Study on Stress Memorization by Argon Implantation and Annealing

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Introduction

The stress memorization technique (SMT) is one of the performance boosting technologies for the current front-end process of CMOS. Concerning this technique, several methods have been proposed so far: annealing poly-Si gate electrodes with a capping layer after source and drain (S/D) implantation [1], implantation and annealing of S/D region capped with a stress film [2], annealing poly-Si gate electrodes capped with a stress film without a pre-implantation [3], and so on. The mechanism of stress "memorization", however, has not been clarified yet.

We consider the "memorization" might occur with multiple causes such as (i) introduction of heterogeneous atoms by implantation, (ii) poly-grain growth of gate electrode by annealing, or (iii) end-of-range-defect formation in a silicon substrate by implantation, and these phenomena can be enhanced by capping a stress film. In this study, as the first step of the investigation, we examined the effect of argon implantation and annealing of silicon substrates with and without a stress film.

Experimental

The implantation was done on a p-type silicon wafer with a 10-nm thick thermal oxide layer. An additional SiN film of 100 nm thick with different internal stress (-1698 or 6 MPa) was further deposited in some cases. The implantation species, energy, and dose amount were argon, 100 keV, and 5×10^{14} cm^{-2}, respectively. We selected argon for the implant because it is inert, can easily amorphize silicon, and can be desorped by annealing. After the implantation, the wafers were subjected to a thermal annealing at 900°C for 30 s. Several samples were further annealed at 950°C.

Strain and crystallinity at the surface region of the samples were characterized by UV-Raman spectroscopy. An argon ion laser (λ=364 nm) was used as an excitation source whose penetration depth is approximately 5 nm in silicon. Depth profile of residual argon concentration was measured by secondary-ion mass spectrometry.

Results and Discussion

Figure 1 shows shift and full-width at half maximum (FWHM) of Raman peaks corresponds to a silicon-silicon vibration mode for various samples. A remarkable blue shift was observed for all the samples. But the FWHM values were rather higher than the un-implanted bulk value (3.0 cm^{-1}). This shift might thus correspond to the incomplete damage recovery after 900°C annealing and not to tensile stress. Note that there is no remarkable difference in peak shift and FWHM between the samples II-IV with a capping SiN film but those values are smaller than those for the sample I (might be due to crystallization enhancement or temperature rise by SiN capping).

Effect of additional annealing at 950°C was then examined. Annealing time dependences of peak shift and FWHM for the sample I are shown in Fig. 2, and the dependence of argon concentration is shown in Fig. 3. The FWHM value decreased after annealing at 10 min. or longer and approached to the bulk value. Note that this re-crystallization process is slower than the usual cases like the S/D implantation. The dependence of peak shift exhibited a parallel behavior to FWHM. The strain level approached to a slightly compressive state. Argon concentration also behaved parallel but not eliminated even after a long-time (25 min.) annealing. The above results indicate that (i) implanted argon hinders re-crystallization as was previously pointed out [4], (ii) a SiN film can help re-crystallization but is no effect on the stress memorization, and (iii) there is some possibility that residual argon causes stress. As the next step of the investigation, studies on the patterned silicon wafers and poly-silicon gate samples that can clearly show the effect of stress film [5] are under way.

Summary

We studied stress memorization by argon implantation and annealing. It is shown that the implantation-damage recovery by annealing with a capping film has no effect on stress memorization.

References

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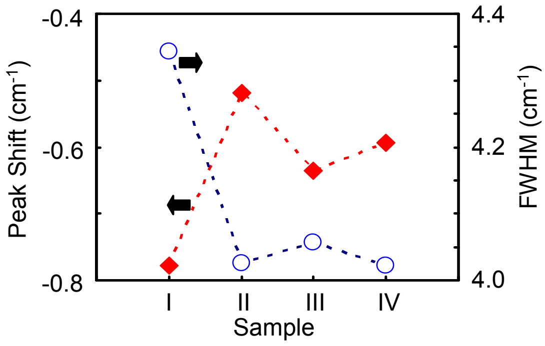

Fig. 1 Raman-peak shift and FWHM for various samples, I: w/o SiN capping, II: SiN capping, III: SiN removed after annealing, IV: high stress SiN capping

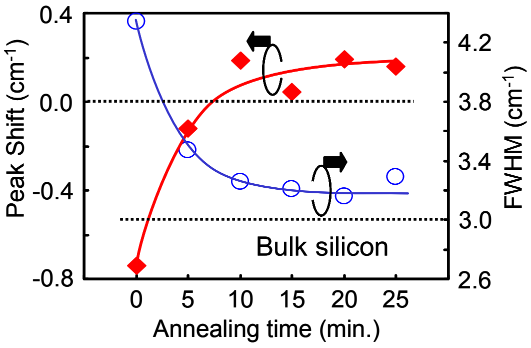

Fig. 2 Annealing time dependence of Raman-peak shift and FWHM for sample I.

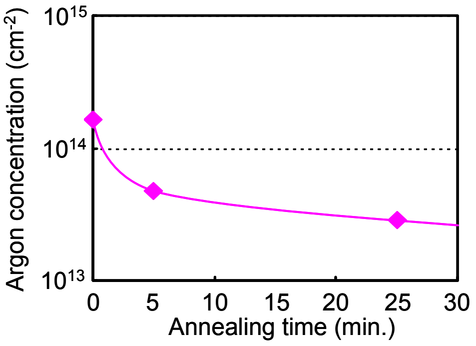

Fig. 3 Annealing time dependence of argon sheet concentration for sample I.