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Photoluminescence of Low-Energy B± Implanted Silicon under Ultraviolet Light Excitation

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1. Introduction

Formation of ultra shallow p-n junctions of the order of 10 nm is necessary for the fabrication of deep sub-quarter micron metal-oxide-semiconductor field-effect transistors (MOS-FETs). Low energy ion implantation is a promising candidate for realizing such shallow junctions. Shishiguchi et al.[1)] have reported the formation of 50-nm-depth shallow junction for deep sub-quarter micron p-channel MOS-FETs by using low energy B^+ implantation and rapid thermal annealing (RTA). However, various defects such as the {311} defect have been reported to be induced even in the case of the very low energy ion implantation.[2)] These defects may cause the transient enhanced diffusion and affect the performance of MOS-FETs. Therefore, detailed analysis is necessary for the defects induced by the low energy ion implantation and the following thermal annealing.

Photoluminescence (PL) is a powerful method investigating defects in semiconductors. However, the penetration depth of the visible light, which is usually used in the PL measurement of Si as the excitation source, is about a few μm for Si and the PL signal from the shallow region is hindered by the emission from the deeper region. In this paper, we report the PL of the 0.5-keV B^+-implanted Si under ultraviolet (UV) light excitation. The penetration depth of the UV light (351 and 364 nm in this study) is about 0.05 μm for Si and we can detect the emission from the shallow region of the order of 10 nm below the surface.

2. Experiments

The substrates used in this study were (100) Czochralski-grown Si wafers with a resistivity of 10-20 Ωcm doped with P. Samples were implanted at room temperature with 0.5-keV B^+ ions to a dose of 1.0×10^{14}-1.0×10^{15} cm^{-2}. The implanted samples were annealed at 950-1050°C by RTA (100°C/s) in a N_2 atmosphere or in a N_2+O_2(10%) atmosphere. The depth profile of the implanted B atoms was measured by secondary ion mass spectroscopy (SIMS). The SIMS measurements revealed that the implanted B atoms were located within 50 nm below the surface even after the annealing.

PL spectra were measured at 4.2 K. The samples were excited by the 351 and 364 nm lines of an Ar ion laser. The emission from the samples was analyzed with a 32 cm single monochromator with a 600 groove/mm grating blazed at 1 μm and was detected with a cooled Ge detector. We also measured the PL spectra under the visible light (the 488 nm line of an Ar ion laser) excitation for a comparison.

3. Results and Discussion

PL spectra of the samples implanted with 0.5-keV B^+ to a dose of 1.0×10^{15} cm^{-2} and annealed at various temperatures are shown in Figs. 1 and 2 for the cases of the visible and the UV light excitations, respectively. In these figures, the PL lines labeled P observed in all the spectra are the emission due to excitons bound to P impurities in the substrate.[3)] The superscripts NP, TO, and TO+O^Γ indicate the phonons which assist the transition.

Besides those lines, the band labeled B appears under the UV light excitation for the annealed samples. This band grows in intensity as the annealing temperature is increased. We consider that this band originates from the impurity band formed by the implanted B atoms because the peak position and the band shape are very similar to those observed in the heavily-doped Si.[4)] It should be noticed that the B band is observed only in the case of the UV light excitation. The implanted B atoms are located in the shallow region of the order of 10 nm below the surface and the PL signal from this region cannot be detected under the visible light excitation.

In Figs. 1 and 2, the line labeled I1 and the broad band in the energy range of 0.7-1.0 eV appear in the spectra. The I1 line appears only in the as-implanted samples. The broad band becomes weak after the annealing. The I1 line was reported to be due to the point defects such as divacancies[5)] while the detailed nature of the broad band has not yet been clarified.

PL spectra of the samples implanted with 0.5-keV B^+ to a dose of 5.0×10^{14} cm^{-2} and annealed at 1000°C in the different atmospheres are compared in Fig. 3 under the UV light excitation. In this case, the broad band is relatively strong and some structures can be seen. The broad band consists of at least two bands with peaks at about 0.83 and 0.97 eV. The broad band is stronger for the samples annealed in a N_2+O_2(10%) atmosphere.

We tentatively assign the broad band to the point defects and/or their clusters induced by the ion implantation and the following annealing. When the annealing atmosphere includes oxygen, the surface of the sample is oxidized. This induces two effects on the defect formation and annihilation. One is the effect of the SiO_2 layer preventing the out-diffusion of the point defect. If there is a SiO_2 layer on the surface, point defects cannot diffuse out from the surface. Another effect is the generation of the interstitials by the SiO_2 formation. These interstitials diffuse in the substrate and may form the clusters during the annealing. According to these effects, the annealing in a N_2+O_2 atmosphere enhances the defect formation.

In Fig. 4, PL spectra of the samples annealed in a N_2+O_2 atmosphere are compared under the UV and the visible light excitations. The relative intensity of the 0.83 eV band is weaker under the visible light excitation while that of the 0.97 eV band is almost the same. Then the defect related to the 0.83 eV band is located near the surface while the region of the 0.97-eV defect extends to the deeper region.

4. Conclusions

We have observed the emissions due to the B impurity band and the defects in the shallow region of the order of 10 nm below the surface of the 0.5-keV B^+-implanted Si under UV light excitation. The annealing in a N_2+O_2 atmosphere enhances the defect formation. The 0.83-eV defect is located near the surface while the region of the 0.97-eV defect extends to the deeper region.

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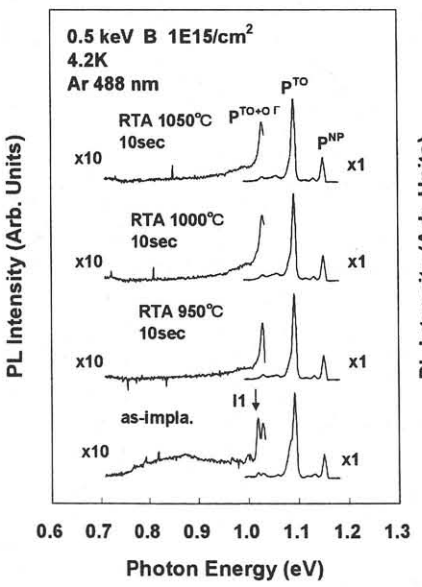

Fig.1. PL spectra of the samples implanted with B^+ and annealed at various temperatures under visible light excitation. The notation "x10" indicates that the original intensity is magnified by a factor of 10.

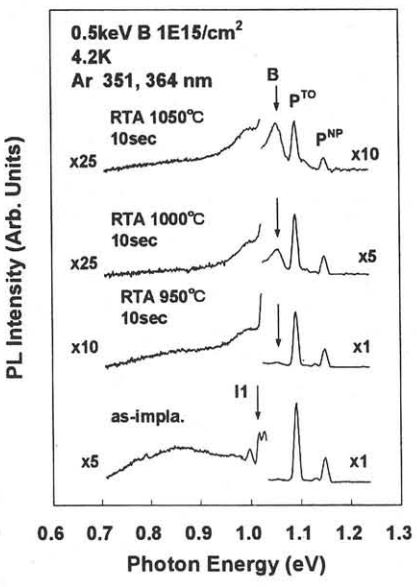

Fig.2. PL spectra of the same samples as in Fig. 1 under UV light excitation.

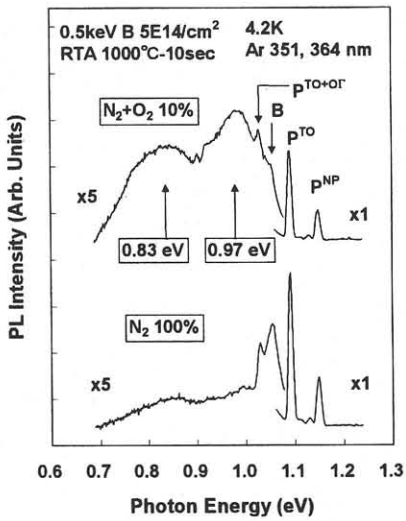

Fig.3. PL spectra of the samples implanted with B^+ and annealed at 1000°C in the different atmospheres.

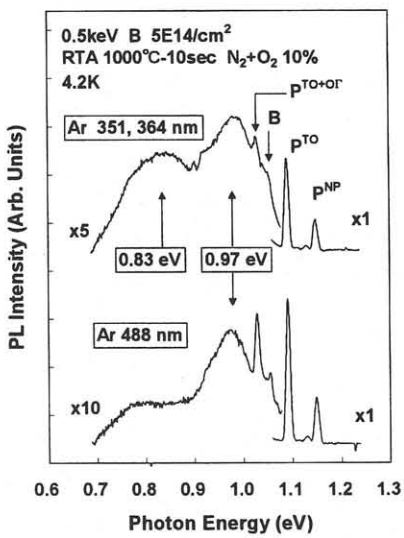

Fig.4. PL spectra of the samples implanted with B^+ and annealed at 1000°C in a N_2+O_2 atmosphere under UV and visible light excitations.