Dielectric layers with embedded semiconductor nanocrystals (NCs) are widely studied, in order to overcome difficulties of non-volatile memory devices connected with technology scale-down, and to develop Si-based light emitting diodes (LEDs). In fact, a lot of research has been dedicated to study the quantum-confined electronic states in low dimension structures of group IV indirect-gap semiconductors such as Silicon (Si) and Germanium (Ge). Artificially controlled processes and the natural formation of quantum dots (QDs) of these materials would open new possibilities for the application of these materials in novel integrated optoelectronics and microelectronics devices.

Although related metal–insulator–semiconductor (MIS) structures can be prepared on any semiconductor substrate, silicon-based structures are the most important ones for the technological development. The most common structure used for both memory and LED purposes is the metal or poly-Si/SiO\(_x\)/Si structure with Si NCs embedded in the SiO\(_x\) layer [1]. However, alumina or stacked dielectrics are also used as dielectric matrix and Ge and SiGe nanocrystals are also often formed inside these matrices. Constant shrinking of the thickness of gate dielectrics to below 2-3 nm has led to a search for alternative materials, whose dielectric constant is higher than that of SiO\(_2\), but whose other properties remain similar to SiO\(_2\), which is the case of Al\(_2\)O\(_3\). A dielectric constant (\(\varepsilon_{\text{Al}_2\text{O}_3} = 9\)) more than twice that of SiO\(_2\) (\(\varepsilon_{\text{SiO}_2} = 3.9\)), a band gap of 9eV, good mechanical properties and high temperature resistance, makes Al\(_2\)O\(_3\) a good candidate to replace SiO\(_2\) as a gate dielectric material and an ideal material for Si processing conditions.

Several techniques are being used to fabricate Ge NCs, such as RF co-sputtering, ion implantation, evaporation–condensation, electron beam evaporation, chemical vapour deposition, and pulsed laser deposition. In this work Ge NCs embedded in alumina thin films were deposited over Silicon (111) substrates using RF magnetron co-sputtering technique. Annealing was performed in order to improve the crystallinity of the Ge phase in the films and achieve control over the NCs size [2].

Ge NCs of suitable size and good crystalline quality were obtained by different techniques, including X-ray diffraction (XRD) (Fig. 1, inset), Raman spectroscopy (Fig. 1) and high resolution transmission electron microscopy (HRTEM) (Fig. 2a). The NCs size was estimated from Raman spectra using Fauchet and Campbell model [3] and from X-ray diffraction using Debye-Scherrer equation [4]. Statistical average diameters were obtained from HRTEM pictures.

A good agreement between the three techniques for the size estimation was observed for smallest NCs. However, for larger NCs (> 20 nm) there is a discrepancy between XRD and Raman results. For this sample the LO Raman peak presents a blue shift relative Ge bulk and X-ray peaks are shifted for higher angles relative to the Ge diamond structure. A possible explanation for this shift is the compressive stress exerted on Ge NCs by the Al\(_2\)O\(_3\) matrix [5, 6]. Further detailed studies are in course in order to clarify both confinement and stress effects.
References:


Figures:

Fig 1: Raman spectrum of one annealed Ge/Al2O3 film (800°C/1hour/4.6E-3 mbar air pressure). The LO peak is red shifted relatively to Ge bulk. Inset: XRD spectrum, clearly revealing (220), (311) and (400) reflections corresponding to peaks from Ge diamond structure. The average NC’s size increased from approximately 3.4 (as-grown) up to 7.3 nm (annealed).

Fig 2 – a) A cross section high-resolution TEM micrograph of the Ge/Al2O3 annealed film from Fig.1; The lattice fringes from Ge NC’s are visible; b) Ge NC’s size distribution calculated for this sample was 8 ± 3 nm, in agreement with the estimation made using Debey-Scherrer formula on XRD spectrum of Fig.1.

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