Exploring the potential of Si and Ge amorphous nanostructures for photonic applications

R. Serna, J. Martín-Sánchez, J. Toudert
Instituto de Optica, CSIC
Serrano 121, 28006 Madrid
Spain

The optical properties of crystalline IV-group-semiconductor nanostructures as Si and Ge have been thoroughly investigated in the last years with special emphasis on porous structures, nanoparticles, nanowires and nanolayers. One of the key reasons behind the study of Si and Ge nanostructures lies in the interest of developing low cost photonic devices fully compatible with the state-of-the-art Si technology. Although bulk Si and Ge show inefficient light emission because of their indirect band-gap, strong light emission by nanostructured Si has been observed in the visible/near–infrared (IR) due to quantum confinement effects. In addition, the sensitizing capabilities of Si-based nanostructures for efficient light emission by rare-earth (RE) ions in the IR has been demonstrated in nanocomposite materials codoped with Si nanostructures and RE ions . Remarkably, Ge has also received an increasing attention due to some of its specific properties that can offer advantages with respect to Si due to its larger carrier mobility, lower bandgap and larger exciton Bohr radius that can lead to higher confinement, and a higher sensitivity of the band-gap to nanostructure size variations. On the other hand, amorphous nanostructures have been less studied due to the inherent difficulty to characterize them. Interestingly, it has been shown that they also show tunable optical band-gap properties [2] and are indeed very efficient sensitizers for RE ions [3]. Additionally, they can be produced following a low-cost low-temperature processes and it is expected a lower strain in the nanostructure embedded in the matrix due to their more flexible amorphous structure.

In this work, we report our recent results on the design and synthesis of nanocomposite thin films based on Si or Ge amorphous nanostructures embedded in amorphous aluminum oxide (a-Al_2O_3), labeled as a-Si:a-Al_2O_3 and a-Ge:a-Al_2O_3, respectively. The films have been prepared by the non-equilibrium technique of pulsed laser deposition at room temperature in vacuum. The formation of the nanostructures is achieved in-situ by the alternated ablation of semiconductor (Si orGe) and a-Al_2O_3 targets, with no post-depostion annealing processes. The formation of the semiconductor nanostructures is monitored during deposition by real-time reflectivity measurements. Figure 1 shows a cross-section energy filtered transmission electron microscopy (EFTEM) image of one multilayered a-Si:a-Al_2O_3 film containing amorphous Si nanostructured layers separated by the embedding a-Al_2O_3 matrix. The amorphous nature of both the Si nanostructured layers and the embedding a-Al_2O_3 is evidenced in high resolution transmission electron microscopy images [3].

The quantum confinement properties of the a-Si:a-Al_2O_3 and a-Ge:a-Al_2O_3 nanocomposite films have been studied through their optical response from the near-UV to the near-IR using both transmittance measurements at normal incidence and variable angle ellipsometry measurements from 60 to 75º. From these measurements, it is shown that the real part of the refractive index in the near-IR region of the spectrum increases as a function of the semiconductor content. A clear absorption edge, which is linked to the optical band-gap of the semiconductor nanostructures, is observed. This optical band-gap is red-shifted as the semiconductor content in the film increases and depends on the nature of the semiconductor. It shifts in the 2 to 3 eV range for Si and from 1 to 4 eV for Ge [4].

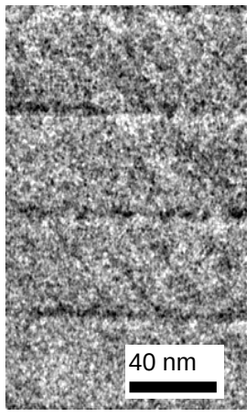

Figure 1. Cross-section EFTEM image from a a-Si:a-Al_2O_3 multilayer nanostructured film. The image has been obtained by selecting the energy window of Al in a-Al_2O_3 at 60 eV. The dark areas correspond to Si-rich regions and bright background to the a-Al_2O_3 matrix.

Finally, the potential of these a-Si and a-Ge nanostructures as efficient sensitizers for Er^{3+} ions will be discussed. In particular we will show a strategy for achieving efficient light emission from a single layer of Er^{3+} ions with a low areal density (~ 10^{13} at/cm^{-2}) by a a-Si nanostructured layer (Fig 2).).

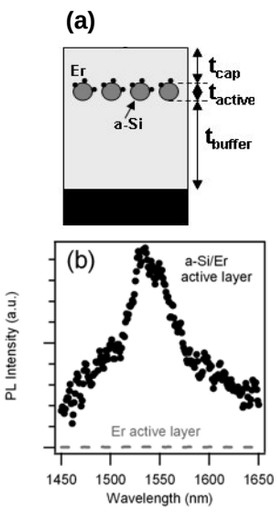

Figure 2. (a) Schematic structure of a single active layer film formed by a Si nanostructure co-doped with Er. The thickness of the a-Al_2O_3 buffer layer is designed in order to achieve an optimized excitation.
(b) Photoluminescence spectra of the a-Si/Er co-doped layer schematically shown in (a) under excitation at 488 nm. The photoluminescence of a layer with no a-Si is also shown for comparison.

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