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# Synthesis of Uniformly Doped Ge Nanowires with Carbon Sheath

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While there are plenty of studies on synthesizing semiconducting germanium nanowires (Ge NWs) by vapor-liquid-solid (VLS) process, it is difficult to inject dopants into them with uniform dopants distribution due to vapor-solid (VS) deposition. In particular, as precursors and dopants such as germane ($GeH_4$), phosphine ($PH_3$) or diborane ($B_2H_6$) incorporate through sidewall of nanowire, it is hard to obtain the structural and electrical uniformity of Ge NWs. Moreover, the drastic tapered structure of Ge NWs is observed when it is synthesized at high temperature over 400°C because of excessive VS deposition. In 2006, Emanuel Tutuc et al. demonstrated Ge NW pn junction using p-type shell as depleted layer. However, it could not be prevented from undesirable VS deposition and it still kept the tapered structures of Ge NWs as a result. Herein, we adopt $C_2H_2$ gas in order to passivate Ge NWs with carbon sheath, which makes the entire Ge NWs uniform at even higher temperature over 450°C. We can also synthesize non-tapered and uniformly doped Ge NWs, restricting incorporation of excess germanium on the surface. The Ge NWs with carbon sheath are grown via VLS process on a $Si/SiO_2$ substrate coated 2 nm Au film. Thin Au film is thermally evaporated on a $Si/SiO_2$ substrate. The NW is grown flowing $GeH_4$, HCl, $C_2H_2$ and $PH_3$ for n-type, $B_2H_6$ for p-type at a total pressure of 15 Torr and temperatures of 480～500°C. Scanning electron microscopy (SEM) reveals clear surface of the Ge NWs synthesized at 500°C. Raman spectroscopy peaked at about ～300 $cm^{-1}$ indicates it is comprised of single crystalline germanium in the core of Ge NWs and it is proved to be covered by thin amorphous carbon by two peaks of 1330 $cm^{-1}$ (D-band) and 1590 $cm^{-1}$ (G-band). Furthermore, the electrical performances of Ge NWs doped with boron and phosphorus are measured by field effect transistor (FET) and they shows typical curves of p-type and n-type FET. It is expected to have general potentials for development of logic devices and solar cells using p-type and n-type Ge NWs with carbon sheath.

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