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Ge Nanowires: Sn Catalysts and Ge/$Ge_{1-x}Sn_x$ Core-Shell Structures

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Characterization of Ge nanowire formation by vapor-liquid-solid (VLS) growth, using Au as the catalyst, has been shown to facilitate non-equilibrium processes such as low-temperature growth of Ge nanowires below the Ge-Au eutectic temperature, and formation of metastable structures and compositions in the catalysts [1-5]. Non-equilibrium growth also offers possibilities for metastable solute trapping of other components in the nanowire. Here we show results for the Ge/Sn system, using Sn as either the catalyst for Ge NW growth, or to form a Ge/$Ge_{1-x}Sn_x$ core-shell nanowire. Incorporating Sn into the nanowires offers the possibility of increasing the carrier mobility, and of achieving a direct band-gap for efficient light absorption and emission by pushing the concentration of Sn in Ge beyond the equilibrium value [6]. Fig. 1 shows the morphology and single crystallinity of nanowires grown using Sn as the catalyst. The catalyst, formed by evaporation and partial etching of thin Sn layers on Ge substrates, produces wires with typical diameters <10 nm and a <110> growth axis. Many of the nanowires grow without kinking; however the image in Fig. 1 shows that even kinked wires are single crystal. Nanowires that are grown using Au catalysts, with Sn added via the introduction of $SnCl_4$ gas partway through the growth process to form core-shell structures, are shown in Fig. 2. Sn is incorporated into the liquid catalyst droplet, which enlarges the catalyst and the nanowire diameter. During end-of-growth cool-down Sn and Ge are rejected from the catalyst resulting in tapered ends, with Au remaining at the tip. These nanowires have a <111> growth axis; they contain planar defects in the lower half of the wire as shown in the STEM image of Fig. 3, whereas the upper half of the wires are defect free. The planar defects are particularly visible in the left wire, which is tilted to a <110> orientation. Figure 4 shows high resolution aberration corrected images of the defects. These defects, which sometime appear as a single plane, do not appear to be stacking faults as there is no shift of the intersecting (111) planes across the defect; their structure is being investigated further. Preliminary EDS analysis of the shell composition indicates a Sn concentration of ~4 at%, well above the <1 at% equilibrium value, and possible further accumulation of Sn at the planar defects. We are currently investigating the growth parameters needed to achieve higher Sn concentrations while minimizing defects, and will also report on photoluminescence measurements of the nanowires [7, 8].

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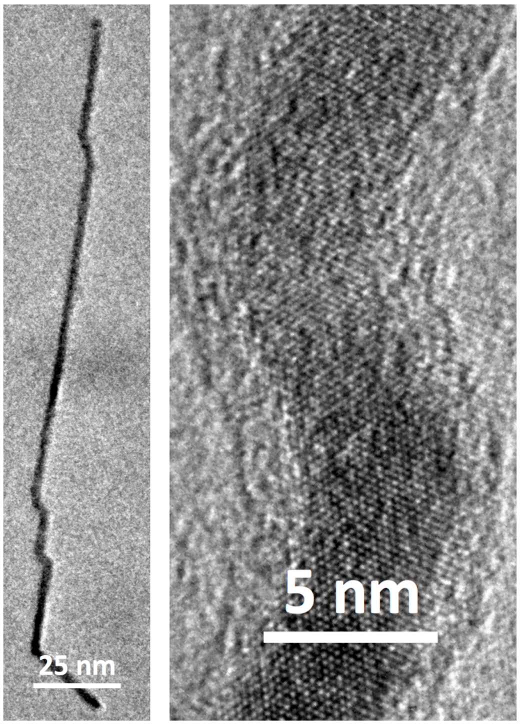

Figure 1. A Ge NW grown with a Sn catalyst: the NWs are single crystal, approximately 5 nm in diameter, and have a <110> growth direction.

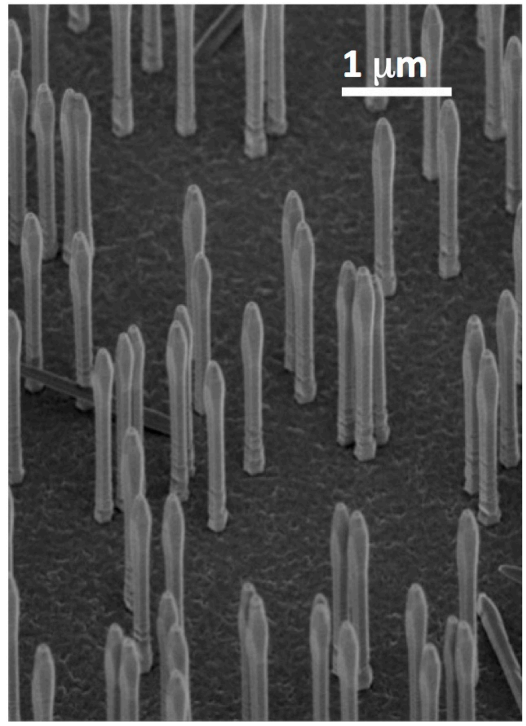

Figure 2. An SEM image shows the tapered morphology of $Ge/Ge_{1-x}Sn_x$ core-shell nanowires grown using Au catalysts.

Figure 3. STEM images of the core-shell NWs show planar defects in the bottom half of the NWs.

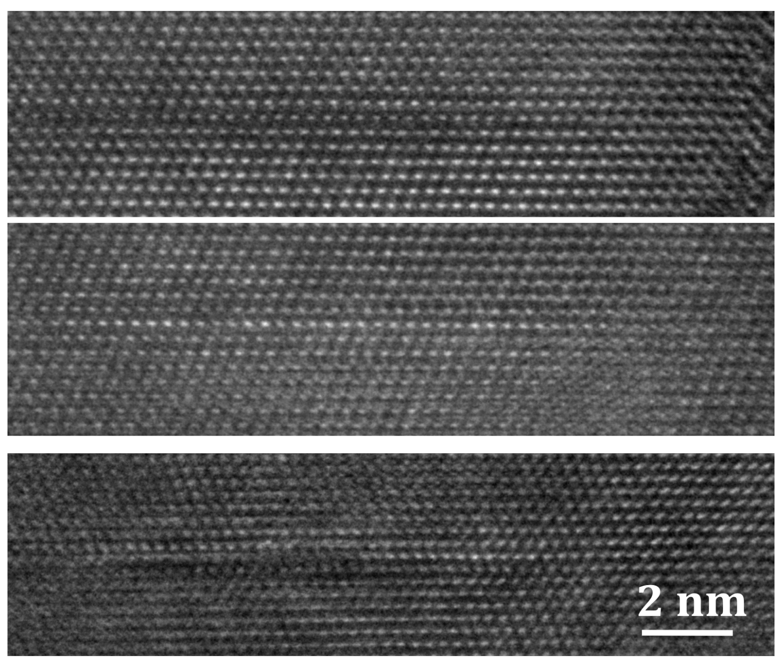

Figure 4. High resolution images of the planar defects show that the contrast may result from a single plane and that they are not stacking fault defects.

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