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Boron Segregation to {311} Defects Induced by Self-Implantation Damage in Si

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1. Introduction

For implant damage below the amorphization threshold, the pair diffusion model predicts a boron pile-up at the surface during thermal annealing due to the existence of a large gradient of interstitial concentration. This has been used to explain the reverse short channel effect [1]. However, the boron pile-up at the surface has not yet been observed directly. We present the experimental observation of boron redistribution near the surface induced by silicon self-implantation damage. It was observed for the first time that boron atoms pile-up during annealing in the {311} defect region rather than at the surface. A new diffusion model is required to predict the boron profile near the surface, which has a great influence on the threshold voltage of MOSFETs.

2. Results

Czochralski (100) Si wafers with the *uniform* boron concentration of 2.7×10^{17}cm^{-3} were implanted at room temperature, followed by annealing in nitrogen ambient. Si ions instead of dopants such as B, P and As atoms were implanted to avoid difficulties of data analysis arising from the presence of dopant gradient or internal electric field. Figure 1 shows SIMS measurements of the boron profiles. Before annealing, the boron profile was flat. After annealing at 670℃ for 1 min, the boron atoms accumulate in the region extending from 0.05 μm to 0.15 μm. The boron accumulation leads to a B-depleted region extending from 0.15 μm to about 0.4 μm. The boron accumulation at a depth of 0.1 μm increases with annealing time. The concentration of the boron peak decreases with further increasing annealing time. The position and the decay time of the boron peak are consistent with those of {311} defects, so it seems that the boron pile-up is due to the boron segregation to {311} defects [2].

Figure 2 shows the boron profile after 90 min annealing and the interstitial profile produced by Si implant. The boron segregation peak forms in the region where the interstitial concentration exceeds 3×10^{17}cm^{-3}. Because of the influence of the surface, boron atoms do not segregate near the surface though the interstitial concentration exceeds 3×10^{17}cm^{-3}. For high energy implant of 150 keV, the boron segregation peak also forms in the region where the interstitial concentration exceeds 3×10^{17}cm^{-3}. Figure 3 shows the dependence of the boron segregation position on implant doses. No boron segregation peak can be observed for the implant dose below 5×10^{12}cm^{-2}. This is consistent with the fact that no {311} defects form when the implant dose is less than 5×10^{12}cm^{-2}. When the dose is higher than the amorphization threshold, two boron segregation peaks can be observed. One is due to the boron segregation to {311} defects, the other is due to the boron segregation to the end-of-range (EOR) dislocation loops. The boron segregation to {311} defects is observed in the region between the peak due to the EOR dislocation loops and the interstitial concentration of 3×10^{17}cm^{-3}.

Figure 4 shows the total number of boron atoms accumulated in the pile-up region, calculated from the

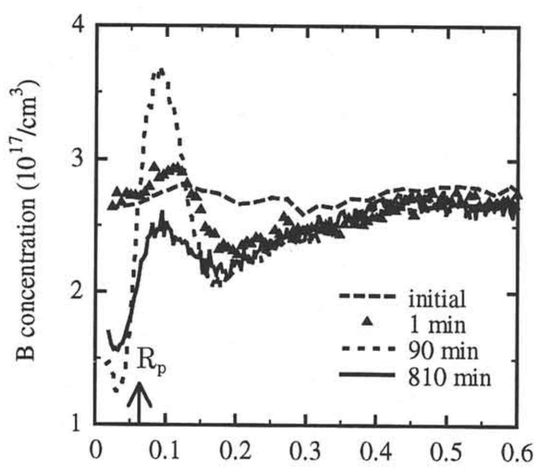

Fig. 1 Boron profiles for the samples implanted with 50 keV Si, 5×10^{13}cm^{-2}, and annealed at 670℃ for various times.

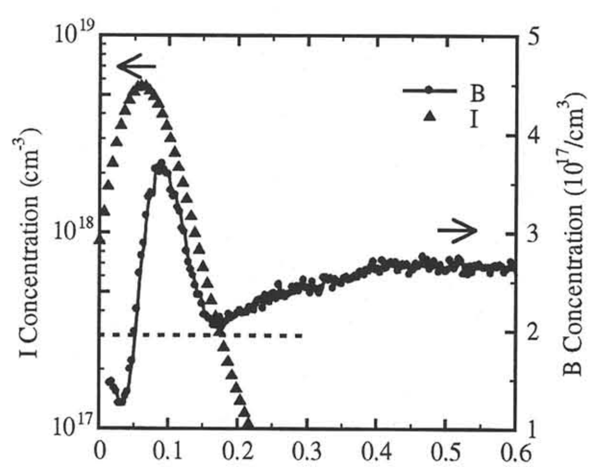

Fig. 2 Interstitial and boron profiles for the sample implanted with 50 keV Si, 5×10^{13}cm^{-2}. The boron profile was measured after annealing at 670℃ for 90 min.

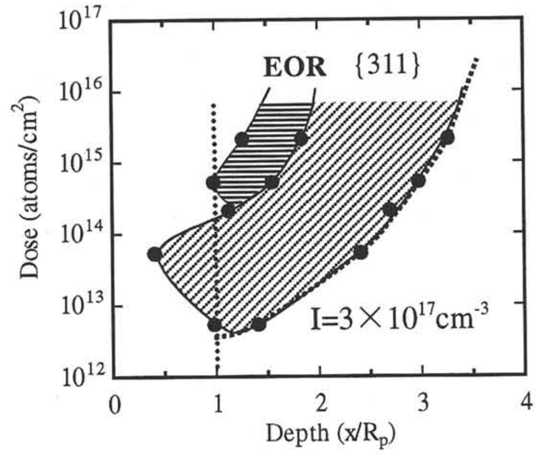

Fig. 3 The position of boron segregation region for samples implanted with 50 keV Si, followed by annealing at 720℃.

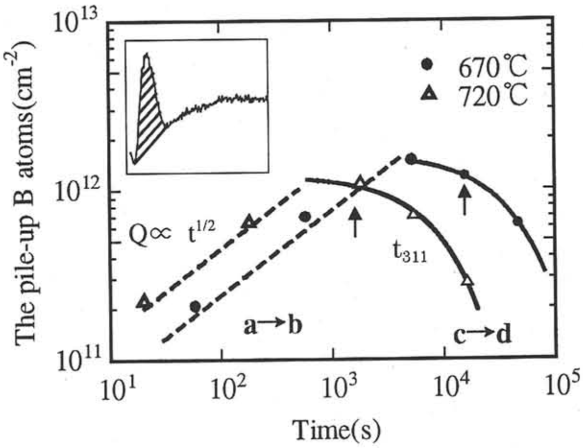

Fig. 4 The areal density of accumulated boron atoms for the samples implanted with 50keV, 5×10^{13}cm^{-2} Si. The increase of the areal density corresponds (a) and (b) in Fig. 5, the decrease corresponds (c) and (d) in Fig. 5. The arrows indicate the characteristic decay time of {311} defects.

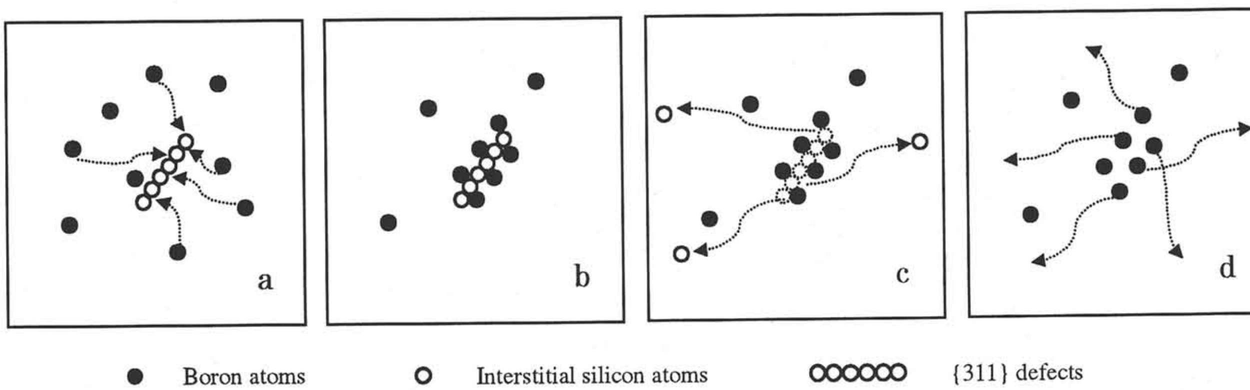

Fig. 5 Schematic model of boron segregation to a {311} defect a) boron flux to the {311} defect, b) boron segregation at the {311} defect, c) dissolution of the {311} defect, d) boron diffusion away from the {311} defect region.

shaded area in the inset. The number of the accumulated boron atoms increases with time in the initial stage of annealing. With the increase of annealing time, it reaches its maximum then decreases. The boron segregation was observed in annealing temperature range from 620℃ to 820℃. For lower temperature annealing, it reaches its maximum more slowly and has a greater peak value. After reaching its maximum, the number of the accumulated boron atoms falls off exponentially with characteristic decay time of 14 h at 670℃ or 3 h at 720℃. Stolk et. al. reported that the areal interstitial density in {311} defects has a similar decay characteristics [2]. This also supports the idea that the boron pile-up peak originates from the boron segregation to {311} defects.

The process of boron segregation to {311} defects is schematically illustrated in Figure 5. The slower diffusion of boron atoms does not follow up the pace of the formation and dissolution of {311} defects. The process of boron segregation to {311} defects is limited by the diffusion. Therefore, the number of boron atoms accumulated in the pile-up region increases in proportion to $t^{1/2}$, and then it falls off exponentially with longer characteristic decay time than {311} defects.

3.Conclusions

The boron pile-up in {311} defect region was first observed. Boron atoms pile up in the region between 0.05μm and 0.15μm, which leads to a boron-depleted region extending from 0.15μm to 0.4μm in Si-implanted silicon substrates on annealing. The boron pile-up originates from the boron segregation to {311} defects. The boron segregation peak forms in the region where the interstitial concentration exceeds 3×10^{17}cm^{-3}. The annealing time dependence of the number of boron atoms accumulated in the pile-up region is correlated with the annealing time dependence of interstitials contained in {311} defects.

Acknowledgments

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Refernces

1) C. S. Rafferty et al: IEDM Tech. Digest 311 (1993).
2) P. A. Stolk et al: J. Appl. Phys. **81** (1997) 6031.