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STRAIN RELAXATION MECHANISM IN THE Si-SiO$_2$ SYSTEM AND ITS INFLUENCE ON THE INTERFACE PROPERTIES

D.Kropman[1], E.Mellikov[1], A. Öpik[1], K. Lott[1], O.Volobueva[1], T.Kärner[2], I.Heinmaa[3], T.Laas[4], A.Medvid[5]

[1]Tallinn University of Technology, [2]Tartu University, [3]Institute of Chemical Physics and Biophysics, [4]Tallinn University, [5]Riga Technical University

Abstract

The results of the investigation of stresses relaxation by strain by means of EPR spectra, IR absorption spectra, SEM and samples deflection are presented. It has been shown that stresses relaxation mechanism depended on the oxidation condition: temperature, cooling rate, oxide thickness. The stresses relaxation by the strain occur due to the opposite sign of the thermal expansion coefficient of Si-SiO$_2$ and Si$_3$N$_4$ on Si in the Si-SiO$_2$-Si$_3$N$_4$ system. Laser irradiation allows to modify the system stresses.

Introduction

It is known that internal mechanical stresses due to the differences in the thermal expansion coefficient between films and substrates and lattices mismatch appear in the Si-SiO$_2$ system during the process of its formation and that point defects generation and redistribution reduce partially the surface strain. However, no investigation of this process on the atomic scale has been carried out so far. The purpose of the present work is to investigate the strain relaxation mechanism in the Si-SiO$_2$ system by means of EPR, IR absorption spectroscopy, scanning electron microscopy (SEM) and samples bending measurements.

Experimental

Si n-type with 15 Ω·cm resistivity and (111) orientation was used. The oxides were thermally grown in dry oxygen at 1100-1200 ^{o}C. The SiO$_2$ film thickness varied from 0.2 μm to about 0,5 μm. The density of point defects was varied by varying the cooling rate of the samples (3 of 25 ^{o}C/s). The EPR spectra were taken at 115 K by an X-band ESR 231 spectrometer. To evaluate the influence of the defects structure on the stresses in SiO$_2$, the measurements of SiO$_2$ IR absorption spectra were carried out. The strain in the Si SiO$_2$ system was investigated by means of SEM. Laser irradiation (λ=520nm, 10mW/cm^2) was performed after oxidation before Al evaporation.

Results and discussion

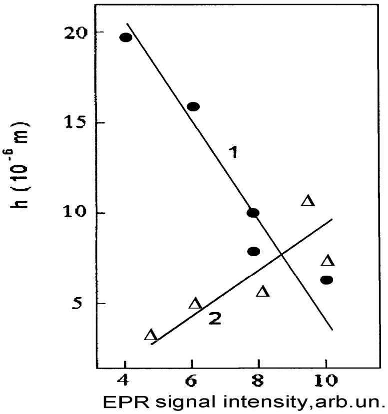

Fig.1. Relation between the deflection of samples and EPR signal of Pa centers for the samples oxidized at 1100 (1) and 1200°C (2)

It has been found that samples bending increases or decreases simultaneously with EPR signal intensity depending on the oxidation temperature, oxidation time and cooling rate (Fig.1). It may be due to the relaxation of stresses by the strain accompanied by point defects gettering and by creation of point defects by the stresses[1]. It has been found that in case of a lower oxidation temperature (1100^{0}C) the deflection of the samples decreases with an increase of the EPR signal intensity (E\`centres in SiO_2 and vacancy complexes in Si) while at a higher oxidation temperature (1200^{0}C) the deflection of the samples and EPR signal intensity increase simultaneously [2]. The revealed differences in the strain dependence on the point defects density (type) at different oxidation temperature allow to suggest that relaxation mechanism of the internal mechanical stresses (IMS) is different. Oxygen diffuses during oxidation at 1100^{0}C through the oxide to the interface where oxidation happens and is associated with a volume expansion. Part of the volume is released by injection of Si self-interstitials into Si. At 1200^{0}C diffusion of Si from the interface into oxide occurs and the oxidation reaction happens in the oxide. This process is associated with vacancy injection into the Si. The decrease of the deflection with an increase of the vacancies type point defects EPR signal intensity indicates that self-interstitial Si atoms injection are responsible for the stresses in the samples oxidized at 1100^{0}C. This oxidation kinetics model is in agreement with point defects generation kinetics in the Si-SiO_2 system proposed in [3] and confirmed experimentally [4]. It has been suggested that the incorporation of the ionic charge into the oxide causes repulsive forces expanding the silicon wafer [5]. This allows to explain this simultaneous increase of the E\` centers of EPR signal intensity and deflection in samples oxidized at 1200$^0$C. E\`centers cause repulsive forces expanding Si wafer and giving rise for the deflection in Si-SiO_2 structure.

EPR signal dependence on the oxidation time reveal one or two maximums depending on the cooling rate. Interdependence between EPR signal and IR absorption line-width exist at 1100cm^{-1} in fast-cooled samples (Fig.2). The decrease of the EPR signal is accompanied by the increase of the IR absorption line width in slowly cooled samples. Compressive stresses appear at the interface after Si_3N_4 deposition samples bending cheing sign and instead the tensile stresses. This can occur due to diminishing of the internal mechanical stresses as a result of the opposite sign of thermal expansion coefficient of SiO_2 and Si_3N_4 on Si. To check this assumption, the Si-SiO_2 and Si-SiO_2-Si_3N_4 structures cross-section microphotos, obtained by high resolution scanning electron microscopy were made (Fig.3,4). It can be seen that after Si_3N_4 deposition the thickness of the SiO_2 films decreases (Fig.3,4) and after subsequent laser irradiation the thickness of the SiO_2 film increases.(Fig.5). Simultaneous with oxides thickness increasing after Si-SiO_2-Si_3N_4 structures laser irradiation increases the samples bending that indicated higher compressive stress in SiO_2. It has been revealed that Si-SiO_2 structure laser irradiation is accompanied by E`centers EPR signal diminishing.

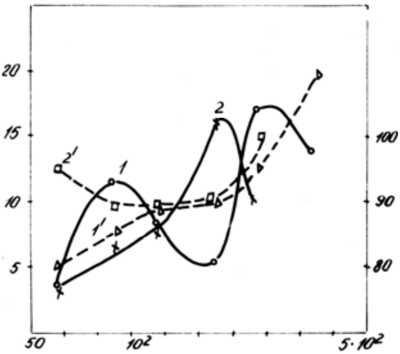

Fig.2. Dependence of the EPR signal (1, 2) and the line-width of SiO_2 IR absorption at 1100 cm-1 (1', 2') on the oxidation time, cooling rate 25 (1, 1') and 3°Cs (2, 2')

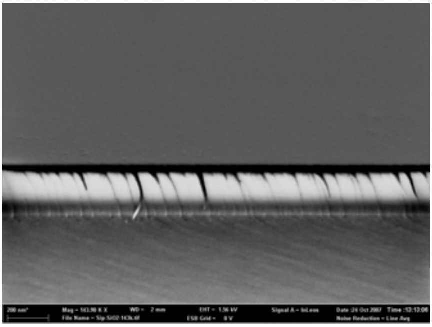

Fig.3. Si- SiO_2 structure cross-section microphoto. SiO_2 thickness is 200 nm

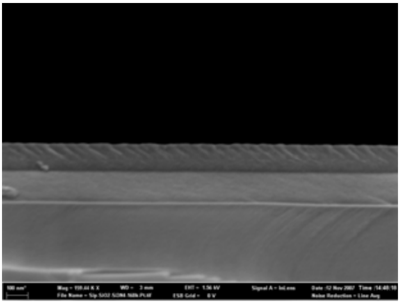

Fig.4. Si- SiO_2-Si_3N_4 cross-section microphoto. Si_3N_4 thickness is 100 nm. SiO_2 thickness diminished (150 nm)

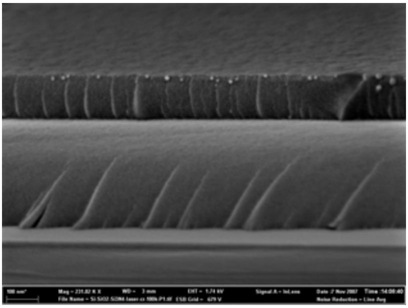

Fig.5. Si- SiO_2-Si_3N_4 cross-section microphoto after laser irradiation. SiO_2 thickness is 300 nm, Si_3N_4 thickness is 150 nm

Conclusions

The obtained results confirm that an interdependence between the created stresses and relaxation in the Si-SiO_2 structure and point defects in Si and SiO_2, and the point defects on the Si surface give rise to the defects in SiO_2 exists. It has been established that the dependence of the EPR signal intensity from vacancy type defects on the oxidation time is non-monotonous and is accompanied by a non-monotonous change of the IMS. The value of IMS in the Si-SiO_2 systems may be reduced by laser irradiation.

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