Role of Oxygen on the Implantation Related Residual Defects in Silicon

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Abstract

The role of oxygen concentration on the formation/evolution of residual defects in implanted and rapid thermal annealed silicon was studied in samples with various oxygen concentrations. Photoluminescence (PL) study showed a strong correlation between the D-line intensity and the oxygen concentration. Transmission electron microscopy (TEM) measurements also suggested the extended defects were more favored in the high oxygen sample. High frequency capacitance-voltage (C-V) measurements revealed excess acceptors that were further investigated by Deep level transient spectroscopy (DLTS). A hole trap with activation energy of 450 meV was detected and was suggested to relate to agglomerations of point defects associated with more than one type of 3D-metal related deep levels.

Introduction

Understanding the role of inherent impurities such as oxygen, carbon, hydrogen and nitrogen in Si, especially their influence on the formation and evolution of implantation related residual defects is becoming more and more important as the device size is scaling down towards deep submicron regime [1]. For example, for the extremely shallow junctions, implantation induced damage results in transient enhanced diffusion of dopants (TED), which in turn restricts the shallow junction formation. The role of oxygen and nitrogen on the end of range (EOR) defects was mentioned

by Maher [2] as a possible cause for defect "hardening". Lorenz [3] studied the effect of oxygen on the formation of EOR defects and concluded that the conditions for defect formation favored samples with high oxygen concentrations. In this paper we report the investigation of the effect of oxygen concentrations in the starting CZ silicon on the residual defects more comprehensively in terms of optical, electrical and structural properties of defects.

Experiment

The starting material were boron doped p-type (100) CZ silicon wafers. We selected two types of samples, one type was with higher oxygen content (HiO) and the other type was with lower oxygen content (LoO). We then implant the wafers with Ge to amorphize them, followed by rapid thermal annealing to generate the implantation-related defects. The sample information and implantation conditions are summarized in table 1. Solid Phase Epitaxial regrowth of the amorphized layers was carried out by rapid thermal annealing in nitrogen for 20 seconds. Cross sectional TEM (XTEM) and plan view TEM (PTM) were carried out using a Phillips CM12 microscope operating at 120 kV. Ge concentration profiles and atomic lattice location were checked using 1.5 MeV He⁺ Rutherford backscattering spectrometry (RBS) and channeling analysis. PL measurements were carried out at 8.5 K using excitation by the 514 nm line of an Ar⁺ laser at 50 mW. Room temperature C-V measurements were

carried out at 1MHz. A Bio-Rad DL4600 system was used for the DLTS measurements. For details refer to reference [7].

Table 1. Sample information & implantation conditions

Sample	Boron doping ($\times 10^{15}$ cm^{-3})	Oxygen content ($\times 10^{17}$ cm^{-3})	$^{74}\text{Ge}^+$ dose ($\times 10^{15}$ cm^{-2})	$^{74}\text{Ge}^+$ energy (keV)
HiO	3.2	9.5	1+1	800 + 400
LoO	2.3	7.5	1+1	800 + 400

Results and Discussions

Figure 1 (a) and (b) are XTEM micrographs showing the EOR dislocation loops and the threading dislocations. The dislocation loops in both samples were located just beyond the original α/c interface at a depth of approximately $0.75 \mu\text{m}$ from the sample surface. Figure 1 (c) and (d) are the PTEM micrographs showing the threading dislocations. Table 2 summarizes the TEM results.

Table 2. Summary of TEM results

Sample	Mean dislocation loop diameter (nm)	Area density of dislocation loops (cm^{-2})	Area density of hairpin dislocations (cm^{-2})
HiO	33	2.6×10^{10}	1.2×10^9
LoO	40	1.3×10^{10}	4×10^8

Figure 1 (a) and (b):XTEM micrographs of HiO and LoO samples respectively. (c) and (d):PTEM micrographs of HiO and LoO samples respectively.

The EOR region becomes highly supersaturated with self-interstitials during implantation. The evolution from the supersaturation of point defects to the EOR dislocation loops is believed via the intermediate defect configurations (IDC) proposed by Tan [4]. Narayan [5] developed a model suggesting that the coarsening of dislocation loops occurred primarily by dislocation glide and conservative climb processes. Meekison [6] showed that after the formation of such dislocation loops they then increased in size and decreased in number by diffusion between loops and subsequently decreased in size before being eliminated by diffusion to the wafer surface. The fact that our TEM results revealed that the low oxygen sample had a bigger mean loop diameter with a lower mean loop density implied that the coarsening of dislocation loops in this sample was more favored than in the high oxygen sample. In other words it would be more difficult to remove the EOR defects in the high oxygen sample because the oxygen "hardened" the material and making glide and climb process less favored. The higher density of threading dislocations in the high oxygen

sample was suggested to have resulted from the higher nucleation centers in this sample [7].

PL results are shown in Figure 2 (a) and (b) for HiO and LoO samples respectively. The 0.81 eV and 0.87 eV broadband lines were clearly seen in both samples. Other lines at energies 0.919 eV, 1.034 eV, 1.093 eV, 1.098 eV were also observed. The ratio of the integrated area under the 0.81 eV (D1) and 0.87 eV (D2) lines to the integrated area under the 1.093 eV (transverse optical phonon sideband of boron bound exciton B_{TO}) and 1.098 eV (TO phonon sideband of free-exciton luminescence $FE(TO)$) peaks was used as a means to obtain the (relative) total number (per unit area) of D1/D2 related radiative defects in the two samples. The results being 20.4 for the HiO and 7.5 for the LoO samples. PL spectra from dislocated silicon exhibit a number of characteristic lines termed D1 to D6 [8]. The 0.81 eV and 0.87 eV lines in this work were at the energies of the D1 and D2 lines. D-lines from ion-implanted silicon were reported by Uebbing [9] as the main feature of the PL spectra and the TEM showed slip dislocations. Shreter [10] reported ion-implanted silicon with D2 line dominating PL spectra and TEM of these samples showed EOR defects. Two models have emerged regarding the origin of the D-line. One is regarding the radiative electronic transition involving capture into a strain field potential associated with the dislocation. The other involves excitonic collapse onto impurities residing at dislocations and possibly interacting with point defect clusters present in dislocated samples [11].

Our results support the second model and might explain that the enhanced interaction between residual defects and impurities was responsible for the larger D-line signal observed in the high oxygen sample.

Figure 2. (a) and (b) are PL results for HiO and LoO samples respectively

Apparent free carrier concentration profiles from C-V measurements are shown in Figure 3 (a). The concentrations of the excess acceptors in the HiO and LoO samples were $3.36 \times 10^{14} \text{ cm}^{-3}$ and $1.06 \times 10^{14} \text{ cm}^{-3}$ respectively. The actual location of the excess acceptors with maximum concentration was found to be $0.22 \mu\text{m}$ beyond the actual α/c boundary after adjustment calculations [7], in consistent with published data [12]. Investigation of deep defect levels in the same region was done by DLTS and compared with literature [12][13][14]. The hole emission activation energy of the trap was about 450 meV. Figure 3(b) shows a typical DLTS spectrum. The width of peak was larger than that due to a single deep level, indicating it probably consisted of several traps. This broad peak was suggested to relate to agglomerations of point defects that were associated with more than one type of 3d-metal related defects accumulated beyond the α/c boundary.

Figure 3. (a) apparent free carrier concentration profiles from C-V measurements. (b) DLTS spectrum from LoO sample.

Conclusion

The effect of oxygen concentration on implantation residual defects has been studied. PL results showed bigger defect related (D-line) signal in the high oxygen sample. TEM implied the extended defects might be more difficult to remove in the high oxygen sample. C-V measurements revealed excess acceptor levels beyond the α -c boundary, which were related to deep hole traps measured by DLTS measurements. Comparison with literature suggested they may be agglomerations of point defects associated with more than one type of 3D-metal related deep levels.

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