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SYNTHESIS AND ANALYSIS OF SILICON NANOWIRES GROWN ON Si (111) SUBSTRATE AT DIFFERENT SILANE GAS FLOW RATE

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ABSTRACT

Silicon nanowires were grown on Si (111) substrates by very high frequency plasma enhanced chemical vapor deposition (VHF-PECVD). The nanowires were grouted at 450 °C and 21 watt RF power. Pure silane (99.9995%) and gold colloid were used as precursor and catalyst respectively for growth of wires. The nanowires were investigated using scanning electron microscopy (SEM). Their crystallity and compositions were studied using X-ray diffraction method and energy dispersive X-ray (EDX) spectroscopy. The growth of Si nanowires is controlled by conventional vapor-liquid-solid (VLS) mechanism. The results showed that there were gold particle on the top of wires. The silane flow rates does effect the quantity of Si nanowire. The Si nanowires length changes from 350 nm to 5.5 μm for Si flow rate of 5 to 20 sccm, respectively. XRD and EDX results revealed that the nanowires composed of mainly Si with small percent of Au and oxygen.

Keywords: silicon nanowire; PECVD

INTRODUCTION

One-dimensional nanomaterials, such as nanotubes, nanowires and nanobelts, have generated a lot of scientific interest for understand their novel physical properties and developing nanoscale electronic and optoelectronic devices [1-3]. Naturally, silicon nanowires (SiNWs) as one of the candidates of this group are particularly attractive materials [4-7]. In fact, their physical, optical, and chemical properties are differt from their bulk counterparts.

SiNWs can be synthesized by various techniques, such as molecular beam epitaxy (MBE), laser ablation, low-temperature chemical vapor deposition (CVD) methods; plasma enhanced chemical vapor deposition (PECVD) [8-12]. Among them, the PECVD process is a familiar technique to grow Si nanowires at low temperatures with excellent quality and high purity. It should be mentioned that the silane (SiH_4) flow rate is an important factor for more reliable growing the Si nanostructures during the PECVD process.

In this work, we reported the synthesis of SiNWs on silicon wafers by means of very high frequency plasma enhanced chemical vapor deposition (VHF-PECVD) with gold colloid catalyst. The source of SiNWs came from pure silane gas. The effect of silane gas flow rate on structural properties of Si nanowire grown on Si substrate has been investigated. The SiNWs were measured by scanning electron microscopy (SEM). Furthermore, the crystallity and compositions are studied using energy dispersive X-ray (EDX) spectroscopy and X-ray diffraction spectra. Finally, Raman spectroscopy was also used to more investigate the SiNWs.

EXPERIMENTAL DETAILS

The silicon nanowires were grown by very high frequency plasma enhanced chemical vapor deposition in a VHF-PECVD reactor using vapour-liquid-solid mechanism. Initially, n-type Si (111) was cleaned with mixture of HCl, DI water and H_2O_2. The Si wafer was then cleaned to remove the native oxide and coated with gold colloid at room temperature. The Si-coated samples were loaded in the VHF-PECVD reactor under vacuum conditions. After that pure SiH_4 (99.9995%) gas was introduced with flow rate between 5 and 20 standard cubic centimeter per minute (sccm) at 450 °C temperature and 21 watt RF power to synthesis of nanowires. Finally, the samples were cleaved for measurement.

The morphology of SiNWs on the Si substrate was directly observed on a scanning electron microscope (SEM, JEOL, JSM-6701F). The elemental composition of the nanowires was analyzed through energy dispersive X-ray spectrometer (EDX). Their crystal phase pattern and characteristics of the synthesized SiNWs were analyzed by using an X-ray diffraction (XRD), with Cu Kα radiation. Moreover, to examine the as-synthesized SiNWs in more detail, Raman spectroscopy measurement were performed room temperature.

RESULTS AND DISCUSSION

Figures 1(a-d) show an SEM image of the SiNWs grown on Si (111) substrate, which deposited with gold colloid as catalyst by using VHF-PECVD method. The figure shows that large amounts of nanowires are formed, where most of wires produced are the long, tapered with a length up to 5 μm. Tapering can be attributed to the uncatalyzed deposition of Si on the sides of wires during growth. All of the nanowires are terminated by the Au nanoparticles with the diameter about 30 nm at their tips. The morphology of the nanowire is determined by the original size of the Au nanoparticles and growth condition as gas flow rate, temperature and etc. These nanowires were grown at constant temperature 450 °C and with different saline gas flow rates 5-20 sccm. It is clearly seen that the silane flow rate plays an important role in the morphologies of silicon nanowires.

Figure 1 reveals that the length of wires grown at 5 sccm to 20 sccm increases. The Si nanowires grown at 5 sccm also have thinner diameter with respect to nanowires grown

with other conditions.

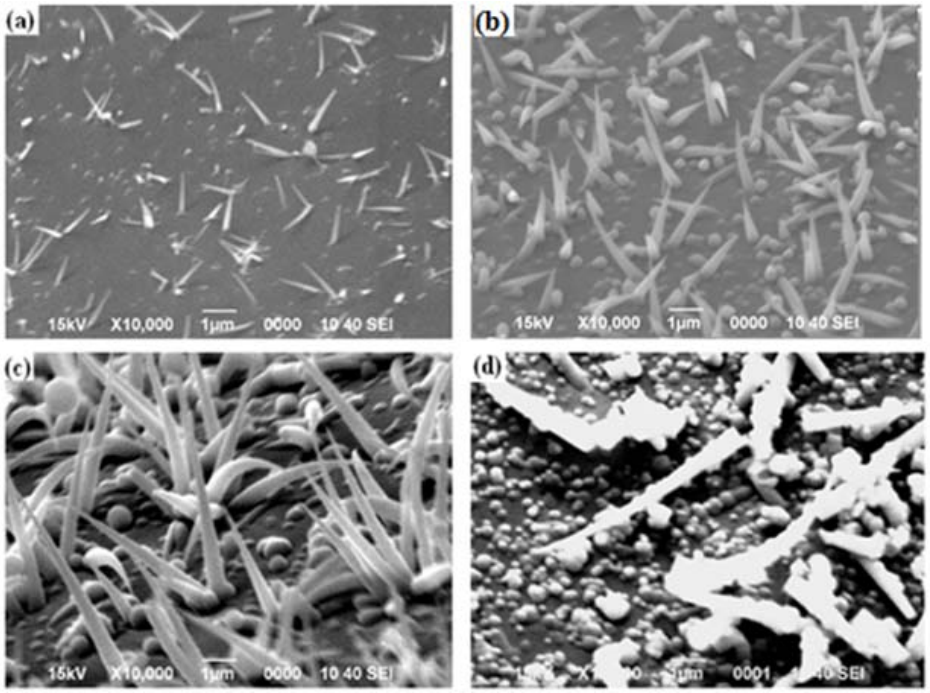

Figure 1: SEM images of silicon nanowires grown at 450 °C and various silane gas flow rate; a) 5 sccm b) 10 sccm c) 15 sccm d) 20 sccm

Figure 2 shows the EDX spectrum of silicon nanowires grown at 20 sccm. The EDX taken from nanowires indicates the presence of Si, O and Au. The Au nanoparticle located on top of the synthesized SiNW. This suggests that an Au catalyst-assisted VLS mechanism is happened in the growth of SiNWs. The EDX data show that more than 75% of material in wires includes silicon and amount of oxygen is about 10%. Also Au nanoparticles make less than 1.5% of wires. As seen in the figure there are a small amount of carbon, oxygen, and platinum in spectra. The detected Pt in the spectra is the effect of the coating of samples for preparation measurement EDX. Almost 13.5% of materials in samples are including C and Pt that is not parts of the wires. According to EDX result we found that SiNWs are made from Si and oxygen where Si placed in core of wires and their sheathed outer layer is oxygen layer.

The XRD measurement of the samples was done, to expound the composition of the nanowires. The crystal structure was investigated using and X-ray diffraction (XRD). Figure 3 shows the XRD spectrum of the SiNWs grown on the Si substrate with various silane gas flow rate, which displays peaks of the Si (1 1 1), (2 2 0), (3 1 1), Au, and SiO_2, indicating that the SiNWs were the well crystalline structure [13]. The XRD results reveal that the array of SiNWs is polycrystalline structure. According to spectrum in figure the Si (111) peak has high intensity. The lattice parameter of the SiNWs calculated from the interplanar spacing of the most intense (1 1 1) peak with d =

0.3147 nm is aSiNWs = 0.5412 nm, which is smaller than the standard value aSi= 0.5430 nm for bulk silicon. It can be understood that results obtained by the XRD pattern indicate different orientations. Also the XRD pattern confirmed EDX result.

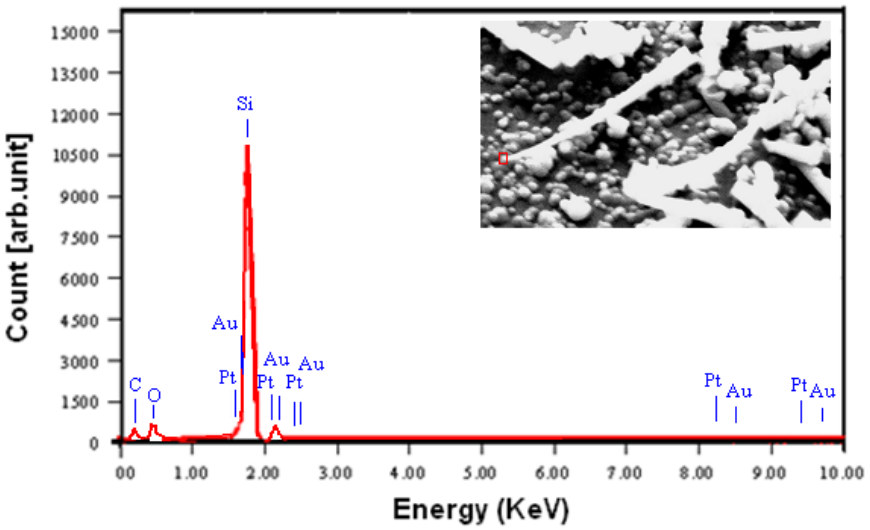

Figure 2: The EDX spectrum of a silicon nanowire grown at 450 °C and 20 sccm

The spectra are taken from tip of nanowire. The result shows that the SiNWs was composed of silicon and a small quantity of Au and oxygen. Au peak is for gold catalyst. C and Pt peaks originated from carbon tape and coating for EDX analysis.

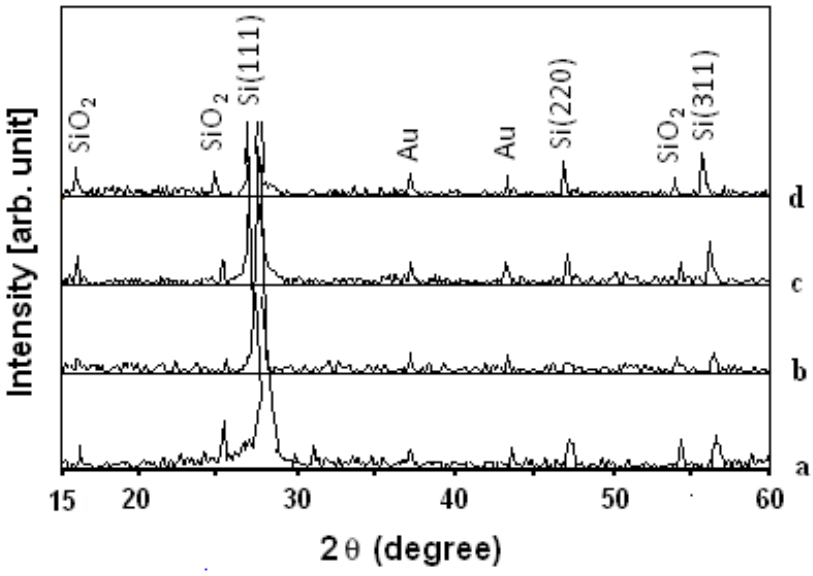

Figure 3: XRD patterns of the SiNWs on Si (111) substrate at various silane gas flow rate: (a) 5 sccm, (b) 10 sccm, (c) 15 sccm, and (d) 20 sccm

Figure 4 shows Raman spectra of the SiNWs fabricated at 5, 10, 15, and 20 sccm by using PECVD. It also shows Raman spectra of Si substrate and the SiNWs fabricated at 5, 10, 15, and 20 sccm, which reveals that there are five peaks at 522, 519.43, 518.11, 517, 516.23 cm^{-1} concern to Si, d, c, b and a, respectively. Usually, these peaks are regarded to be the first-order transverse optical phonon mode (TO) [14]. The spectra reveal that the peaks with different intensity are good symmetric. It is obviously the Raman spectrum that is similar to that of the SiNWs synthesis by other researchers [15, 16].

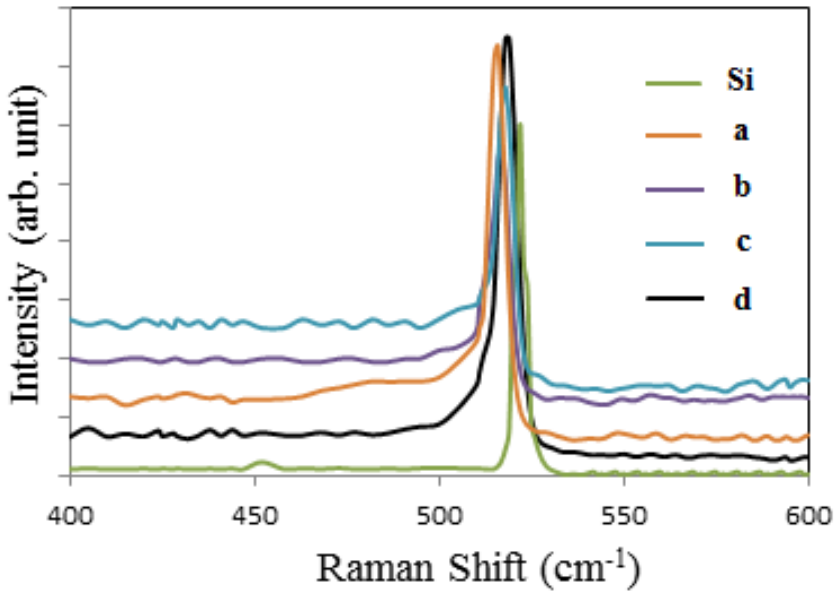

Figure 4: Raman spectra of the SiNWs fabricated using PECVD at various Silane flow rate; a) 5 sccm b) 10 sccm c) 15 sccm d) 20 sccm

CONCLUSION

In summary, we successfully synthesized the SiNWs by gold colloid as catalyst with the growth direction (111), (220), and (311) via VHF-PECVD method and VLS mechanism, respectively. In this experimental work the effect of silane gas flow rate was investigated, where this parameter plays important role on the growth of SiNWs. The SEM images show the crystalline SiNWs with average diameter of about 80-300 nm and length of about 5 micrometers. SiNWs grown in this work are polycrystalline.

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