Ge/GeSn Nanowires for Mid-infrared Sensing and Imaging

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Mid-infrared (MIR) optoelectronic devices are of utmost importance to a plethora of applications such as night vision, thermal sensing, autonomous vehicles, free-space communication, and spectroscopy. To this end, leveraging the ubiquitous silicon-based processing has emerged as a powerful strategy that can be accomplished through the use of group IV germanium-tin (GeSn) alloys. Indeed, due to their compatibility with silicon and their tunable bandgap energy covering the entire MWIR range, GeSn semiconductors are frontrunner platforms for compact and scalable MIR technologies. However, the GeSn large lattice parameter has been a major hurdle limiting the quality of GeSn epitaxy on silicon wafers. These limitations are further exacerbated as $Ge_{1-x}Sn_x$ layers and heterostructures with Sn contents at least one order of magnitude higher than the solubility are needed for device structures relevant to MWIR applications. In this regime, the as-grown layers are typically under a significant compressive strain, which impacts the bandgap directness and increases its energy at the Γ point, thus hindering the device performance and limiting the covered range of the MIR spectrum. This compressive strain buildup not only affects the band structure but also limits the incorporation of Sn atoms in the growing layer, making the control of Sn content a daunting task.

Herein, we show and discuss how sub-20 nm Ge nanowires provide effective compliant substrates to grow $Ge_{1-x}Sn_x$ alloys with a composition uniformity over several micrometers with a very limited build-up of the compressive strain. $Ge/Ge_{1-x}Sn_x$ structures with Sn content spanning the 6 to 18 at.% range are achieved [1-3]. Atomic-level properties of this class of nanoscale materials were investigated by combing atom probe tomography and transmission electron microscopy. Their optical properties were also extracted using photoluminescence studies combined with k.p theory. Moreover, the obtained $Ge/Ge_{1-x}Sn_x$ core/shell nanowires were subsequently integrated in the fabrication of tunable phototransistors and photodetectors exhibiting a cutoff wavelength in the 2.1-3.9 µm range as the Sn composition is varied from 8% to 18% (Fig. 1 (a)) [1]. Furthermore, we successfully demonstrated the use of these nanowire-based detectors in uncooled imagers enabling the acquisition of high-quality images under both broadband and laser illuminations without the use of the lock-in amplifier technique (Fig. 1 (b)). The stable gate-modulated photocurrent in a single $Ge/Ge_{0.82}Sn_{0.18}$ nanowire top-gated phototransistor under 2.33 µm illumination will also be shown and discussed.

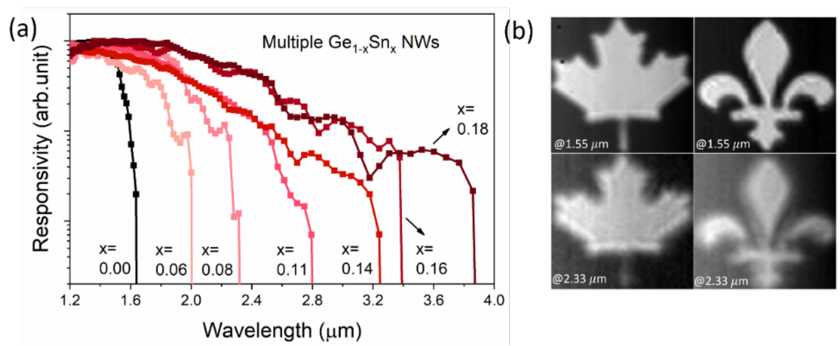

Figure 1. (a) Relative responsivity spectrum of the multiple $Ge/Ge_{1-x}Sn_x$ core/shell NWs. (b) Single-pixel images measured by the NW photodetectors under 1.55 µm and 2.33 µm.

References

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