Ge NANOCRYSTALS EMBEDDED IN ALUMINA FOR NON VOLATILE MEMORY APPLICATIONS

S. R. C. Pinto, A. G. Rolo*, A. Chahboun*, ** and M. J. M. Gomes**

** Physics Department, University of Minho, 4710 – 057 Braga, Portugal*
*** Physics Department, Dhar Mehraz Sciences Faculty, BP 1796, Fès, Morocco*
sarapinto@fisica.uminho.pt

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_2O_3. A dielectric constant ($\varepsilon_{Al2O3} = 9$) more than twice that of SiO_2 (ε_{SiO2}=3.9), a band gap of 9eV, good mechanical properties and high temperature resistance, makes Al_2O_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 cristallinity 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_2O_3 matrix [5, 6]. Further detailed studies are in course in order to clarify both confinement and stress effects.

References:

[1] Zs.J. Horváth, *Current Applied Physics* 6 (2006) 145–148
[2] P. Caldelas et al, in press in Journal Nanoscience and Nanotechnology.
[3] I. H. Campbell, F. M. Fauchet, Solid State Commun. 58, (1986) 739
[4] E. Lifshin, X-Ray Characterisation of Materials, Wiley-VCH, New York, (1999) p.37
[5] I. D. Sharp et al, Journal. Applied Physics 100, (2006) 114317, and references there in.
[6] O. Conde et al, Journal of Crystal Growth 247 (2003) 371-380

Figures:

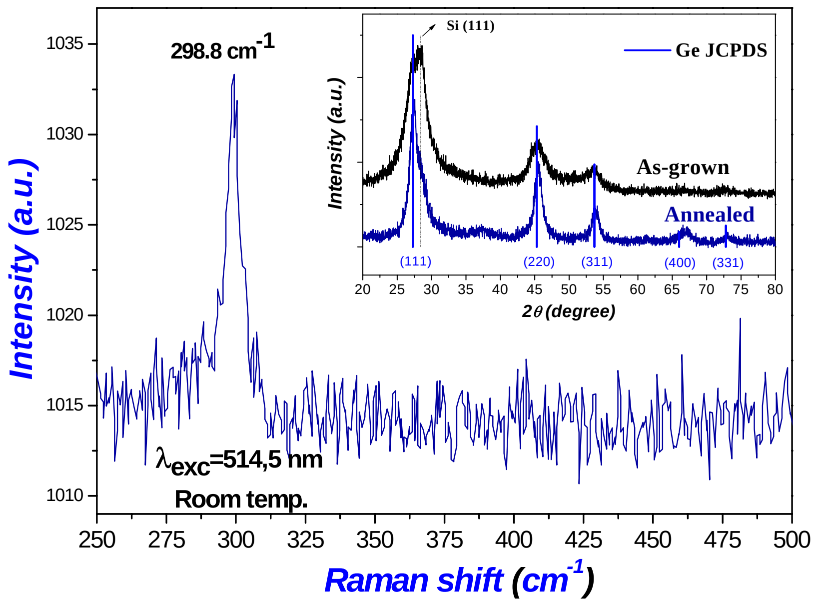

Fig 1: Raman spectrum of one annealed Ge/Al_2O_3 film (800ºC/1hour/4.6E^{-3} mbar air pressure). The LO peak is red shifted relatively to Ge bulk. Inset: XRD spectrum, clearly revealing (220), (311) and (400) reflections corresponding to peaks from Ge diamond structure. The average NC's size increased from approximately 3.4 (as-grown) up to 7.3 nm (annealed).

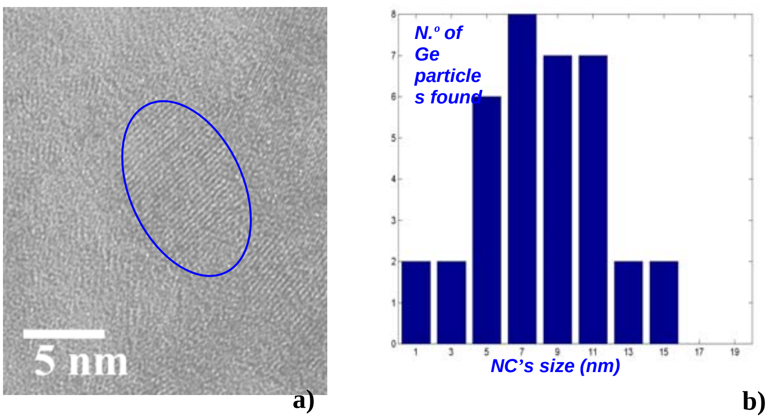

Fig.2 – a) A cross section high-resolution TEM micrograph of the Ge/Al_2O_3 annealed film from Fig.1; The lattice fringes from Ge NC's are visible; **b)** Ge NC's size distribution calculated for this sample was 8 ± 3 nm, in agreement with the estimation made using Debey-Scherrer formula on XRD spectrum of Fig.1.

Acknowledgements

This work has been partially supported by the European Commission through project called SEMINANO under the contract NMP4-CT-2004- 505285, by FCT-Fundação para a Ciência e a Tecnologia-Portugal, and by the "Programa Operacional Ciência e Inovação 2010-POCI 2010" co-financed by FEDER (Fundo Comunitário Europeu) throught the Project POCTI/FIS/56930/2004. SRCP thanks FCT for the financial support (grant SFRH/BD/29657/2006).