Interaction between Oxygens and Secondary Defects Induced in Silicon by High Energy B^+ Ion Implantation and Two-Step Annealing

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Abstract : Intrinsic gettering is usually used to improve wafer quality which is an important factor for reliable ULSI devices. The two-step annealing method was adopted in order to investigate interactions between oxygens and secondary defects during oxygen precipitation process in lightly and heavily boron doped silicon wafers with high energy $^{11}B^+$ ion implantation. Secondary defects were inspected nearby the projected range by high resolution transmission electron microscopy. Oxygen pileup was measured in the vicinity of the projected range by secondary ion mass spectrometry for heavily boron doped silicon wafers.

Key Words : Intrinsic gettering, Secondary defects, Oxygen pileup, High energy ion implantation

1. Introduction

There are many initial defects and oxygens in the silicon wafer. The shape of the defects might be changed through the sequences of many interactions during thermal processes. Ostwald Ripening theory indicate larger precipitates become more larger than others combining with relatively small one through the many thermal cycles[1,2]. M. Tamura, et. al. reported the dependency of oxygen pileup on mass number. The pileup was observed for that the mass number is above 17 but not observed for the mass number below 12. This indicate many interactions between oxygens and Frenkel defects made by ion trajectory[3].

In this papers we inspected secondary defects and oxygen pileup for the case of two type of oxygen concentration levels by high resolution transmission electron microscopy (HRTEM) and secondary ion mass spectrometry(SIMS).

2. Experiments

P-type and epitaxial wafers were used to compare boron and oxygen concentration effect on secondary defects and oxygen pileup. The p-type wafers (ρ= 4~12 Ωcm, [Oi]: ~12.6 ppma) and epitaxial wafers(p^- epitaxial layer thickness ≈ 10 μm, ρ= 11~15 Ωcm, p+ silicon substrate: ρ= 0.01~0.02 Ωcm). The interstitial oxygen concentration in epitaxial layer and p-type wafers measured by SIMS. It is well known that many Frenkel defects and an amorphous layer are generated around the projected range(R_P) of ions in the substrate after high fluence implantation into silicon. In order to investigate the influences of high energy ion implantation damage on secondary defects and oxygen pileup, $^{11}B^+$, 1.2MeV, $1.0\sim1.09\times10^{15}/cm^2$ ion implantation was done for the wafers. Two-step annealing was adopted to study secondary defects and the oxygen pileup around R_P. As the first step, the annealing treatment in N_2 ambient at 700℃ for 20 hours was done to nucleate oxygen precipitates and expended defects for all wafers and, as the second step, the annealing at 1000℃ for 10 hours was carried out for growth of these nuclei. After the two-step annealing, the carrier and oxygen interstitial(Oi) concentration of the samples was measured by SIMS. And the secondary defects and oxygen precipitates were inspected by HRTEM.

3. Results and discussion.

Fig. 1 shows the concentration profile of boron and oxygen interstitial in epitaxial wafer measured by SIMS for B implanted and two-step annealed sample. The peak depth for p-type wafer was about 2 μm and peak concentration of boron is about $1.2\times10^{19}/cm^3$. The gradient of oxygen concentration from bulk to the surface was changed slowly. There are no significant interactions between oxygen interstitial and damaged layer nearby R_P because low interstitial oxygen concentration from surface to 10 μm into the bulk.

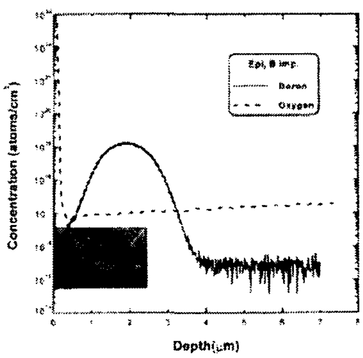

Fig. 1. Boron and oxygen concentration profiles after $^{11}B^+$, 1.2MeV, $1\times10^{15}/cm^2$ ion implantation into epitaxial silicon wafer followed by 700℃, 20hrs + 1000℃, 10hrs, isocronal annealing in N_2 ambient.

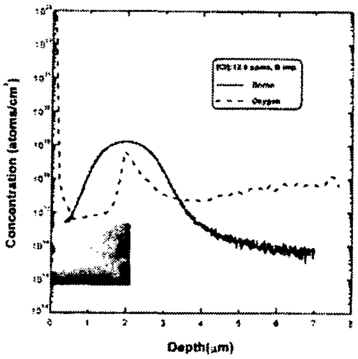

Fig. 2. Boron and oxygen concentration profiles after $^{11}B^{+}$, 1.2MeV, $1\times 10^{15}/cm^{2}$ ion implantation into 12.6 ppma [Oi] in silicon wafer followed by 700℃, 20hrs + 1000℃, 10hrs, isocronal annealing in N_2 ambient.

Fig. 2 show that the SIMS results for interstitial oxygen concentration is 12.5 ppma. For this case of relatively high concentration of interstitial oxygen compared to the former case, oxygens and carbons diffuse from bulk to the surface and have interaction with many defects in demage layer. As a results of this processes, many complexes made by oxygens and borons nearby R_P.

Fig.3 shows annealing time dependencies of oxygen concentration profile and oxygen precipitates on annealing time. Here C_{Oi} is initial oxygen concentration and the concentration difference between equalibrium oxygen concentration (C_{eq}) and bulk oxygen concentration cause oxygen diffuse out to the surface. When the condition for t = t_3, there are no oxygen precipitates and then become denuded zone for the case of lower oxygen concentration than equalibrium oxygen concentration, otherwise is vice versa. Fig.4 shows interactions between oxygen and secondary defects in the silicon for the samples high energy boron ion implantation followed by two-step annealing. In this out diffusing processes, oxygen should meet crystal misfit layer nearby R_P and interact. That is, damaged layer nearby R_P have both compressive stress and tensile stress. Tensile stress caused by radial length difference between silicon and oxygen make many silicon interstitials trapped in the damaged layer, and induce many big dislocation loops, oxygen precipitations through the interactions.

For the interactions force stronger than the case of critical force, that is, r is small enough so that the condition of interaction force is larger than the critical force, We can suggest a new model that the interaction force is described as the following equation (1).

$$F_{int} \propto \frac{\sigma_d \times \sigma_{oi}}{r^2} \qquad (1)$$

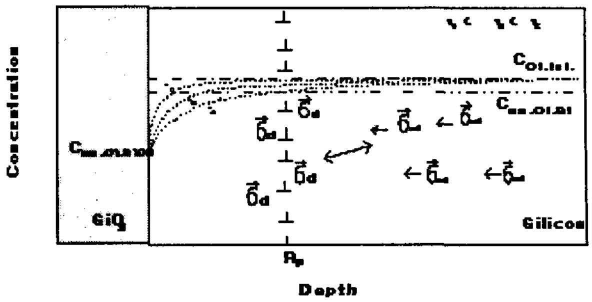

Fig. 3. A model for interactions between stresses induced by dislocations and interstitial oxygens during thermal processing.

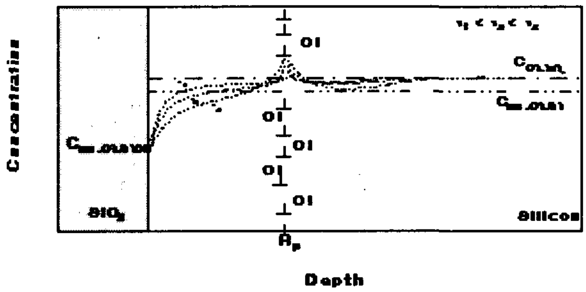

Fig. 4. Oxygen pile-up caused by interactions between stresses induced by dislocations and interstitial oxygens during thermal process.

Here σ_d is compressive stress and tensile stress in the dislocations and σ_{oi} is tensile stress caused by silicon interstitials. r is distance between two type of stresses.

4. Conclusions

Oxygen pileup was observed for the concentration of oxygen interstitials is 12.5 ppma after boron high energy ion implantation followed by two-step annealing. This paper suggests a new model as following. Many tiny dislocation are generated at the beginning of the annealing cycle after ion implantation, which causes many residual damages about projected range. Because these dislocations always involve tensile and compressive stress, these dislocations and oxygen interstitials interact with each other and finally oxygen attracted by strong stress about R_P.

참고 문헌

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