Sulfur-assisted growth of silicon nanowires using the VLS Method

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Semiconductor nanowires have attracted a lot of attention as promising material candidates in areas such as photonics, electronics, and life sciences. Much effort has been devoted to developing one-dimensional (1D) materials, as seen from a surge in the number of relevant publications. Silicon nanowires are one of the most important 1D nanomaterials and have recently attracted considerable attention. The vapor–liquid–solid (VLS) method using gold (Au) as a catalyst is one of the most prevalent approaches used for Si nanowire synthesis [1]. Recently, Si nano-needles grown by the VLS method using metal-sulfur catalysts have been reported [2]. Using new catalytic materials provides the VLS method new opportunities for fabricating high quality, well-ordered Si nanowires. In this paper, we report the sulfur-assisted growth of Si nanowires by simple thermal treatment. Silicon nanowires have been successfully synthesized by simple thermal treatment without any metal catalyst. For cases without metal catalysts, Si nanowires are grown by VLS processes assisted by sulfur.

Si nanowires were synthesized by sulfur-assisted thermal chemical vapor transport. Sulfur powder (99.99%) and (111)-oriented Si substrate were sealed in a quartz capsule evacuated to a base pressure of 40 Pa. The quartz capsule was transferred into a horizontal furnace, annealed at about 1200 °C for 10 min and then quenched in water. For reference, we also prepared an Au-covered Si substrate. In this case, the Au layer of about 5 nm in thickness is deposited on Si substrates using vacuum thermal evaporation. The crystal structure of the Si nanowires was characterized by X-ray diffraction (XRD; RINT2500) under a 2θ-2θ scan using Cu-Kα radiation as an X-ray source. The surface morphology of the Si nanowires was analyzed by SEM (JSM-6300).

Figures 1 and 2 show typical SEM images of the as-prepared nanowires grown with and without a metal catalyst. We can clearly see well-aligned Si nanowire arrays that grow uniformly with no metal catalyst. The nanowires are straight, smooth, and relatively vertical to the Si substrate. The corresponding XRD patterns of the samples show that the fabricated nanowires can be indexed to a Si diamond structure with lattice constants of a = 5.43 Å. The relatively intense peak corresponding to the (111) crystal plane suggests that the Si nanowires are preferentially oriented in a <111> direction. The sulfur-assisted growth of the Si nanowires without a metal catalyst may be attributed to the silicon sulfide acting as the vapor-phase source and melted catalyst droplet for VLS growth. During thermal treatment at 1200 °C, the quartz capsule is filled with silicon sulfide vapor, which is the vapor-phase source for VLS growth. This is because the sublimation point of SiS is 940 °C and the boiling point of SiS₂ is between 1100–1200 °C. Silicon sulfide also acts as melted catalyst droplets that form on the surface of the substrate during the cooling process as the melting point of SiS₂ is 1090 °C.

Figure 1 SEM images of Si nanowires grown by simple thermal treatment using no metal catalyst.

Figure 2 SEM images of Si nanowires grown on a Au-covered Si substrate.