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Structural and Chemical Characterization of Ge/GeSn Core/Shell Nanowires

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Integration of group IV semiconductors on silicon substrates offers a broad range of applications in optoelectronic devices [1]. $Ge_{1-x}Sn_x$ semiconductors are offering the possibility of manipulation of plasmonic properties and tunability of their bandgap energy making them potential materials for improvements of the photodetector's operation performance in the mid-infrared spectrum, with energies in the 0.4-0.9 eV range [2]. Fabricated in the form of heterostructured Ge/GeSn core/shell nanowires, these nanostructures are showing interesting structural characteristics allowing strain relaxation in the GeSn shell [3]. Therefore, in this research, we investigate the structure and chemical composition the core/shell Ge/GeSn nanowires with different Sn concentrations incorporated in the shell. For this work, atomically resolved high-resolution scanning transmission electron microscopy (HR-STEM) and electron energy loss spectroscopy (EELS) were used to identify structural defects affecting the growth and to provide chemical composition analysis at nm spatial resolution.

HR-STEM imaging confirms that the core/shell nanowires have complex morphologies deviating from uniformly straight growth facets (**Figure 1 a**). Nano-scale facets and ledges are visible when observing the samples with HR-STEM. While we observe that most wires are very straight, there are also several that grow with curved profiles, suggesting that the composition of the wire is not uniform. Defects such as stacking faults, twin boundaries, and edge dislocations were found in several regions along these nanowires (**Figure 1 b**). The growth direction was confirmed to be [111]. Detailed analysis, using Fourier transforms of the lattice images, however, suggest a slight deviation of this crystallographic direction with respect to the macroscopic growth direction. Detailed analysis with Moiré interferometry [4] also reveals evidence of defects which were also confirmed with the HR-STEM images on these samples. Chemical mapping was performed using core loss EELS. The data confirmed core/shell Ge/GeSn compositional structures. However, non-uniform Sn distribution in the GeSn shell was found (**Figure 2**). The concentration of Sn in the GeSn shell varies with the region of interest. Furthermore, quantitative analysis of the Sn content revealed that the concentration of Sn is lower than expected and the content is non-uniform. This can possibly be the origin of the non-straight growth of some wires due to the non-uniform incorporation of Sn. Furthermore, islands of tin oxide on the nanowire's facets were also observed. Chemical analysis also confirmed the presence of gold as a catalyst at the tips of the nanowires.

The next step in this work includes local measurement of the bandgap of these core/shell Ge/GeSn nanowires and investigation of their plasmonic properties using low-loss EELS with high spatial resolution [5]. The influence of the structural defects and non-uniform chemical composition on the plasmonic behaviour of these nanowires will be further investigated. [6]

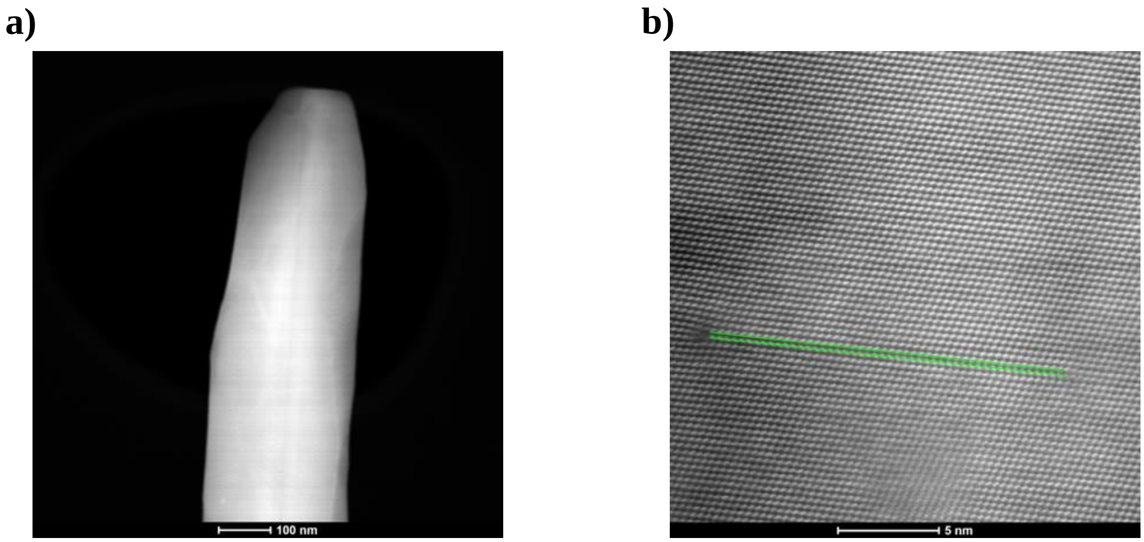

Figure 1: Experimental results showing nanowires structure; **a)** HR-STEM image of a small field of view of a core-shell nanowire showing nanoscale facets and a very narrow inner core (less than 10nm); **b)** HR-STEM image of the crystalline lattice. The green line shows the location of a stacking fault and the position of a dislocation core (at the left end of the green lines).

Figure 2: Elemental maps of Ge (Red) and Sn (green) obtained with EELS chemical analysis.

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