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Novel activation method of B by soft X-ray undulator

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1. Introduction

According to International Technology Roadmap for Semiconductor (ITRS), physical gate length will need to be reduced to 13nm with corresponding junction depth of 9nm by 2013[1]. The ion implanting technology can control dopant atoms location, but implanting influences on a crystal structure. As a result, dopants diffuse too rapidly in thermal annealing process to control the diffusion depth [2,3]. Therefore, fabrication of an ultra-shallow junction with low temperature is required [4].

We propose a novel activation method of B dopant at low temperature by using soft X-ray undulator.

2. Experimental

B ion was implanted to Si (100) wafer (n-type, 8-12Ωcm) with an energy of 5keV, a dose quantity of $2\times10^{15}cm^{-2}$ and an implant angle of 7 degree off. In this condition, implantation depth and dose quantity were 150 nm and $1.33\times10^{20}/cm^{-3}$ respectively.

For the activation, soft X-ray irradiation in vacuum and annealing in nitrogen atmosphere were carried out.

Soft X-ray was generated by a SOR facility, NewSUBARU using short undulator. The storage-ring energy was 1.0GeV. The photon energy was decided by considering the core electron energy level of Si and B dopant.

The irradiation conditions are summarized in Table Ⅰ. The photon energy irradiated to sample was controlled by the undulator gap. The pressure during irradiation was 6×10^{-5} Pa. Sample temperature was measured by a pyrometer.

Sheet resistance was measured by four-point probe method.

Activation ratio is given by Irvin curve and dopant dose quantity. Activation energy was estimated by Arrhenius plot of activation ratio.

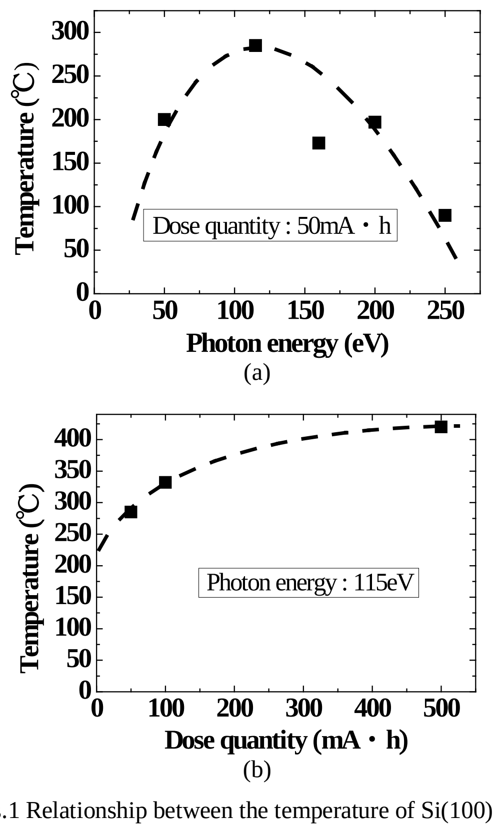
Table Ⅰ. Condition of the soft X-ray irradiation.

Photon energy (eV)	50 115 160 200 250	115
Dose quantity (mA･h)	50	50 100 500

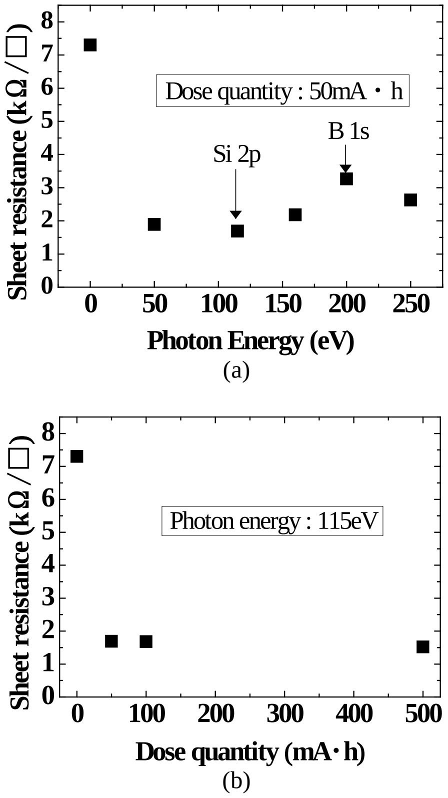
3. Results and discussion

Figures 1 (a) and (b) show the relationships between the temperature of Si (100) wafer and the photon energy of soft X-ray, and the dose quantity during the irradiation. The temperature at the photon energy at 115eV, which corresponds to the energy level of Si 2p core-electron, shows the highest value of 285°C. The Si 2p core-electrons of Si atom are excited by soft X-ray irradiation and they relax resulting in a temperature increase of Si wafer. On the other hand, the temperature becomes large from 285 to 420°C with an increase of dose quantity from 50 to 500mA・h.

Figures 2 (a) and (b) show dependences of sheet resistance on photon energy and dose quantity. With an increase of the photon energy from 115 to 200eV, the sheet resistance increased from 1.7 to 3.3 kΩ/□. The sheet resistance



Figs.1 Relationship between the temperature of Si(100) wafer and the photon energy (a), and dose quantity (b) during the irradiation.



Figs.2 Dependences of sheet resistance on photon energy (a) and dose quantity (b).

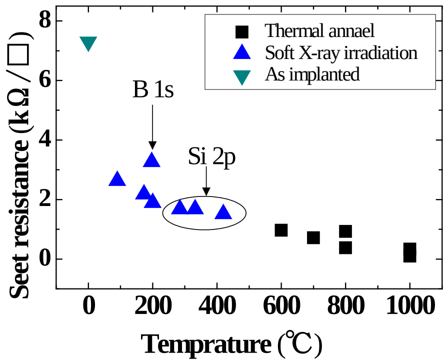


Fig. 3. Sheet resistance as a function of sample temperature.

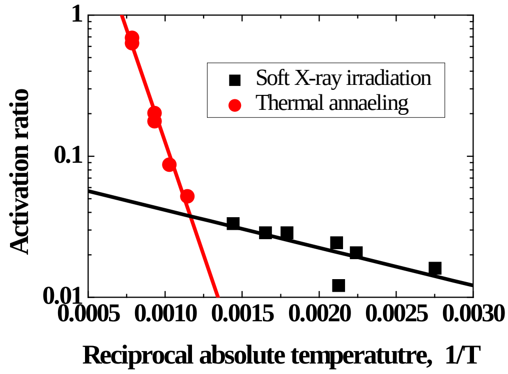


Fig.4. Relationship between dopant-activation ratio and reciprocal absolute temperatures 1/T.

was the largest at 200eV and it was the smallest at 115eV. These phenomena are related with the excitation of B1s core-electron and Si 2p core-electron.

On the other hand, the sheet resistance slightly decreased with increasing the dose quantity because of increment in sample temperature.

Figure 3 shows the sheet resistance as a function of sample temperature. It is found that the sheet resistance decreased in the range of 90 to 420°C in spite of low temperature process. The sheet resistance of samples subjected to photon with energy at Si 2p and B 1s level were 1.5 and 3.3 kΩ/□, respectively.

Figure 4 shows the relationship between activation ratio and reciprocal absolute temperature 1/T. The activation energy in each process was estimated from slope of Arrhenius plots. The activation energies of thermal annealing and soft X-ray irradiation were 0.63 and 0.053 eV, respectively. Although the activation ratio is small for soft X-ray irradiation, the activation of B dopant proceeds under low temperatures of 90 to 420°C.

Next, the activation mechanism of B by soft X-ray irradiation is discussed. The activation by thermal annealing generally occurs by movement of dopant atoms to lattice sites of Si. This process corresponds to the Arrhenius plot for thermal annealing shown in Fig. 4. By the way, it has been already shown that the soft X-ray irradiation enhances the atom diffusion via excitation of core-electrons of Si [5]. This result reminds the following simple description. Because the size of B atoms is smaller than that of Si atom, the enhancement of Si diffusion by soft X-ray irradiation, which results in nucleation and growth of a-Si, triggers the movement of B atoms resulting in the diffusion of B atoms to the lattice sites of Si atoms.

4. Conclusions

Novel activation method of B dopant using soft X-ray undulator was examined. The activation of B dopant precedes 90 to 420°C, although the activation ratio is small. The activation ratio of B subjected to photon with energy at Si 2p is larger than that at B 1s level. The activation energy of B during soft X-ray irradiation is 0.053eV. The activation mechanism is as follows: Because the size of B atoms is smaller than that of Si atom, the enhancement of Si diffusion by soft X-ray irradiation, which results in nucleation and growth of a-Si, triggers the movement of B atoms resulting in the diffusion of B atoms to the lattice sites of Si atoms.

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