Effect of whisker diameter on field emission properties of silicon carbide whiskers grown by chemical vapor deposition

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Due to its covalent bonding, silicon carbide (SiC) possesses a low density, a low thermal expansion coefficient, a high melting point, and high strength and hardness. Thus, it is now one of the most important structural ceramic materials [1]. It also has unique electronic properties, making it suitable as a semiconductor material that can be used at high power and high frequency in severe high temperature environments [2]. Also, owing to the excellent physicochemical properties of SiC micro- and nano-sized structures, many researchers have recently investigated the synthesis of various SiC nanomaterials such as nanorods, nanowhiskers, nanowires, and nanopowders [3]. Furthermore, the electron field emission properties of silicon carbide nanorods have also been reported in recent studies [4–6].

The applications of SiC whiskers are expanding due to their high aspect ratios and high theoretical strength [7]. SiC whiskers are grown using several techniques [5, 8, 9]. However, there were several problems because previous techniques used metallic catalysts. Therefore, we developed a non-metallic catalyst process and successfully grew silicon carbide whiskers. We investigated the coating microstructure and surface morphology by scanning electron microscopy (SEM, Hitachi S-2700/FESEM, Hitachi S-4200).

We also examined the field emission properties of the samples. The apparatus and the conditions for testing the electron field emission were same with those of previous work [10].

Details of the deposition system were described in a previous work [11]. We used MTS (methyltrichlorosilane; CH_3SiCl_3, Acros Organics Co., USA) for the source and high purity H_2 for the carrier and diluent gas. In order to reduce the diameter of whiskers, isotropic graphite carbonized at 1000 °C for 1 hr was used as a substrate.

Heating was performed under a H_2 atmosphere. When the deposition temperature was achieved, the flowing diluent and carrier gas resulted in deposition which was stabilized using the pressure of a bubbler. The input gas ratio, α (H_2/MTS), was 50, and deposition temperature was 1000 °C.

Fig. 1 shows an SEM images of the deposits at the stationary condition with pressure of 5 Torr, input gas ratio (α) of 50 and deposition temperature of 1000 °C. The mean whisker diameter of whiskers was 80 nm.

The field emission properties can be affected by the band gap, electron affinity [12], and microstructural morphology etc. [13]. Among these factors, the microstructural morphology is one of the most important factors for samples of the same materials. In particular the sharper the morphology of the emission tip, the better is the electron emission. In order to verify this phenomenon, we compare the result of this study with that of our previous work [10].

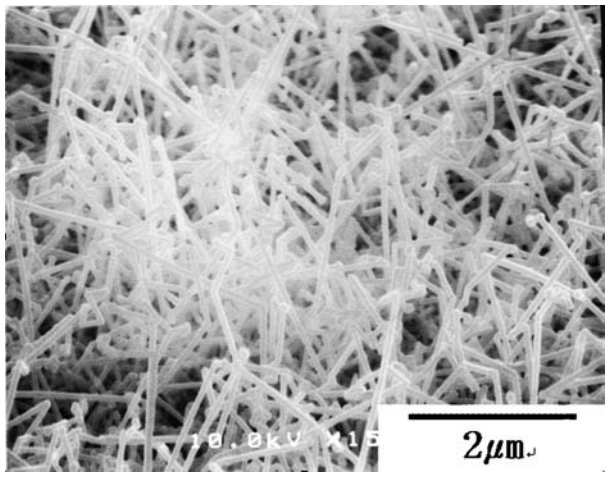

Figure 1 SEM images of whiskers which were obtained at input gas ratio (α) of 50 and 1000 °C.

Fig. 2 shows the result of I-V scanning of whiskers grown at pressure of 5 Torr, input gas ratio (α) of 50 and

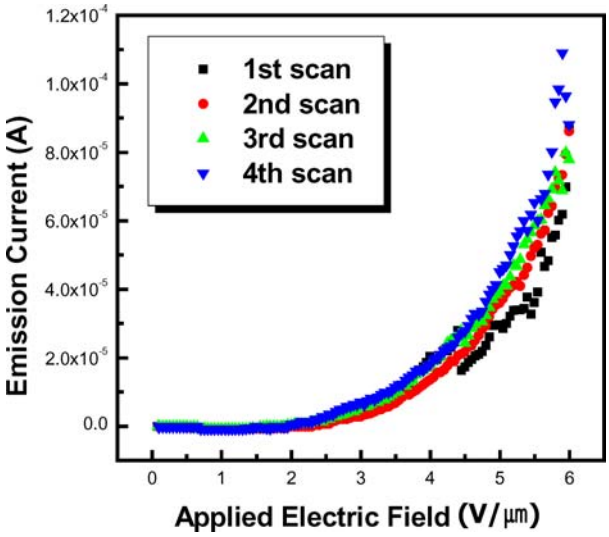

Figure 2 *I–V* characteristics of SiC whiskers which were grown at 1000 °C. ($P = 5$ Torr, $\alpha = 50$).

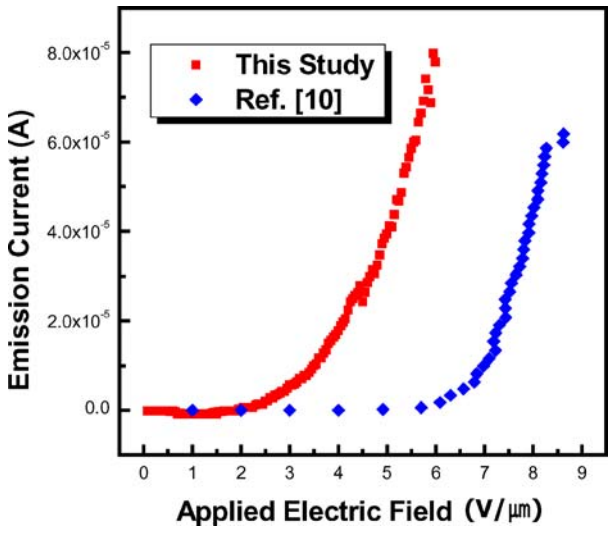

Figure 3 Comparison of the I–V characteristics of SiC whiskers of this study vs. previous study [10]. (a) 80 nm whiskers in this study ($T = 1000\,^{\circ}$C, $P = 5$ Torr, $\alpha = 50$), (b) 285 nm whiskers in Ref. [10] ($T = 1050\,^{\circ}$C, $P = 5$ Torr, $\alpha = 30$).

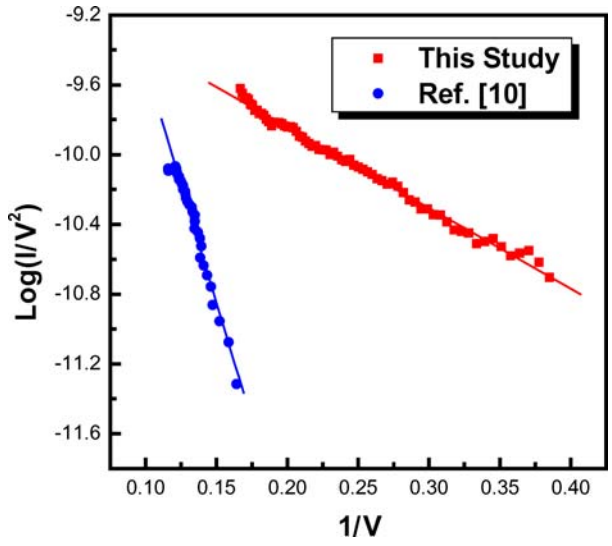

Figure 4 Comparison of the Fowler–Nordheim plot of SiC whiskers of this study vs. previous study [10]. ($T = 1000\,^{\circ}$C, $P = 5$ Torr, $\alpha = 50$).

deposition temperature of 1000 °C. We performed the I–V scanning for 3 to 7 times to stabilize the results of emission current. The value of the turn-on field is about 2.5 V/μm. In order to compare the result quantitatively, we compare this result with previous work [10].

Fig. 3 shows the result of the most stabilized $I-V$ scanning result of this study and the best result of previous work [10], respectively. As you can see in Fig. 3, the value of the turn-on field of this study is 2.5 V/μm and lower than that of previous work of 6 V/μm. Also the value of the emission current of this study is higher than that of previous work. The mean whisker diameter of this study is 80 nm and that of previous work is 285 nm. We can expect that the reason why the result of this study shows better emission properties than that of previous work is due to the smaller mean whisker diameter.

Fig. 4 shows the result of analyzing the data of Fig. 3 according to Fowler–Nordheim equation. The linearity of the plot indicates that field emission is done by the cold field emission mechanism [14].

In summary, to examine the structural effect on field emission property we grew the SiC whiskers of 80 nm diameter. The lowest turn-on field of previous work [10] was 6 V/μm with whisker diameter of 280 nm. When we compared the value of the emission current of this study with that of previous work, it was also higher than that of previous work [10]. The field emission property of the fibers in this study is better than that reported in previous work [10]. It is considered that the reason is due to the smaller mean whisker diameter.

In general, it is known that the sharper the morphology of the emission tip, the better is the electron emission; we have verified this phenomenon in this study.

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