Activation of Boron Atoms implanted in Silicon at a low temperature

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Introduction

Ion implantation is an essential technology for incorporating dopant atoms in semiconductor. However, heating process at a temperature higher than 600°C is required for activating implanted region in general owing to the large activation energy for moving dopant atoms from the interstitial sites to the lattice sites or recrystallizing disordered silicon states caused by high energy ion implantation. The activation of dopant atoms at a low temperature is a problem to apply the ion implantation technology to device fabrication at low temperature processing. We proposed two-step ion implantation argon precursor ion (Ar^+) followed by boron dopant ion (B^+) implantations to achive low temeprature activation [1,2]. This papper reports the appropriate condition of formation of disordered states by the two step implantation and of recrystallization of the disordered region by the post heating 400°C, whcih promotes effective acrivation of the doped silicon.

Experimental

Ar^+ precursor ata dose of 6.0x10^{13} cm^{-2} at 70 keV and RT to the top and rear surfaces of n-type CZ single crystalline silicon substrates with a thickness of 500 µm and a resistivity higher than 1500 Ωcm. The projected range of Ar R_p(Ar) was 80 nm. B^+ ions at 1x10^{15} cm^{-2} were subsequently implanted at RT. The acceleration energies changed from 5 to 50 keV to give the projected range of B R_p(B) ranging from 23 to 175 nm. The samples were then heated by 400°C for 30 min in the air atmosphere.

Optical reflectivity spectra of the silicon surfaces were measured using a conventional optical spectrometer. They were analyzed using a numerical calculation program developed with the optical interference effect and the effective dielectric media approximation with a model of seven silicon layered structure with different crystalline volume ratio X. The effective disordered amorphous depth A_{eff} was defined by integration of (1-X) with depth direction.The sheet resisvitity was analyzed by 9.35-GHz-microwave-transmittance measurement system [3]. The microwave transmittance after absorption by free carriers in the silicon substrate was analyzed with a finite-element numerical calculation program made with a Fresnel-type microwave interference effect and the free carrier absorption to estimate the sheet resistivity.

Results and Discussions

Figure 1 shows A_{eff} as a function of R_p(B) for the samples as-implanted (solid circles) and subsequently heated at 400°C for 30 min (open circles) for the 6x10^{13} cm^{-2} Ar^+ at 70 keV followed by 1x10^{15} cm^{-2} B^+ two-step-implanted samples. The single 6x10^{13} cm^{-2} Ar implantation at 70 keV caused small disordered state with A_{eff} of 1.2 nm, as shown by an arrow a. A_{eff} were very low values for R_p(B) of 23 and 42 nm. On the other hand, A_{eff} increased from 32 to 61 nm, as R_p(B) increased from 61 to 113 nm. When R_p(B) further increased to 175 nm, A_{eff} decreased to 38 nm. This means the implantation of Ar^+ and B^+ cooperatively caused the disordered states. The post heating at 400°C for 30 min decreased A_{eff}. Especially, in the case of R_p(B) of 61 nm, A_{eff} was marked decreased from 32 to 1.8 nm by the post heating. On the other hand, high A_{eff} value about 20 nm remained for R_p(B) higher than 96 nm. A_{eff} had a peak at R_p(B) of 100 nm, which was lower than Rp(Ar) of 80 nm. This indicates that serious defect states, which especially remained after heating, were formed when B atoms traversed the Ar peak concentration region with the high acceleration energies. A_{eff} was resonantly decreased to 6% of the initial A_{eff} for the sample as-implanted at R_p(B) of 61 nm by post heating at 400°C. In that condition, X decreased to about 0.48, which means that many crystalline sites remained. The crystalline nucelation sites probably had a role of promotion of recrystallization by the post heating at 400°C. Figure 2 shows the sheet resistivity a function of R_p(B) for the samples heated at 400°C for 30 min. The sheet resistivity was high of 1371 Ω/sq for R_p(B) of 23 nm. It markedly decreased to 189 Ω/sq as R_p(B) increased. to 61 nm. The sheet resistivity increased again to a high value of 1767 Ω/sq as R_p(B) increased to 175 nm. The sheet resistivity of 189 Ω/sq resulted in the activation ratio of 0.33 under assuming a hole mobility of 50 cm^2/Vs in the heavily doped condition. The results of Figs 1 and 2 show the appropriate condition of activation of doped silicon region. The reduction of crystalline volume ratio to about 0.5 probably reduced the average bonding energy in the silicon lattice system. Crystalline sites remained also probably promote recrystallization of the boron doped region by the post heating. Effective activation was consequently achived.

References

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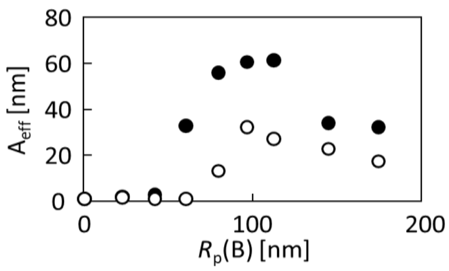

Fig.1 A_{eff} as a function of R_p(B) for the samples as-implanted (solid circles) and subsequently heated at 400°C for 30 min (open circles)

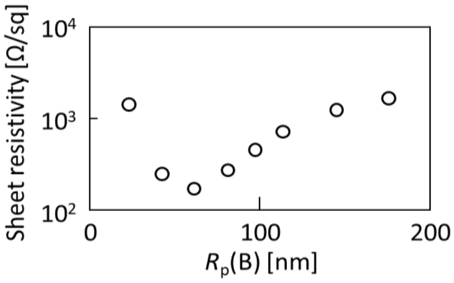

Fig.2 Sheet resistivity a function of R_p(B) for the samples heated at 400°C for 30 min