, which is simultaneously incorporated into the p^+ poly-Si gate with boron ions. In addition, the sheet resistances and boron profiles in poly-Si/oxide/si wafers were also analyzed.

Experimental

In this experiment, we pay attention to principal doping step for the formation of p^+ poly-Si gated MOS capacitors. Figure 1 shows a process sequence for the p^+ poly-Si gate fabrication. After the plasma nitridation onto the gate oxide, either B^+ or $B_{18}H_X^+$ was implanted into the p^+ poly-Si layer. Conventional poly implant annealing (PIA) was performed at 950°C, and spike poly implant annealing at 1075°C with lamp-based equipment. We analyzed doping characteristics and surface morphologies using secondary ion mass spectrometry (SIMS), transmission electron microscopy (TEM), atomic force microscopy (AFM), and a conventional four-point probe. The hydrogen contents in the poly-Si films were examined by TDS (Thermal Desorption Spectroscopy) and SIMS. The electrical properties, such as the leakage current and capacitance-voltage (C-V) characteristics of p+ poly-Si gate, were measured by use of 4155B and HP4284A.

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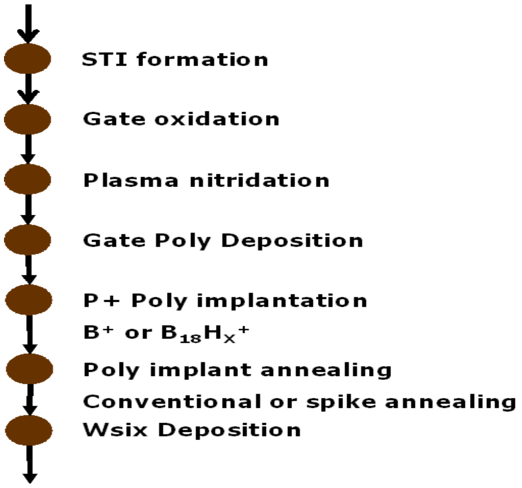


FIGURE 1. Process sequence for p+ poly-si gate fabrication

Results and Discussion

The ion beams for boron cluster implantation were generated from solid $B_{18}H_{22}$. Figure 2 shows the SIMS profiles of boron in an as-implanted poly-Si gate/plasma nitridation/gate oxide/Si substrates. The implantation was performed at 2.5keV-equivalent energy and 2.00E16-ions/cm^2-equivalent dose, corresponding to the extraction energy of 50keV and a dose of 1.11E15 ions/cm^2 of cluster ions. During $B_{18}H_X^+$ cluster implantation, 11B and 10B was implanted simultaneously. The composition ratio of 10B and 11B was 27% and 73%, respectively.

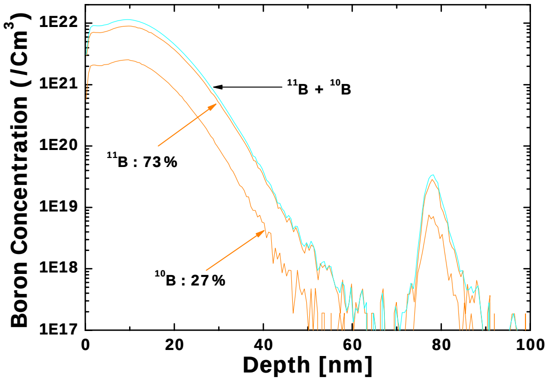


FIGURE 2. Typical SIMS ^{10}B and ^{11}B depth profiles of as-implanted poly/oxide/Si substrates. The implants were done with a $B_{18}H_X^+$ beam extrated at 50keV (2.5keV equivalent implant energy). The composite profile was obtained by a liner sum of the ^{10}B and ^{11}B profiles.

Figure 3 shows boron profiles in 50keV $B_{18}H_x^+$ implanted or 2.5keV B^+ implanted poly-Si films both before and after poly implant annealing. The implantation was performed at 50keV-equivalent energy and 1.60E16-ions/cm^2-equivalent dose corresponding to extraction energy of 50keV with an electrical dose of 8.88E14 ions/cm^2. The implanted poly-Si/oxide/si substrates undergo an identical conventional anneal at 950°C. The SIMS profiles of $B_{18}H_x^+$ and B^+ implants represent only 11B dopant concentrations.

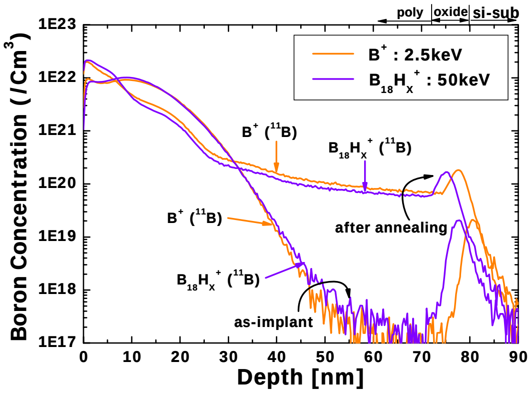


FIGURE 3. SIMS profile of boron, of $B_{18}H_X^+$ at 50keV and B^+ at 2.5keV before and after poly implant annealing.

The SIMS profile of as-implanted $B_{18}H_x^+$ is broader than that of B^+. Due to the fact that poly-Si is an amorphous layer, a channeling phenomenon of boron dopants from clusters or conventionals is hard to consider. Therefore, the broader as-implanted profile can be thought as an effect of atomic mass mixing. After PIA, $B_{18}H_x^+$'s boron concentration at the poly-Si/oxide interface decreased more than B^+'s one. Due to this reason, Rs increased more than 6%.

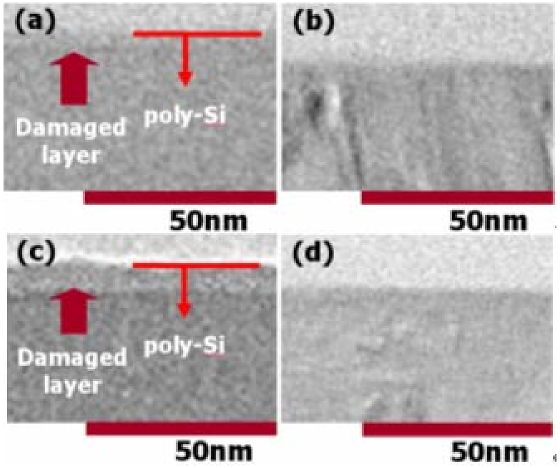


FIGURE 4. shows cross-sectional TEM photographs of 50KeV $B_{18}H_x^+$ implant (a) before and (b) after PIA and 2.5keV B+ implant, (c) before and (d) after PIA. The PIA was performed by conventional-RTA at 950°C.

Figure 4 shows cross-sectional TEM photographs of a 50KeV $B_{18}H_x^+$ implant and a 2.5keV B^+ implant both before and after poly implant annealing. The PIA was carried out by was conventional-RTA at 950°C. In the as-implanted case, the ratio of $B_{18}H_x^+$'s damaged layer is about 3 times of the ratio of B^+'s one.

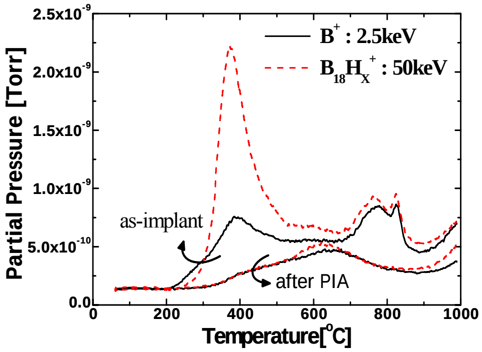


FIGURE 5. M/Z2 spectra of hydrogen for $B_{18}H_x^+$ and B^+ implants both before and after poly implant annealing.

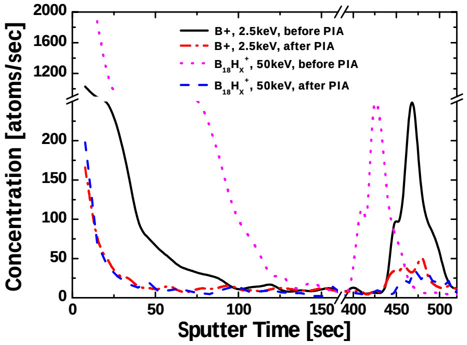
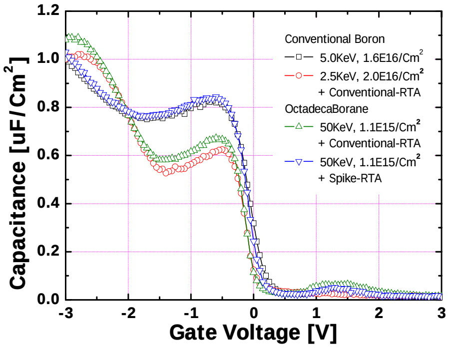


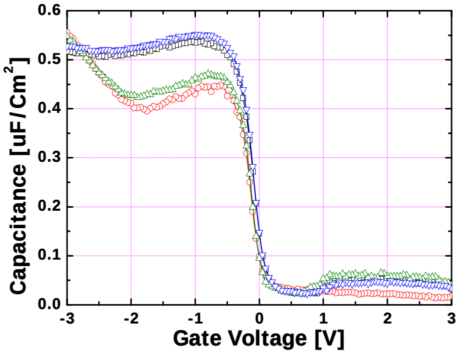
FIGURE 6. SIMS profiles of hydrogen for $B_{18}H_x^+$ and B^+ implant both before and after poly implant annealing.

Figure 5 shows M/Z 2 spectra of hydrogen of $B_{18}H_x^+$ and B^+ implant both before and after poly implant annealing. In the $B_{18}H_x^+$ case, occurrence of H_2 desorption in 200~800℃ range must be due to the solid $B_{18}H_{22}$ source. After PIA, H_2 desorption characteristics of $B_{18}H_x^+$ become similar to those of B^+. This result can be verified by SIMS profiles of hydrogen shown in Fig. 6.

Figure 7 shows C-V characteristics of p^+ poly-Si gate converted by $B_{18}H_x^+$ and B^+ counter doping from n^+ doped poly-Si. $B_{18}H_x^+$ and B^+ implant were progressed by a equivalent energy (2.5keV) and dose (2.0E16/Cm^2). Inversion capacitance for $B_{18}H_x^+$ implant increased about 3% and 5% at gate voltage of -1V for thick oxide (55Å) and thin oxide (25Å) capacitors.



(a) Thin p+ poly-Si Gate



(b) Thick p+ poly-Si Gate

FIGURE 7. C-V characteristics of p+ poly-Si gate converted by $B_{18}H_x^+$ and B+ counter doping from n^+ doped poly-Si gate.

After $B_{18}H_x^+$ implantation, spike annealing was performed at 1,075℃ in ambient O_2. The inversion capacitances obtained by present experiments are improved more then 25% and 40% compared with the conventional PIA $B_{18}H_x^+$ and the conventional PIA B^+ respectively. In the case of B^+ implant at 5keV and dose of 1.6E16/Cm^2, inversion capacitance increases only about 3%. These tendencies can be explained by increasing of boron's activation ratio in poly-Si considering spike-RTA application and suppression of boron out-diffusion in ambient O_2.

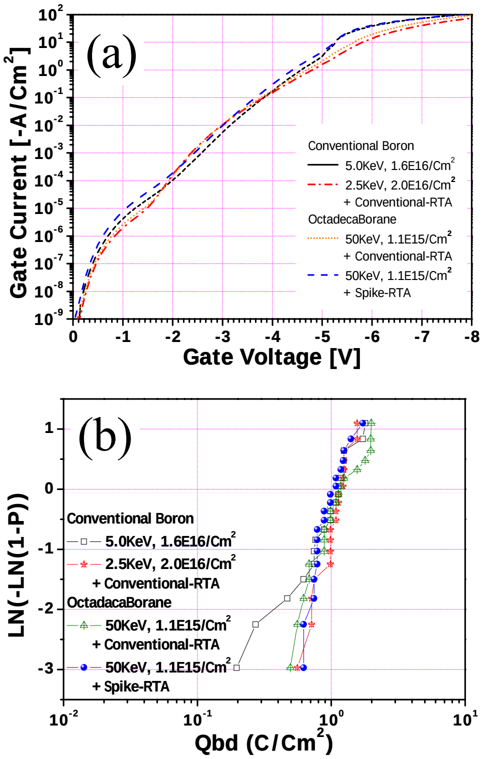


FIGURE 8. (a) leakage current-voltage and (b) cumulative distribution of charge-to-breakdown with p+ poly-Si gate

converted by $B_{18}H_x^+$ and B^+ counter doping from n^+ doped poly-Si gate.

Figure 8 shows leakage current-voltage and cumulative distribution of charge-to-breakdown (Q_{bd}) of gate oxide with p^+ poly-Si gate converted by $B_{18}H_x^+$ and B^+ counter doping from n^+ doped poly-Si. Since conventional poly implant annealing was performed, any difference between $B_{18}H_x^+$ and B^+ can not be observed. In the case of Spike PIA progression, increase of leakage current can be thought as the increase of electrons trapped by boron penetrated-oxide. In the case of Q_{bd} characteristics, there is no significant difference in the annealing methods and types of boron.

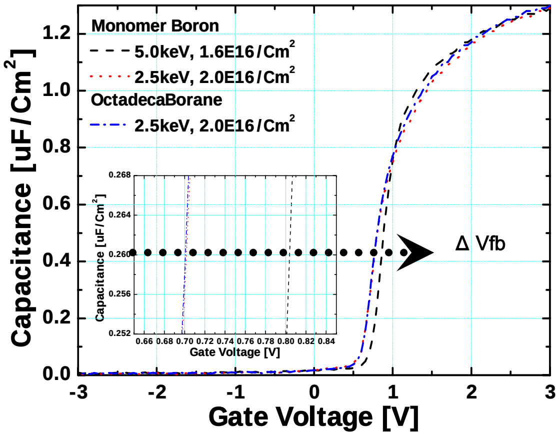


FIGURE 9. Boron penetration characteristics of $B_{18}H_x^+$ and B^+ after conventional PIA at 950℃.

Figure 9 shows Boron penetration characteristics of $B_{18}H_x^+$ and B^+. Conventional PIA was performed at 950 ℃. When $B_{18}H_x^+$ and B^+ counter doping were implanted into n^+ doped poly-si, all flat band voltage shifts(ΔV_{fb}) were observed to be almost, same.

Conclusions

We have demonstrated octadecaborane molecular ion implantation for the formation of p^+ poly-Si gated MOS capacitors and examined the characteristics of a high-performance p^+ poly-Si gate.

$B_{18}H_X^+$ cluster implantation consisted of 27% 10B, and 73% 11B in the dose ratio. $B_{18}H_X^+$ shows broader profiles in as-implanted SIMS compare to conventional boron. In the as-implanted case, the $B_{18}H_x^+$'s damaged layer observed in poly-si gate is about 3 times of B^+'s. After poly implant annealing, $B_{18}H_x^+$'s boron concentration at poly-Si/oxide interface decreased. Any damaged layer was not observed in both $B_{18}H_x^+$ and B^+ implanted poly-Si. The hydrogen level of the annealed p^+ poly-Si gate implanted with $B_{18}H_x^+$ was similar to that of sample implanted with B^+.

Improvement in the inversion capacitance (more then 3%) was observed in the case of the cluster ion implantation. It was shown that the flat band voltage shift and leakage current for the cluster ion implantation was at a same level as those for the conventional sample.

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