The impacts of silicon substrate surface conditions on the VLS growth of germanium nanowires

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One-dimensional semiconductor nanostructures have attracted much attention because of their potential applications in the design of novel electronic, photonic, and sensing devices. Due to its high mobility of electrons and holes, Ge nanowires show its potential application in high-speed field-effect transistor. Moreover, Ge nanowires are potentially useful for high-speed quantum computing because of long decoherence time due to their predominance of spin-zero nuclei and the advantage of a large excitonic Bohr radius in Ge (24.3 nm) allowing for quantum confinement to be observed in relatively large structures and at high temperatures.

In these applications, high quality materials are needed, and the past studies have focused on the growth of Ge nanowires. However, only few papers reported on the impacts of the surface conditions on the VLS (vapor-liquid-solid) synthesis of Ge nanowires, and we will discuss them in detail in this paper.

A 0.5-nm-thick Au catalyst layer was evaporated by electron beam evaporation at room temperature on two kinds of substrate, SiO_2-terminated and H-terminated silicon substrates. Depending on the substrate surface conditions, the evaporated Au shows different topography. On the SiO_2-terminated substrate, because the condensing Au adatoms are more strongly bound to each other than to the substrate, these atoms encounter other atoms, nucleate and agglomerate to form stable high-density islands with the diameter of 3~8nm. On the other hand, the Au catalyst prefers to form a wetting layer on the H-terminated substrate.

The Ge nanowires were grown by using a low pressure CVD method with 10% GeH_4 precursors (in an atmosphere of hydrogen) with the total pressure of 5 Torr. On the SiO_2-terminated Si substrate, without high-temperature pre-annealing, high-density Ge nanowires with a diameter of 5~20nm were grown at 300 ^oC. The diameter of nanowires was consistent with the size of Au catalysts. The growth speed of nanowires was around 50 nm/min. The high-resolution TEM images reveal the high-quality single-crystalline Ge nanowires with a lattice constant of 0.565 nm. The nanowires could be grown in both (110) and (111) directions. X-ray diffraction results indicate that the crystal structure of grown Ge nanowires is cubic diamond, and the Au dots on the tip of wires is in the fcc structure, which was also proved by TEM results. It was also found that, with increasing the growth temperature, the nonspecific decomposition of GeH_4 on the nanowire surface was enhanced and the axial growth speed was reduced. As a result, the grown nanowires tend to be shorter and thicker and their surfaces are rough.

In contrast, only very few nanowires were grown on the H-terminated Si substrate under the same growth conditions. After 10 minutes pre-annealing at 450 ^oC in 5% H_2 and 95% N_2 atmosphere, the density of Ge nanowires grown at 300 ^oC increased a few times, but it was still much lower than the density of Ge nanowires grown on the SiO_2-terminated substrate. The SEM images showed that the Au wetting layer was only partially dewetted even after high-temperature pre-annealing. The remaining wetting layer presumably prevents the formation of the nucleation centers and reduces the possibility of axial growth. The GeH_4 will get more chance to be decomposed and deposited to form a film since the AuSi eutectic alloy exits on the whole surface. Further investigations are still in progress to clarify this issue.