Synthesis of Silicon and Germanium Nanowires

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Abstract:

Crystalline silicon (Si) and germanium (Ge) nanowires were grown in toluene heated and pressurized above its critical point. Colloidal gold nanocrystals were used to seed nanowire growth by the supercritical fluid-liquid-solid (SFLS) mechanism with monophenylsilane (MPS) and diphenylgermane (DPG) as reactants. Using a growth temperature of 490°C, the simultaneous addition of MPS and DPG to the reactor led to the formation of distinct Si and Ge nanowires, as opposed to a $Si_{(1-x)}Ge_x$ alloy. The nanowire product was characterized using a range of methods, including x-ray diffraction (XRD), transmission electron microscopy (TEM), scanning electron microscopy (SEM) and nanobeam energy dispersive spectroscopy (EDS) mapping. The optical properties of the nanowires, including the reflectivity and absorptance, were also measured using an integrating sphere.

Experimental Procedure:

The SFLS synthesis procedures for silicon (Si) and germanium (Ge) nanowire growth are very similar. In an attempt to synthesize $Si_{1-x}Ge_x$ alloy nanowires, the reaction was run with the simultaneous thermal decomposition of monophenylsilane (MPS) and diphenylgermane (DPG) precursors. Colloidal Au nanocrystals were used to seed nanowire growth. In an example synthesis, a solution composed of Au nanocrystals and silicon and germanium precursors is injected into pressurized toluene at 490°C and 10 MPa at a flow rate of 0.5 mL/min for 40 min. For the example shown here, the atomic ratio of silicon to germanium precursor was adjusted to 3:1. After synthesis, the nanowires were characterized using XRD, SEM, and TEM.

In addition, we fabricated composite Si/Ge nanowire fabric by combining separate batches of Si and Ge nanowires and measured their optical properties using an integrating sphere. The fabric was made by mixing Si nanowires (75 vol%) with Ge nanowires (25 vol%), drop casting the mixture onto a Teflon® substrate, and removing the resulting film. We then measured the optical absorptance and reflectance of the material.

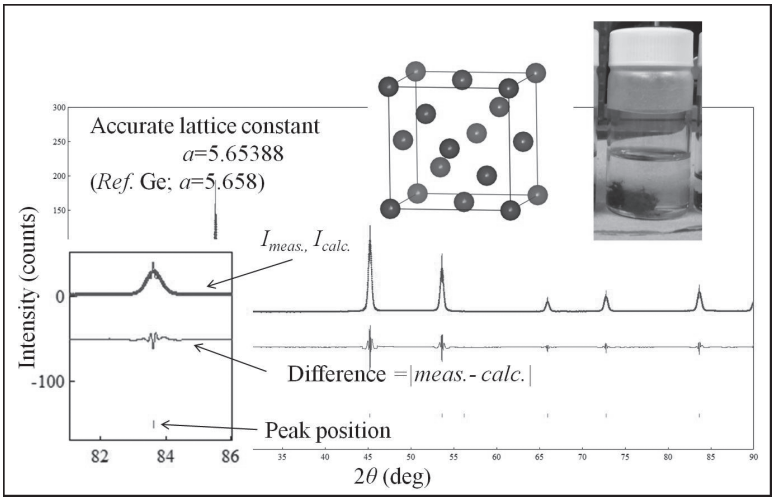

Figure 1: Reitveld analysis of XRD pattern for 25% Ge injection sample.

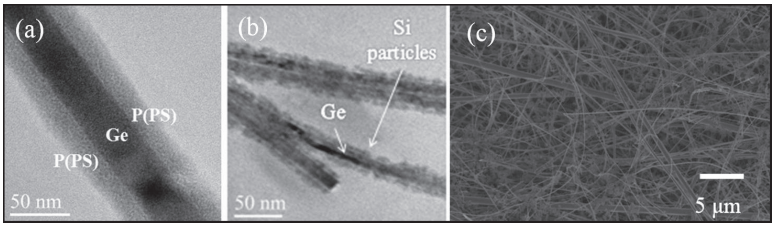

Figure 2: (a) TEM images of Ge nanowires coated with poly(phenylsilane); (b) with Si nanoparticles; and (c) an SEM image of the nanowires.

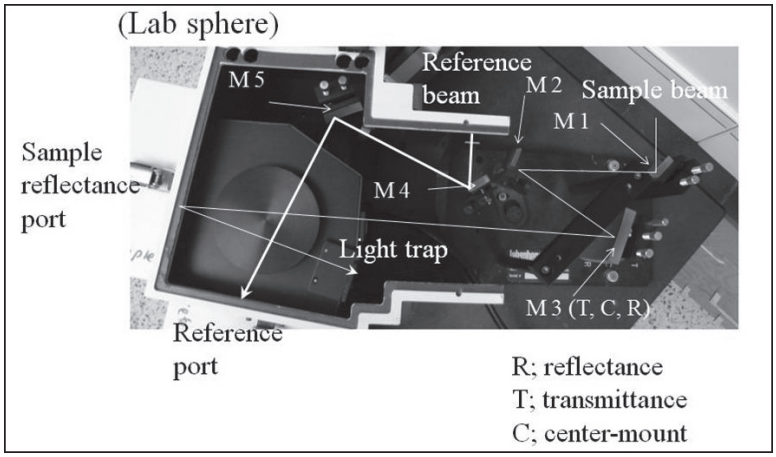

Figure 3: Equipment for measuring optical properties.

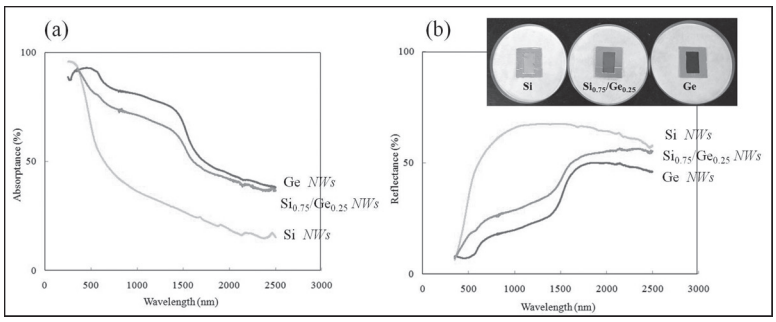

Figure 4: Absorptance and reflectance of composite Si/Ge nanowire fabric

Results and Conclusions:

Figure 1 displays the XRD pattern of the 25% Ge injection sample. By analyzing this XRD pattern, the lattice constant was determined, consistent with that of a pure Ge single crystal. Also, Figure 2 shows SEM and TEM images of the injection sample. According to the SEM image, the maximum diameter of crystalline Si and Ge nanowires was around 1 μm. Furthermore, in the TEM image, we can see a Ge nanowire coated with a poly(phenylsilane) shell and Si nanoparticles, as opposed to a $Si_{(1-x)}Ge_x$ alloy. These compounds were confirmed by FTIR and EDS spectra.

For the optical properties of the composite Si/Ge nanowire fabric, we used a UV-Vis-NIR spectrophotometer in conjunction with an integrating sphere (see Figure 3). We measured absorptance and reflectance of the material as a function of wavelength as seen in Figure 4. First, compared with pure Si and Ge nanowire fabric, the color of the composite sample is quite different. The absorption increases sharply above the optical gap for Si (1.1 eV) and Ge (0.7 eV), respectively. In addition, peaks in the Si spectrum from 2000 nm to 2500 nm are due to absorption of the poly(phenylsilane) shell, and the peak at 600 nm in the Ge spectrum is related to light trapping.

However, for both of spectra, we can say that only a small (25 vol%) addition of Ge nanowires to Si nanowire fabric results in optical properties very similar to pure Ge nanowire fabric.

Future Work:

Synthesis of the $Si_{(1-x)}Ge_x$ alloy nanowire requires further investigation of optical properties for composite Si/Ge nanowire fabrics.

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