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Effect of Plasma Power and Flow Rate of Silane Gas on Diameter of Silicon Nanowires Grown by Plasma Enhanced Chemical Vapor Deposition

(Kesan Kuasa Plasma dan Kadar Aliran Gas Silan Terhadap Diameter Dawai Nano Silikon yang Ditumbuhkan Melalui Deposisi Wap Kimia Berbantuan Plasma)

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ABSTRACT

Silicon nanowires (SiNWs) have been synthesized by plasma enhanced chemical vapor deposition (PECVD) at different power for generation of plasma and different flow rate of silane gas. Silane (10% SiH₄ in Ar) gas with flow rate ranging between 6-15 standard cubic centimeter per minute (sccm) were employed as the source and gold colloid as the catalyst. A p-type Si (100) wafer was used as substrate in this experiment and the substrate's temperature was 370°C. The plasma power range was 12-17 watts. The grown silicon nanowires were analyzed using field emission scanning electron microscopy (FESEM) and energy dispersive X-ray spectroscopy (EDX). FESEM results show that some silicon nanowires are cone like and some of them are cylindrical. The EDX result revealed that the existence of silicon and oxygen elements in the nanowires. The silicon nanowires obtained have different diameters and lengths and the SiNWs consist of silicon core which are surrounded by oxide sheath. It has been found that the plasma power and flow rate of the silane gas influence the size of silicon nanowires growth by PECVD. The diameter of wires decreased from 140 nm to 80 nm averagely when plasma power was increased from 12 to 17 watts. The diameter also increased about 90 nm to 150 nm when the flow rate of silane gas is increased from 6 to 15 sccm.

Keywords: Gold catalyst; PECVD; silicon nanowire

ABSTRAK

Dawai nano silikon (SiNW) telah dihasilkan secara pemendapan wap kimia peneguh plasma (PECVD) dengan kuasa penjanaan plasma dan kadar aliran gas silan yang berbeza. Gas silan (10% SiH₄ dalam Ar) dengan kadar aliran daripada 6 -15 centimeter isipadu piawai seminit (sccm) digunakan sebagai sumber dan koloid emas sebagai pemangkin. Wafer Si (100) jenis-p digunakan sebagai substrat dalam uji kaji ini dengan suhu substrat 370°C. Kuasa plasma adalah dalam julat 12-17 watt. Dawai nano silikon yang ditumbuhkan dianalisis dengan menggunakan Mikroskop Pengimbas Elektron Emisi Medan (FESEM) dan spektroskopi sinar-X penyebar tenaga (EDX). Hasil FESEM menunjukkan sebahagian dawai nano silikon berbentuk kon dan sebahagian berbentuk silinder. Hasil EDX pula menunjukkan kewujudan unsur silikon dan oksigen di dalam dawai. Dawai nano silikon yang dihasilkan mempunyai diameter dan panjang yang berlainan dan SiNW terdiri dari teras silikon yang dikelilingi oleh lapisan oksida. Didapati saiz SiNWs dipengaruhi oleh kuasa plasma dan kadar aliran gas silan. Diameter purata dawai berkurang daripada 140 nm ke 80 nm apabila kuasa plasma bertambah daripada 12 ke 17 watt. Diameter dawai juga bertambah daripada 90 nm ke 150 nm apabila kadar aliran gas silan bertambah daripada 6 ke 15 sccm.

Kata kunci: Dawai nano silikon; emas pemangkin; PECVD

INTRODUCTION

Recently, silicon nanowires have been widely studied due to their novel physical properties and diversity for potential electronic and photonic device applications (Huang et al. 2005; Xiang et al. 2006).

Various techniques have been employed to grow silicon nanowires, such as excimer laser ablation (Morales & Lieber 1998), chemical vapor deposition (CVD) (Chung et al. 2000) and other methods (Wang et al. 1999, Yan et al. 2000; Li et al. 2002). Among these growth methods, plasma enhanced chemical vapor deposition (PECVD) has some potential advantages, such as low operation

temperature, lower chances of cracking deposited layer, good dielectric properties of deposited layer. PECVD involves the Vapour-Liquid-Solid (VLS) mechanism as first proposed by Wagner and Ellis (Wagner & Ellis 1964).

In this study, silicon nanowires (SiNWs) have been synthesized by plasma enhanced chemical vapor deposition (PECVD) at different power for generation of plasma and different flow rate of silane gas. The Si nanowires were characterized by using field emission scanning electron microscope (FESEM) and energy dispersive X-ray spectroscopy (EDX).

EXPERIMENT

SiNWs were grown on Si (100) substrate at temperatures 370°C by very high frequency plasma enhanced chemical vapor deposition (VHF-PECVD) using vapour-liquid-solid mechanism. Small pieces of p-type Si (100) wafer was used as substrate in this experiment and the substrate's temperature was 370°C. Au was used as the catalyst, diluted silane (10% SiH₄ per Ar) as the Si source.

Samples were loaded in the PECVD reactor under vacuum conditions. After that diluted SiH₄ was introduced to chamber. The plasma power range and flow rate silane gas was employed between 12-17 watts and 6-15 sccm, respectively.

SiNWs were observed by field emission scanning electron microscopy (FESEM). The energy dispersive X-ray spectroscopy (EDX) revealed the existence of elements in the nanowires.

RESULTS AND DISCUSSION

In order to study the effect of plasma power and gas flow rate on growth of the SiNWS, we prepared the Au catalyst of silicon nanowires by PECVD using of VLS mechanism on Si (100) substrate. An FESEM image of the SiNWs is displayed in Figure 1. According to the image, most wires produced in this way are long and tapered with a smaller diameter at the tip than at the bottom, needle-like structures. The nanowires originate from Au-Si droplets, and the size of wires depends to this droplet and other parameter such as plasma power and gas flow rate. The formation of Au-Si alloy is a necessary process for the growth of SiNWS. Tapering can be attributed to the uncatalyzed deposition of Si on the sides of wires during growth.

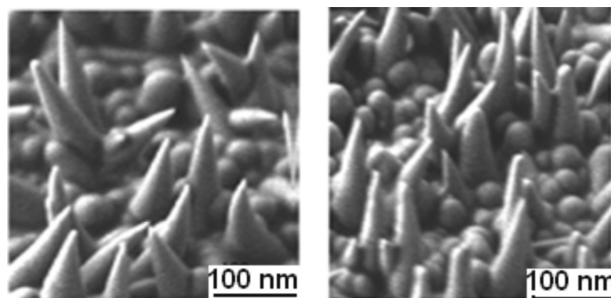


FIGURE 1. FESEM image of the SiNWs on a silicon wafer

Table 1 shows the variation in diameter of silicon nanowires with plasma power and silane gas flow rate. Samples were grown at the same temperature 370°C.

According to Table 1, on average the diameter of wires decreased from 140 nm to 80 nm when plasma power was increased from 12 to 17 watts. In order to use a higher plasma power for higher activation, the silane must be diluted with an etchant such as argon. Silicon nanowires grown with these conditions are shown in Figure 2.

Figure 3(a) shows the diameter of the Si nanowires according to the holding plasma power at 370°C with a SiH₄ flow rate of 14 sccm. The graph shows a decline in diameter of the nanowires when the plasma power was increased.

Figure 3(b) displays changes of diameter of nanowires as function of silane flow rate. The diameter also increased from about 90 nm to 150 nm when the flow rate of silane gas is increased from 6 to 15 sccm. Figure 4 shows silicon nanowires grown with these parameters.

The corresponding EDX data (Figure 5) indicates, a main silicon core and oxide sheath. The as-grown SiNWs

TABLE 1. Plasma power, silane flow rate and diameter of the SiNWs

Temperature(°C)	370	370	370	370	370	370	370	370
Plasma power(watts)	12	14	16	17	15	15	15	15
Silane flow rate(sccm)	14	14	14	14	6	9	12	15
Diameter(nm)	140	123	91	80	90	115	135	150

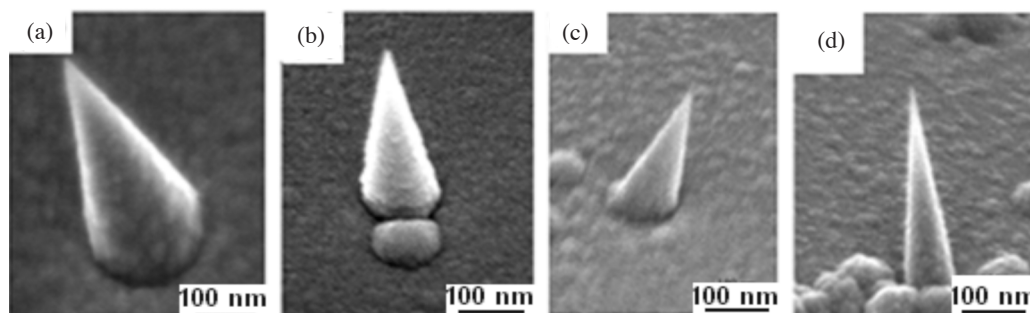


FIGURE 2. FESEM images of the SiNWs synthesized at 370°C and 14 sccm and plasma power at: (a) 12 watt (b)14 watt(c)16 watt and (d)17 watt, respectively

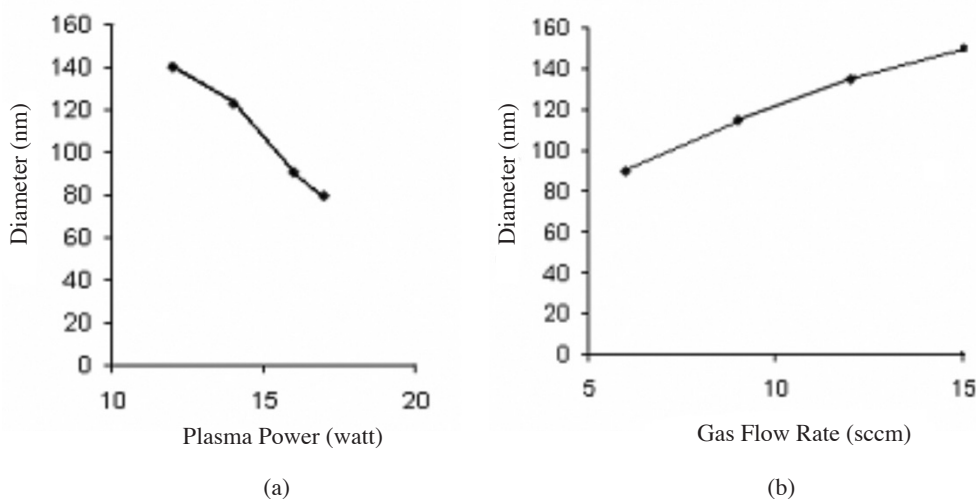


FIGURE 3. (a) Diameter as function of plasma power at 370°C and 14 sccm silane flow rate and (b) diameter as function of silane flow rate at 370°C and 15 watt plasma power

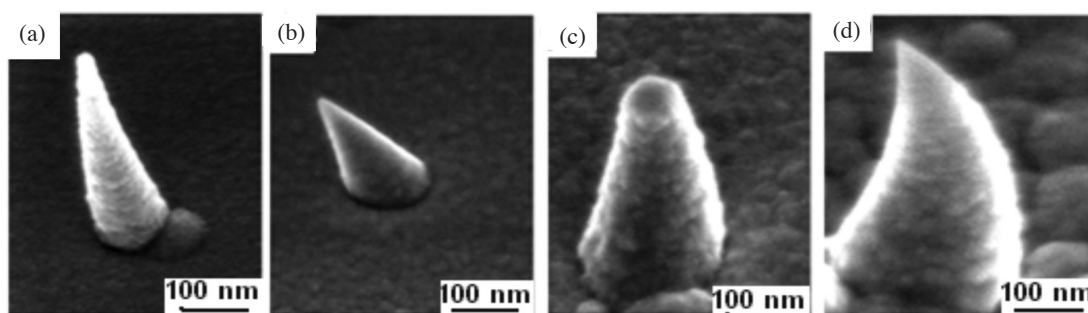


FIGURE 4. FESEM images of the SiNWs synthesized at 370°C and 15 watt and silane gas flow rate at; (a) 6 sccm (b) 9 sccm (c) 12 sccm and (d) 14 sccm, respectively

are mainly silicon with a small amount of oxygen and Au, as indicated by the strong Si peak and weak O and Au peaks in the EDX spectrum. Oxidation sheath on SiNWs was mainly caused by the reaction of the SiNWs and oxygen in the air when the samples are exposed to

atmosphere and was oxidized. The catalyst nanowire interface at the tip of an individual nanowire clearly shows that Au has operated as a VLS catalyst. The Au peak contains only at top of the nanowires as was reported by other researchers (Jeong et al. 2009).

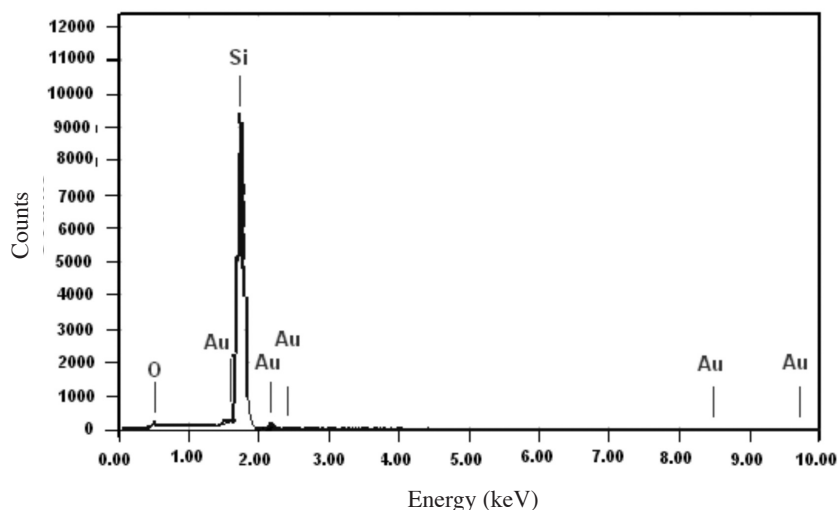


FIGURE 5. EDX spectrum for different positions of the Si nanowires

CONCLUSION

Silicon nanowires have been grown by plasma enhanced chemical vapor deposition at temperatures 370°C and different plasma power and various silane gas flow. The Si nanowires show an uncontaminated silicon core surrounded by oxide sheath. Plasma activation could allow a further decrease in deposition temperature to facilitate direct growth on low temperature substrates. Plasma power plays an important role to the growth of SiNWs. The diameter of wires decreases with the increase of plasma power because of the increased power of decomposition of silane gas.

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