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Cathodoluminescence of Ge- Clusters in Silica Layers

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Scanning transmission electron microscopy (STEM), energy dispersive X-ray analysis (EDX) and cathodoluminescence (CL) have been used to investigate Ge^+-implanted amorphous silicon dioxide layers. Commonly, CL emission spectra of pure SiO_2 are identified with particular defect centers within the atomic network of silica including the nonbridging oxygen-hole center (NBOHC) associated with the red luminescence at 650 nm (1.9 eV) and the oxygen deficient centers (ODC) with the blue (460 nm ; 2.7 eV) and ultraviolet UV band (295 nm ; 4.2 eV), [1].
In Ge doped SiO_2 an additional emission band is identified at (410 nm ; 3.1 eV), see e.g. [2].

The CL measurements were performed in a Zeiss DSM 960 digital scanning electron microscope equipped with a liquid nitrogen cryogenic stage. The CL is excited by an electron beam energy E_o=10 keV and a slightly defocused current $I_o \approx 600$ nA over 100x100 µm and collected via a parabolic mirror, a spectrograph (200-800 nm), and a charge coupled device (CCD) camera, [2].
As samples we have used amorphous, thermally grown SiO_2 layers, 500 nm thick, wet oxidized at 1100 °C on Si substrate. The layers are of microelectronic quality and doped by Ge^+ ions with an energy of 350 keV and a dose of 5×10^{16} ions/cm^2 leading to an atomic dopant fraction of about 4 at.% at a mean depth of about 200 nm, see Fig.1. Afterwards a post-implantation thermal annealing has been performed at temperatures T_a = 700, 900, 1100 °C, for 60 minutes in dry nitrogen, [2].

Fig. 2 shows the CL spectra of the Ge^+implanted samples annealed at different temperatures T_a. The large violet emission band at 3.1 eV due to the Ge dopants is observed and the intensity of this peak increases up to a factor of 250 with increasing annealing temperature T_a up to 900 ^oC. Exceeding the annealing temperature to 1100^{o}C, i.e. to the original oxidation temperature, the CL intensity is reduced again. Thus the thermal annealing process of Ge^+implanted layers leads first to a strong increase of the violet luminescence due to formation of low-dimension Ge aggregates like dimers, trimers and higher formation; finally to destruction of the luminescence centers by further growing to Ge nanoclusters. STEM images in cross section technique [3] show the growing in Ge clusters with increasing annealing temperature, see Fig. 3. The nanocluster diameters are growing with annealing temperature from 1-6 nm at T_a=900 ^{o}C to 1-12 nm at T_a=1100 ^{o}C as shown in Fig. 4. Moreover, due to Ostwald ripening the cluster concentration drops from 4.6 to 2.6x10^{17} per cm^3. However, their luminescent surfaces or surroundings in their sum have been reduced, i.e. the overall luminescence efficiency decreases.

References

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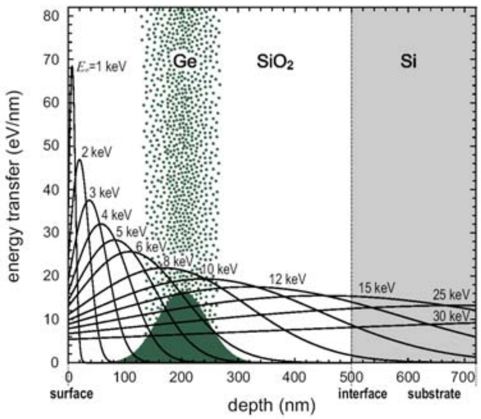

Fig. 1. Electron beam excitation densities in SiO_2 layers for different beam energies E_o and a Ge+ implanted profile in the mean projected range R_p=200nm.

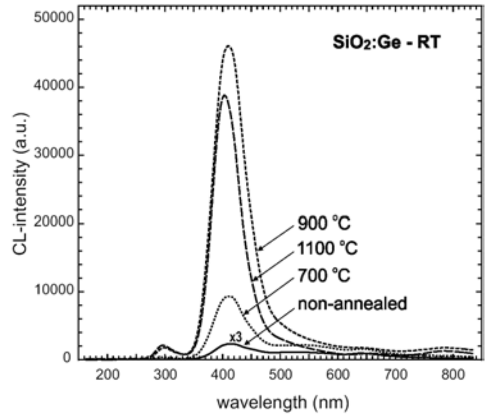

Fig. 2. CL-spectra of thermally annealed Ge implanted SiO_2 layers measured at room temperature (RT); the respective annealing temperatures T_a are indicated.

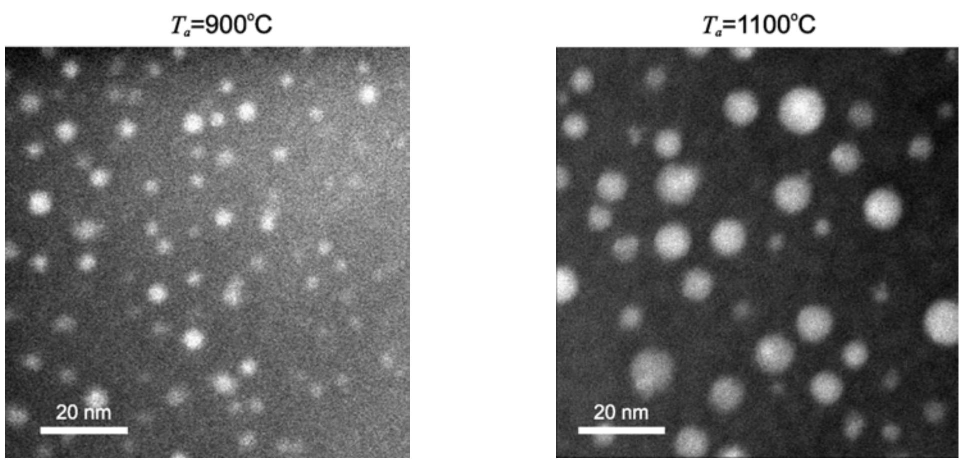

Fig. 3. STEM cross section images of Ge implanted SiO_2 layers showing clusters growing (Ostwald ripening) with increasing annealing tempe-ratures T_a.

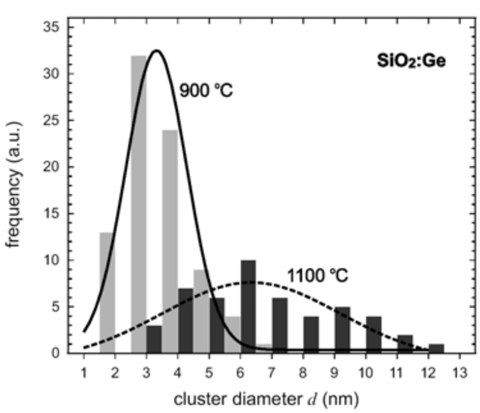

Fig. 4. Ge cluster diameter-distributions as a function of the annealing temperature T_a: the correlated cluster concentrations are N_c = 4.6x10^{17} and 2.6x10^{17} cm^{-3} for T_a=900 and 1100 ^{o}C, respectively.

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