GERMANIUM NANOPARTICLE FORMATION IN THIN OXIDE FILM ON SI BY NEGATIVE-ION IMPLANTATION

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Nanoparticles are required to be formed with well defined size and depth in a very thin oxide film such as gate oxide layer for developing single electron devices due to Coulomb blockade phenomenon. Negative-ion implantation has an advantage of almost "charge-up free" feature even in insulators and is suitable for doping atoms to create nanoparticles with precise controls of depth and dose amount rather than conventional one. There has been interest in extending the technique to the nanoparticle formation with semiconductor elements such as germanium, silicon besides in addition to noble metals. In this paper, we describe germanium negative-ion implantation into silica glass and thin thermally grown oxide film on silicon substrate. The nanoparticles were investigated by optical absorption and cross-sectional TEM observation. Silica glass and 25-nm-thick SiO_2 on Si(100) substrate were implanted with Ge negative ions at 10 keV with $5x10^{15}$ ions/cm^2. Samples were annealed at various temperatures. The calculated depth profile of implanted Ge atoms by TRIM-DYN predicted to be almost Gaussian with a peak concentration of about 7 at.% at 12 nm in depth at the condition. In optical transmittance measurement, the silica glass sample showed an optical absorption band ranging from 200 nm to 275 nm with decreasing its intensity as increase in wavelength after annealing at less than 600°C and as implanted. This absorption well agreed with a high energy tail of the calculated absorption with a peak near 185 nm by surface plasmon resonance (SPR) of Ge nanoparticles in SiO_2. Ge nanoparticles were considered to form in silica glasses. For the SiO_2/Si sample, cross-sectional TEM images showed Ge nanoparticles with the maximum diameter of 4 nm at around 12 nm in depth and they remained there after annealing at more than 700°C.

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