Charge trapping in high-dose Ge-implanted and Si-implanted silicon-dioxide thin films

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This work is devoted to comparative study of charge traps located in Ge and Si implanted silicon dioxide, that used for creation of high-efficiency blue-light emitting electroluminescent (EL) devices, to find out distinction in charge trapping properties such oxides during high-field electron injection.

Thermally grown 80 nm thick SiO_2 film on n-type Si wafer was implanted by Ge^+ ions at energy 50 keV and doses $6.5x10^{15}$ cm^{-2}. As-implanted structures were rapid thermal anneal (RTA) at 1000°C from 6 to 150s. As-measured by Rutherford backscattering (RBS) technique the Ge profile in the as-implanted oxide exhibits a maximal concentration of about 3 at.% about 30 nm below the oxide surface. For the sake of comparison other set of oxidized wafer was implanted by Si^+ ions at an energy of 20 keV with doses of $7x10^{15}$ cm^{-2} and then was rapid thermal annealed. The TRIM calculation shows the similar distribution of Si implanted atoms with maximal concentration of 3 at. % as for Ge implantation. MOS capacitors for electrical measurements were fabricated using sputtered layers of Al for both the gate electrode and the bulk contact.

High-field electron injection into the oxides was performed at room temperature at constant current (J_{inj}= $2x10^{-5}$ A/cm^2), corresponding to operating regime of the EL device. Charge trapping under electron injection into the oxide from the Si substrate has been studied by measurement of changing of the voltage applied to the MOS structure at constant current regime (ΔV_{CC}) and shift of flat-band voltage (ΔV_{FB}) of high-frequency C-V characteristics.

Increase of the ΔV_{CC} during the high-field electron injection in Ge implanted oxide suggests a negative charge trapping in the oxide at the distance more then the tunneling length from injected SiO_2/Si interface. In the same time the ΔV_{FB} shows, firstly, a considerable smaller negative charge trapping then the ΔV_{CC} measurements, and, secondly, at large injected charge a positive charge trapping is appeared, that is not observed from the ΔV_{CC} vs. injected charge (Q_{INJ}) characteristic. Since, the C-V method is sensitive to total net charge and especially to the charge located in the SiO_2/Si interface, we can conclude that in case of the Ge implanted oxide the trapped positive charge is located in the SiO_2/Si interface and does not effect on the ΔV_{CC}-Q_{INJ} characteristic. Thus, from the ΔV_{CC}-Q_{INJ} characteristic the negative charge parameters can be calculated, and the trapped positive charge can be determined by subtraction of the $C_{OX}\Delta V_{FB}$-Q_{INJ} characteristic from the $C_{OX}\Delta V_{CC}$-Q_{INJ} one.

Assuming the first order trapping kinetics for both negative and positive trapping charge the fitting of the $C_{OX}\Delta V_{CC}$-Q_{INJ} characteristics allows to determine of existence of four electron and two hole traps in the Ge implanted and annealed oxides with following capture cross-sections (σ_i) and concentration (Q_i) for 6 s RTA sample: σ_{1e}^{Ge} >10^{-14} cm^2, Q_{1e}=$7.4x10^{12}$ cm^{-2}; σ_{2e}^{Ge} = $1.5x10^{-15}$ cm^2, Q_{2e}=$1.5x10^{12}$ cm^{-2}; σ_{3e}^{Ge} =$2x10^{-16}$ cm^2, Q_{3e}=$1.7x10^{12}$ cm^{-2}; σ_{4e}^{Ge} =$3x10^{-18}$ cm^2, Q_{4e}=$1.1x10^{12}$ cm^{-2}; σ_{1h}^{Ge} =$5x10^{-15}$ cm^2, Q_{1h}=$9.3x10^{11}$ cm^{-2} and σ_{2h}^{Ge} =$3.2x10^{-16}$ cm^2, Q_{2h}=$3.5x10^{11}$ cm^{-2}. Initial unimplanted oxide contains only electron trap with σ_e =$9x10^{-18}$ cm^2 and Q_e=$6.6x10^{11}$ cm^{-2} and the hole trap with σ_h =$3.2x10^{-16}$ cm^2 and Q_h=$2x10^{11}$ cm^{-2}. Thus, the electron traps with large capture cross-section have been created by Ge^+ ion implantation and following high-temperature anneal. It should be noted, that concentration of the electron traps inside of the oxide with σ_{1e}^{Ge} >10^{-14} cm^2 reduces and concentration of the hole traps with σ_{1h}^{Ge} =$5x10^{-15}$ cm^2 increases with an increase of RTA time, that corresponds to decrease of Ge atom concentration inside of the oxide and increase of one at the SiO_2/Si interface, observing by RBS measurements (not presented here) and connected with the Ge atoms diffusion towards the SiO_2/Si interface and also with out-diffusion of the Ge through the surface of the SiO_2 layer.

In case of the Si implanted oxide an accumulation of charge in the oxide under the electron injection is sufficient different from the Ge implanted oxide. First of all, net total negative charge trapped inside of such oxide is considerable smaller than that in the Ge implanted oxide. Secondly, after 6s RTA in the first stage of charge trapping the positive charge generation inside of the oxide with effective capture cross-section σ_{1h}^{Si} = $2.6x10^{-15}$ cm^2 appears. Thirdly, after 150s RTA the trapped charge in the oxide calculated from the ΔV_{CC} and the ΔV_{FB} is completely same up to $4x10^{16}$ e/cm^2 injected charge, that corresponds to the trap location inside of the Si implanted oxide. The last phenomena attests a lack of detectable diffusion of Si atoms towards of the SiO_2/Si interface and defect collection in the region of maximal concentration of the implanted Si. Calculated trap parameters for Si implanted oxide with 6s RTA are following: σ_{1e}^{Si} = $1.6x10^{-15}$ cm^2, Q_{1e}=$3.5x10^{12}$ cm^{-2}; σ_{2e}^{Si} = $1.6x10^{-16}$ cm^2, Q_{2e}=$1.2x10^{12}$ cm^{-2}; σ_{3e}^{Si} =$4.2x10^{-17}$ cm^2, Q_{3e}=$7x10^{11}$ cm^{-2}; σ_{4e}^{Si} =$5.3x10^{-18}$ cm^2, Q_{4e}=$5x10^{11}$ cm^{-2} and σ_{1h}^{Si} =$2.6x10^{-15}$ cm^2, Q_{1e}=$2.7x10^{12}$ cm^{-2}. It should be emphasized that increase of the RTA duration results in an increase of both total negative and positive trapped charges inside of the oxide.

Thus, the high-dose Ge^+ ion implantation with following high-temperature anneal results in a creation of the electron traps inside of the oxide with large capture cross-sections and concentration. Increase of RTA duration leads to Ge atom diffusion in the SiO_2/Si interface and positive charge traps generation in this region. In other hand, after the high-temperature RTA of high-dose Si ion implanted oxide Si atom diffusion towards the SiO_2/Si interface is not observed and traps of positive and negative charges are located inside of the implanted oxide.