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Effect of Ion Implantation on Dislocation Motion in SiGe/Si Heterostructures

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Introduction

Dislocation engineering is an important topic in materials science from the viewpoint of maintaining or relaxing the strain field in materials. In particular, controlling the dislocation in SiGe/Si heterostructure is crucial for the development of the recently introduced strained-Si CMOS technology. However, there exists little research on how a dislocation interacts with the impurities and intrinsic point defects in the SiGe/Si heterostructures.[1–5]

The author has been researching the relationship between oxygen- or nitrogen-implantation and dislocation motion. It was suggested that a threading (TH) dislocation interacts with microdefects, which are produced due to ion implantation and include intrinsic point defects as structural elements.[6,7] In this report, additional experimental proof to support the proposed model is provided.

Experimental

Samples were fabricated using chemical vapor deposition (CVD) at 750°C by forming SiGe layer over 8 inch (100) silicon substrates. The samples used in this experiment are listed in Table I. This table shows the effective stress for each sample. No dislocation was observed in the as-grown material because of its low Ge content and the thin SiGe layer. The SiGe/Si wafer was divided into several species, many of which were used for ion implantation, while the others were used as reference samples. The conditions for ion implantation are shown in Table II.

The use of the indentation method led to the formation of a dislocation source. The tip of a diamond pen was pressed against the surface of the SiGe epitaxial layer. Two different TH dislocations, which were positioned on the opposite sides of an indentation and were mobile with $\boldsymbol{b} = \boldsymbol{a}/2$ (110) on the SiGe (111) plane, propagated in opposite directions from the indentation on the SiGe (111) plane. This resulted in a misfit (MS) dislocation at the interface between the thin SiGe film and the Si substrate. Since four identical (111) planes were presented, a cross-shaped structure was observed after the dislocation movement. The mobility of the dislocation motion was determined by dividing the length of the MS dislocation by the duration of the thermal process.

Experimental results

Figure 1 shows the temperature dependence of the dislocation mobility of the as-grown, oxygen-, and nitrogen-implanted samples. This data was reported in the author's previous research.[6,7] Sample A was used for the measurement. Oxygen and nitrogen were implanted under identical conditions, with an implantation energy and a dose of 45 keV and 6×10^{13} cm^{-2}, respectively. From the SIMS measurement, it was confirmed that the impurity peak is located in the SiGe layer.

It was concluded that ion implantation reduces the dislocation mobility and increases the activation energy of the dislocation motion. The reduction in the dislocation mobility of the nitrogen-implanted sample is lesser than that of the oxygen-implanted sample. The activation energy required for the dislocation motion of the nitrogen-implanted sample is greater than that of the as-grown sample but lesser than that of the oxygen-implanted sample.

Figure 2 shows how the reduced mobility of the dislocations caused by ion implantation recovers to its original value by preannealing (300–800°C) for 10 min. The details of the experimental procedure are shown in the inset of Fig. 2; sample A was used in this experiment. The oxygen implantation condition was the same as that shown in Fig. 1. The nitrogen implantation energy and dose were 45 KeV and 1×10^{14} cm^{-2}, respectively. The same effects are observed for both oxygen- and nitrogen-implanted samples. The higher the preannealing temperature, the greater is the recovery of the dislocation mobility.

Figure 3 shows the out-of-plane X-ray diffraction of the phosphorous (P)-implanted sample, whose implantation energy and dose are 100 KeV and 1×10^{13} cm^{-2}, respectively. Sample B was used. The out-of-plane X-ray diffraction method reveals no difference in the intensity of the SiGe peak; however, a slight shift to a lower angle is observed. Figure 4 shows the effects of ion implantation on the dislocation mobility of a P-implanted sample. Sample B was used with an implantation energy of 100 keV and a dose of 5×10^{12} cm^{-2} or 1×10^{13} cm^{-2}. The peak concentration of P would be obtained at a depth of 150 nm from the SiGe surface. The difference between the dislocation mobility of the P-implanted and as-grown samples was observed using X-ray Lang topography, as shown in Fig. 5. The recovery of the dislocation mobility for the P-implanted sample is apparent at 700℃, as shown in Fig. 6; further, it is similar to that of oxygen and nitrogen.

Discussions

It is well known that oxygen and nitrogen impurities reduce the dislocation mobility by forming aggregates at the dislocation line (pinning effects).[8,9] According to previous researches, group-V impurities enhance the dislocation mobility.[9] However, it was observed that the reduction in the dislocation mobility in the P-implanted samples was the same as that in the oxygen- and nitrogen-implanted samples. These results indicate that certain kinds of defects, which are different from impurities, are related to the reduction in mobility and the increase in the activation energy.

Ion implantation introduces lattice defects such as vacancies and self-interstitials. Due to their considerably large diffusion coefficients, the lattice defects stabilize as microdefects, which include intrinsic point defects as structural elements. The author has proposed a model in which the TH dislocation motion is restricted by the microdefects produced due to implantation, thereby reducing the dislocation mobility.[6,7] To glide further, the TH dislocations have to overcome the additional potential barrier resulting from these microdefects; therefore, the activation energy for the dislocation motion increases.[6,7]

This model explains the dislocation motion of the implanted samples. Due to the mass of oxygen being greater than that of nitrogen, the concentration of intrinsic point defects produced due to oxygen implantation is greater than that produced due to nitrogen implantation under the same implantation conditions. Therefore, the size and density of the microdefects in the oxygen-implanted sample are greater than those in the nitrogen-implanted sample. The proposed model also explains the dislocation motion in the P-implanted samples. The mass of phosphorous is considerably greater than that of oxygen and nitrogen; therefore, even a slight dose of implantation leads to the formation of microdefects, which lead to a reduction in dislocation mobility and an increase in the activation energy.

According to the proposed model, if the microdefects are eliminated or reduced by preannealing, the reduced dislocation mobility can be recovered to its original value. If the microdefects originate from intrinsic point defects that are produced due to ion implantation, then the microdefects will attain thermal stability at approximately the same temperature; further, this temperature does not depend strongly on the implant species. The experimental results demonstrate this tendency, as shown in Fig. 2 and Fig. 6.

Summary

The relationship between dislocation motion and ion implantation was researched. It was observed that the mobility and activation energy of the dislocation motion in the implanted SiGe/Si heterostructure decreased and increased, respectively. It was suggested that these phenomena are attributable to the generation of microdefects, which are produced due to ion implantation and include intrinsic point defects as structural elements.

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References

(1) E. A. Stach, R. Hull, J. C. Bean, K. S. Jones, and A. Nejim: Microsc. Microanal. 4 (1998) 294. (2) R. Hull, E. A. Stach, R. Tromp, F. Ross, and M. Reuter: Phys. Status Solidi A 171 (1999) 133. (3) D. C. Houghton: J. Appl. Phys. 70 (1991) 2136. (4) R. Hull, J. C. Bean, D. Noble, J. Hoyt, and J. F. Gibbons: Appl. Phys. Lett. 59 (1991) 1585. (5) V. T. Gillard and W. D. Nix: Z. Metallkd. 84 (1993) 12. (6) A. Hara, N. Tamura, and T. Nakamura: Ext. Abstr. Int. Conf. Solid State Devices and Materials (2006) p.458. (7) A. Hara, N. Tamura, and T. Nakamura: Jpn. J. Appl. Phys. (in press) (8) K. Sumino and I. Yonenaga: Semiconductor and Semimetals (Academic Press 1994) Vol.42, p.449. (9) K. Sumino: Handbook of Semiconductors (Elsevier 1994) Vol.3, p.73.

Table I. Samples

	Si_xGe_{1-x}	SiGe thickness (nm)	Stress (MPa)
A	X = 0.92	370	260
B	X = 0.97	500	80

Table II. Implantation

	Energy (KeV)	Dose (cm^{-2})
Oxygen	45	6×10^{13}
Nitrogen	45	6×10^{13}
	45	1×10^{14}
Phosphorous	100	5×10^{12}
	100	1×10^{13}

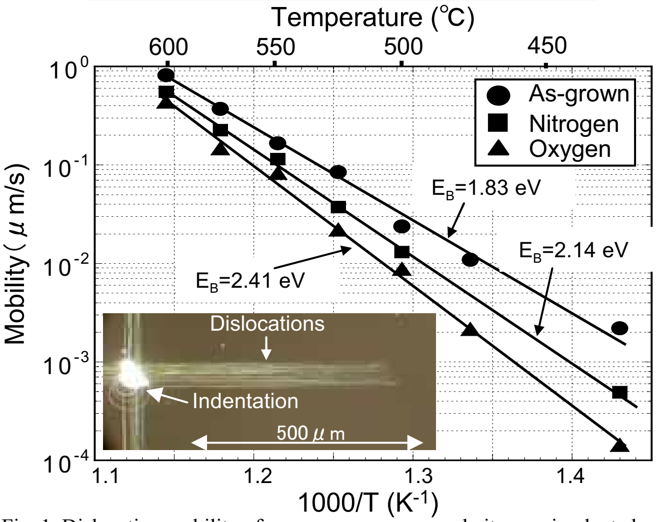

Fig. 1. Dislocation mobility of as-grown, oxygen-, and nitrogen-implanted samples. The implantation energy and dose for both the oxygen and nitrogen implantations are 45 keV and 6×10^{13} cm^{-2}, respectively. Sample A was used. The inset shows the dislocations generated by indentation after annealing at 425℃ for 67 h for the as-grown sample A.

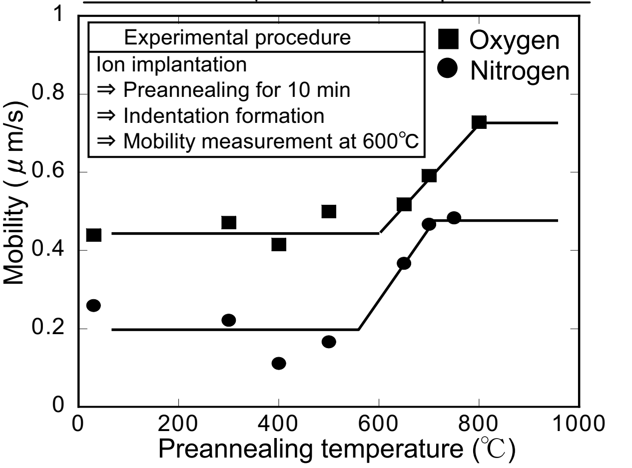

Fig. 2. Recovery of dislocation mobility. The details of the experimental procedure are shown in the inset. The dislocation mobility is measured at 600℃. The implantation energy and dose for oxygen are 45 keV and 6×10^{13} cm^{-2}, respectively. The implantation energy and dose for nitrogen are 45 keV and 1×10^{14} cm^{-2}, respectively. Sample A was used.

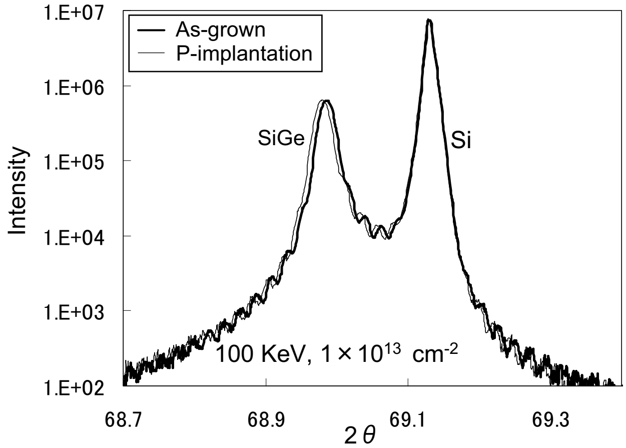

Fig. 3. X-ray diffraction patterns (out-of-plane) of as-grown and phosphorous implanted samples. The implantation energy and dose are 100 keV and 1×10^{13} cm^{-2}, respectively. Sample B was used.

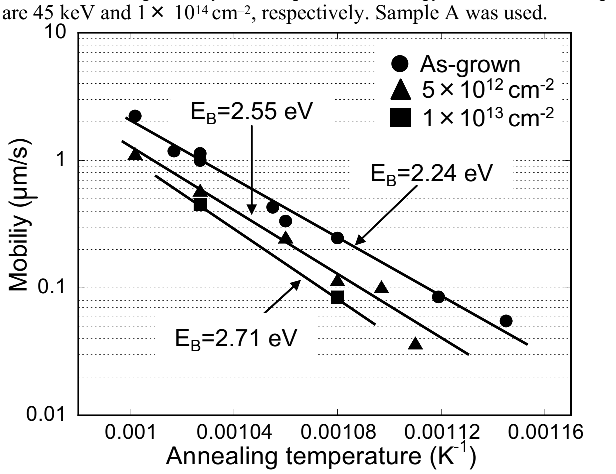

Fig. 4. Dislocation mobility of as-grown and P-implanted samples. Mobility measurement was performed by the etching method. Sample B was used.

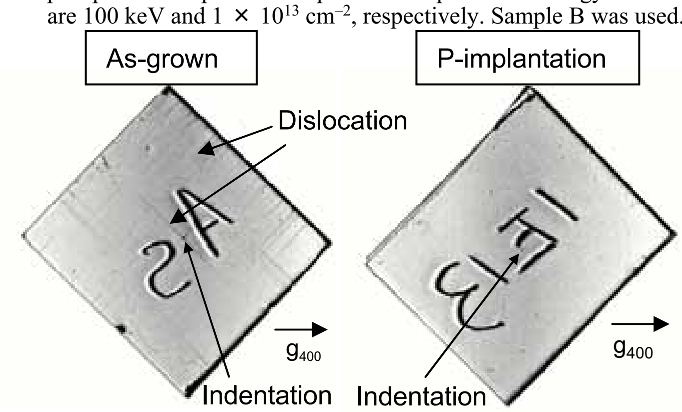

Fig. 5. X-ray Lang topography of dislocation in as-grown and P-implanted samples. Annealing is carried out at 650°C for 2 h 35 min. for both samples. The P-implantation energy and dose are 100 KeV and 1×10^{13} cm^{-2}, respectively.

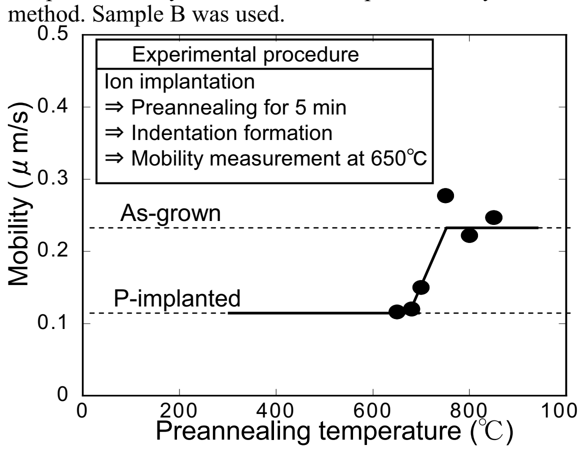

Fig. 6. Recovery of dislocation mobility for P-implanted sample. The details of the experimental procedure are shown in the inset. The dislocation mobility at 650℃ is measured. The implantation energy and dose are 100 keV and 5×10^{12} cm^{-2}, respectively. Sample B was used.