VLS growth of germanium nanowires on SiO_2-terminanted Si (111) substrate

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1 Introduction

One-dimensional semiconductor nanostructures have attracted much attention because of their potential applications in the design of novel electronic, photonic, and sensing devices [1]. Due to its high mobility of electrons and holes, Ge nanowires show its potential application in high-speed field-effect transistor [2,3]. Moreover, Ge nanowires are potentially useful for high-speed quantum computing because of long decoherence time due to their predominance of spin-zero nuclei [4,5] 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 [6] and at high temperatures. To realize these applications, high quality materials are need. And in this paper, we will discuss in detail about the growth of high quality Ge nanowire on SiO_2 substrate.

2 Experimental and discussions

N-type silicon (111) wafers with a resistivity of 0.02 Ω cm were used as substrates. The wafers were cleaned utilizing the RCA standard cleaning procedure before thermal oxidization at 1100 ^{o}C for 2 hours. The oxidized wafers were then loaded into an electron-beam metal evaporation system with a basic pressure of $2*10^{-5}$ Pa and a 0.5-nm-thick Au catalyst layer was evaporated at room temperature. 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.

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. At low GeH_4 partial pressure (0.2sccm GeH_4 and 5sccm H_2), the growth speed of Ge nanowires is low. Some Ge nanorods as shown in Fig1 were grown at 300 ^{o}C for 20 minutes. The diameter of nanorods was consistent with the size of Au catalysts. By increasing GeH_4 partial pressure (10% GeH_4), high density Ge nanowires with diameter of 5~20 nm and length of 1000nm can be gotten (Fig2). The growth speed of nanowires was around 50 nm/min. High-resolution TEM images (Fig.3) reveal the high-quality single-crystalline Ge nanowires with a lattice constant of 0.565 nm. X-ray diffraction results also indicate that the crystal structure of grown Ge nanowires is cubic diamond according to the six typical peaks labeled in Fig.4. According to high-resolution TEM images, we can find that Ge nanowires could be grown in both (110) and (111) directions (Fig3C and Fig.3D).

Fig.3B shows TEM results of Au catalysts on the tip of Ge nanowires. Obviously, it has a single crystalline structure, which was also proved by XRD results (Fig.4). Two peaks originated from the face-centred cubic (FCC) structure of Au can be found. In the case of growth temperature at 350 ^{o}C, it is much clearer and 4 peaks related to Au FCC structure were detected.

By increasing the growth time to 60 min, 3um-long Ge nanowire can be gotten as shown in Fig.5. And maybe due to the nonspecific decomposition of GeH_4 on the nanowire surface, the thicker nanowires with the diameter of 50nm on the bottom were grown.

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 (Fig.6).

3 Conclusion

High-density Ge nanowires with a diameter of 3~20 nm were grown on SiO_2-terminated Si substrate at 300 ^{o}C. TEM and XRD results indicate that Ge nanowires are single crystalline with a lattice constant of 0.565 nm. Ge nanowires could be grown in both (110) and (111) directions. Due to the enhancement of nonspecific decomposition of GeH_4, the thick nanowires with a rough surface were grown at 350 ^{o}C.

References

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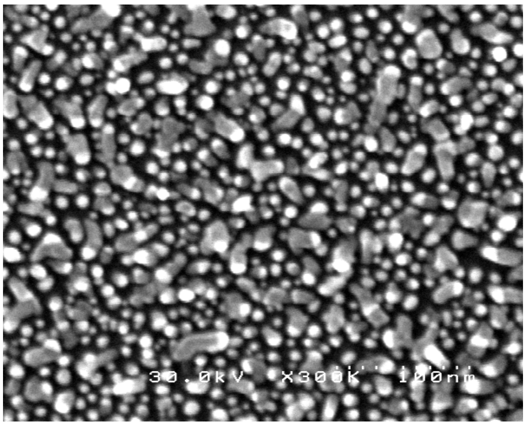

Fig 1 SEM image of Ge nanorods grown at 300 °C and low GeH_4 partiall pressure

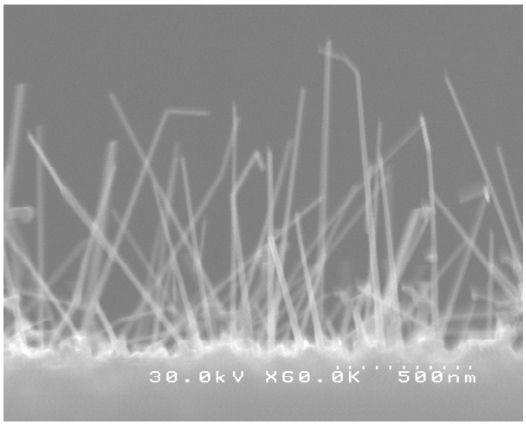

Fig 2 SEM image of Ge nanowires grown at 300 °C and high GeH_4 partial pressure (10%)

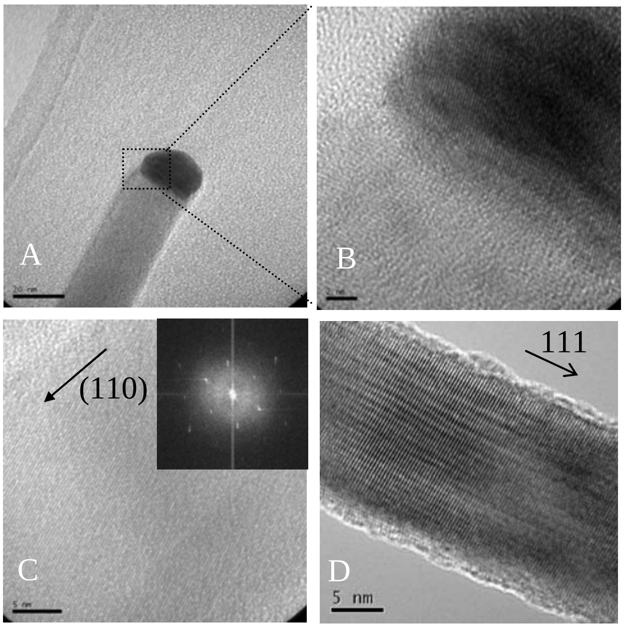

Fig 3 A, TEM image of Ge nanowire. Black part on the tip of nanowire is Au catalyst; B, HRTEM image of Au catalyst on tip of Ge nanowire; C and D, High-resolution TEM images of Ge nanowires grown along (110) and (111) direction respectively.

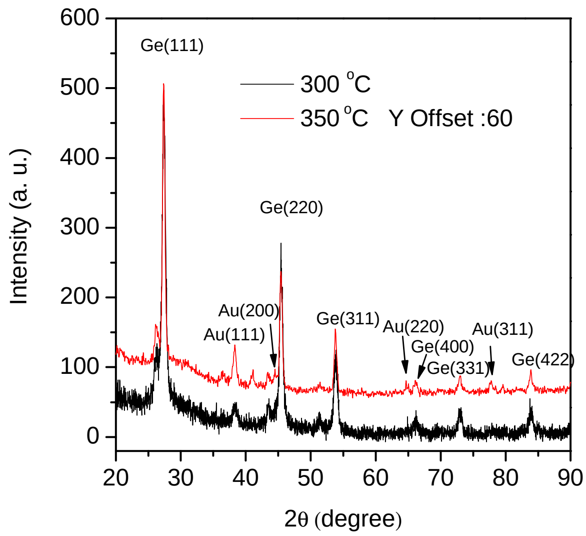

Fig 4 XRD spectrum of Ge nanowires grown at 300 °C (black line) and 350 °C (red line)

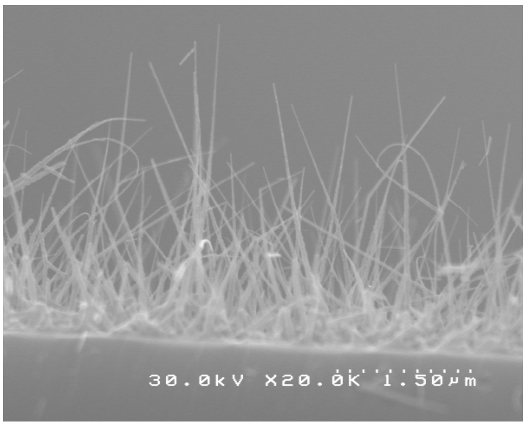

Fig 5 SEM image of Ge nanowires grown at 300 °C and high GeH_4 partial pressure (10%) for 60minutes.

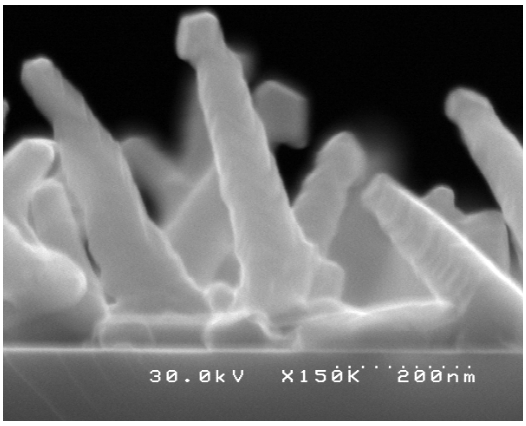

Fig 6 the SEM image of Ge nanowires grown at 350 °C. Other growth conditions are same as that of Fig.2