Journal of Ceramic Processing Research. Vol. 3, No. 3, pp. 205~209 (2002)

J O U R N A L O F
Ceramic
Processing Research

The effect of the substrate on the growth of silicon carbide whiskers by chemical vapor deposition

Dong Chan Lim and Doo Jin Choi*

Department of Ceramic Engineering, Yonsei University, 134 Shinchon-dong, Seodaemun-ku, Seoul 120-749, Korea

Silicon carbide (SiC) has superior mechanical and chemical properties due to its strong covalent bonding. In the special case of SiC whiskers, their application is expanding widely. In general, silicon carbide whiskers are grown with the aid of a metallic catalyst, but this method presents some problems. In the present work, SiC whiskers were grown without a metallic catalyst. SiC whiskers were grown on graphite and silicon substrates to examine the effect of the substrate on the growth behavior. Also, the effects of deposition temperature were studied.

Key words: silicon carbide, whisker, CVD, substrate.

Introduction

Due to its covalent bonding, SiC has low density, low thermal expansion coefficient, a high melting point, and high strength and hardness. Its mechanical and physical properties are excellent, and it is now one of the most important structural ceramic materials [1]. It also has a wide band gap with high electron mobility, so it is considered as a semiconductor material that can be used at high power and high frequency in severe environments at high temperature [2].

Silicon carbide whiskers have high aspect ratios and high theoretical strength, and their applications are expanding [3]. SiC whiskers have been grown by several techniques [4-6]. However, there were several problems because previous techniques used metallic catalysts. In the present work, we developed a process for whisker-growth on graphite substrates without a metallic catalyst and successfully grew silicon carbide whiskers.

In modern industry, silicon is one of the most important materials and its field of application is very large. Therefore, whiskers grown on silicon substrates may also be applied in many industrial fields. In this study, SiC whiskers were also grown on silicon substrates and compared with whiskers grown on graphite.

Experimental Details

Figure 1 shows a schematic diagram of the low pressure chemical vapor deposition (LPCVD) system that was used in these experiments. We used methyltrichlorosilane, CH_3SiCl_3, (MTS) (Acros Organics Co., U.S.A) for the source and high purity H_2 for the carrier and dilution gas. Isotropic graphite, which has a thermal expansion coefficient similar to that of silicon carbide, and a Si (100) wafer, p-type, 8.5-11.5 ohm-cm, were used for the substrates. A graphite susceptor was used as the heater.

The heating process was performed under H_2 atmosphere. When the deposition temperature was reached, the deposition was carried out with flowing carrier and dilution gas with an H_2/MTS ratio of 30 and 50. The pressure was stabilized as the pressure of the bubbler. The deposition temperatures were 1000ºC, 1050ºC and 1100ºC.

For the silicon substrate, we used carbon buffer layer to improve the adhesion and growth of the silicon carbide. The carbonization process on the Si was performed using 3% C_2H_2 in H_2 at 1000ºC for 1 hr. We examined the microstructure and surface morphologies by SEM (Hitachi S-2700/FESEM).

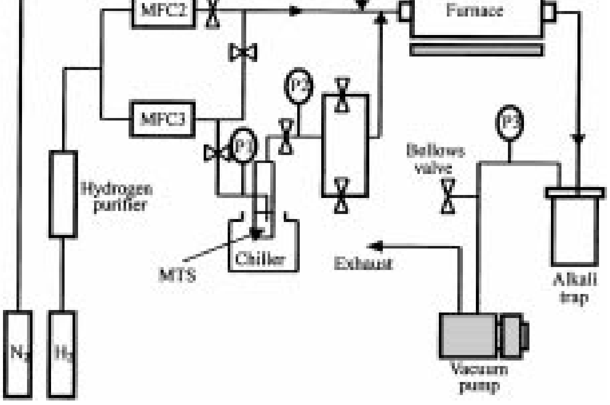

Fig. 1. The schematic diagram of a LPCVD system.

*Corresponding author:
Tel : +82-2-2123-2852
Fax: +82-2-365-5882
E-mail: drchoidj@yonsei.ac.kr

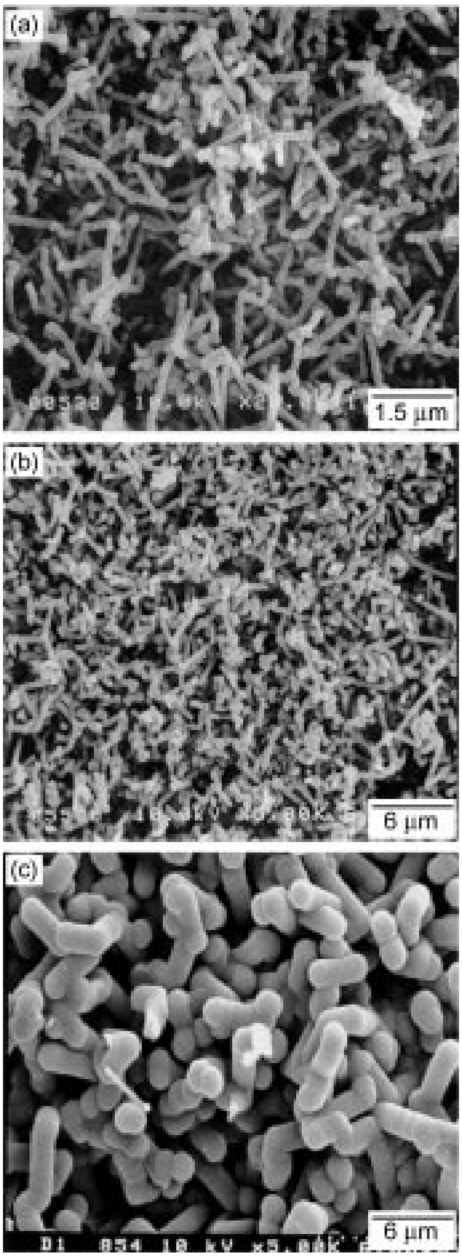

Fig. 2. SEM images of the deposits which were produced on graphite substrate at different deposition temperature. (a) 1000ºC, (b) 1050ºC, (c) 1100ºC (α=30).

Results and Discussion

Figure 2 shows microstructural changes of SiC whiskers grown on graphite substrates at different deposition temperatures, 1000ºC to 1100ºC with the same input gas ratio (H_2/MTS=30) [7]. In Fig. 2a, thin and long whiskers grown at 1000ºC are shown. However, relatively thick and short-shaped whiskers were obtained at 1100ºC. The difference in whisker shape is related to the growth rate and direction. It appeared that axial growth predominated at 1000ºC and that radial growth predominated at 1100ºC. The two different growth mechanisms were apparently competing at

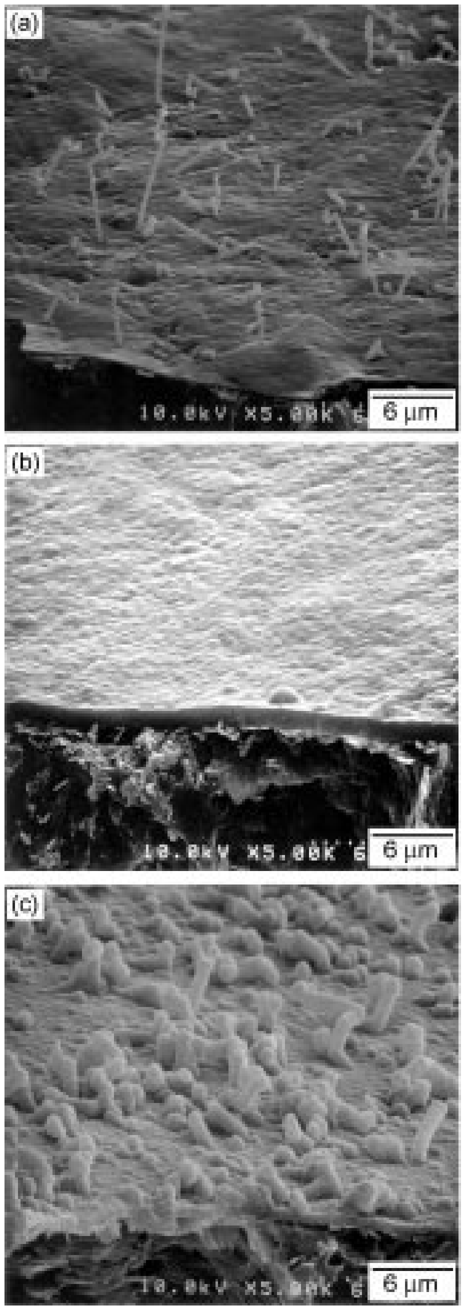

Fig. 3. SEM images of the deposits which were produced on graphite substrate at different deposition temperature. (a) 1000ºC, (b) 1050ºC, (c) 1100ºC (α=50).

1050ºC.

As reported by previous studies, the whisker diameter is influenced by the input gas ratio [7]. As the input gas ratio increases, the mean diameter of whiskers decreases. Therefore, we investigated conditions of high input gas ratio. Figure 3 shows SEM images of the deposits on a graphite substrate at an input gas ratio of 50. At this input gas ratio, a low per-area density of whiskers was seen. This phenomenon may be induced by an increase of the dilution ratio of the reactant gases [8]. As noted above, different growth mechanisms at different deposition temperatures may also occur with

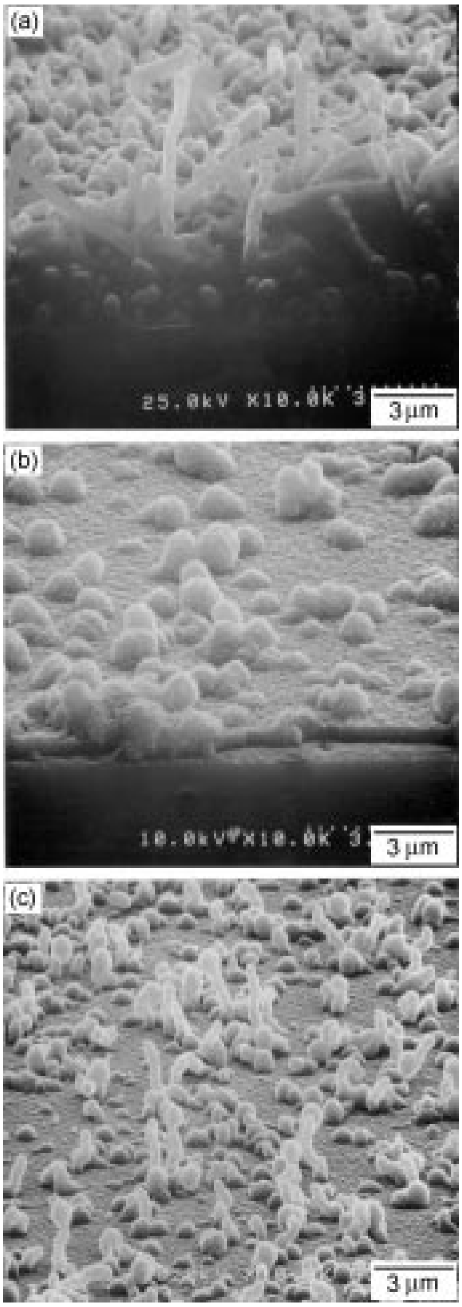

Fig. 4. SEM images of the deposits which were produced on un-abraded and carbon coated Si substrates at different deposition temperatures. (a) 1000°C, (b) 1050°C, (c) 1100°C (α=50).

the input gas ratio of 50.

To examine the effect of the substrate on the silicon carbide deposition, we deposited silicon carbide on an Si substrate. It is known that the deposition of SiC on Si single crystal is very difficult due to differences in thermal expansion coefficients and of lattice constants [9]. Many researchers have deposited a buffer layer to overcome this problem. Therefore, we deposited a carbon on Si using acetylene gas at 1000ºC for 1 hour. Figure 4 shows SEM images of the SiC deposits on un-abraded and carbon coated Si. As described earlier, axial growth was shown at 1000ºC and radial growth was shown at 1100ºC. Also, it is considered that 1050 ºC is a transition region for the growth mechanism. However, it was unusual growth behavior in that whiskers were grown from seed-like small SiC grains at 1100ºC. It is believed that seed-like SiC grains behaved as surface defects to initiate growth. Figure 5 shows the variation of the deposition rate as a function of the deposition temperature. We can see that the deposition rate increased greatly over 1050ºC.

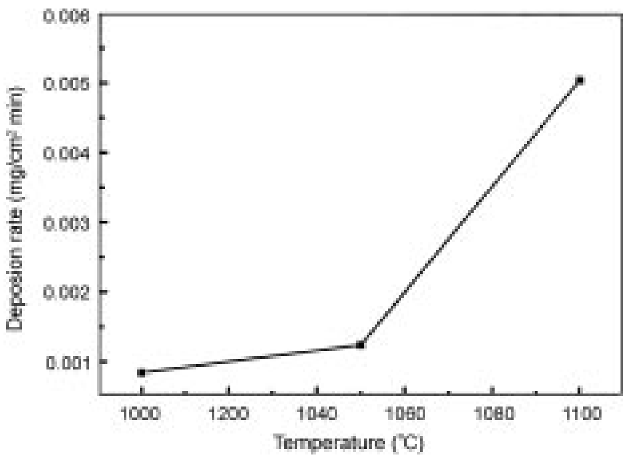

Fig. 5. The variation of the deposition rate as a function of deposition temperature. (α=50, deposition time=2h), un-abraded and carbon coated Si substrates.

Surface energy can be increased due to surface defects, and nucleation and growth proceeds at these sites to lower the surface energy [10]. Therefore, the Si substrate was polished with #2000 SiC abrasive paper before the SiC deposition to produce surface defects. Figure 6 shows SEM images of deposits on these substrates. Overall, the growth of the deposits was good compared with that on the un-abraded Si substrate. The temperature dependency of growth behavior was similar to that of un-abraded Si substrates. However the thick SiC film was grown on this substrate at 1100ºC. It is considered that the deposits grown from defects interact with each other if the spaces between defects are too narrow.

We thought that wider spaces between defects would improve the whisker growth. Therefore, the Si substrate was polished before the SiC deposition with #1000 SiC abrasive paper that has larger abrasive particles. Figure 7 shows SEM images of the deposits on these substrates. Although the whiskers grown on these substrates were a little thinner and longer than those grown on the substrates polished with #2000 SiC abrasive paper, they showed generally similar growth behavior. However, the thick and irregular-shaped whiskers were grown at 1100ºC, the same as those grown on un-abraded Si substrates at 1100ºC. As explained above, it is considered that the morphology of defects was suitable for the growth of whiskers.

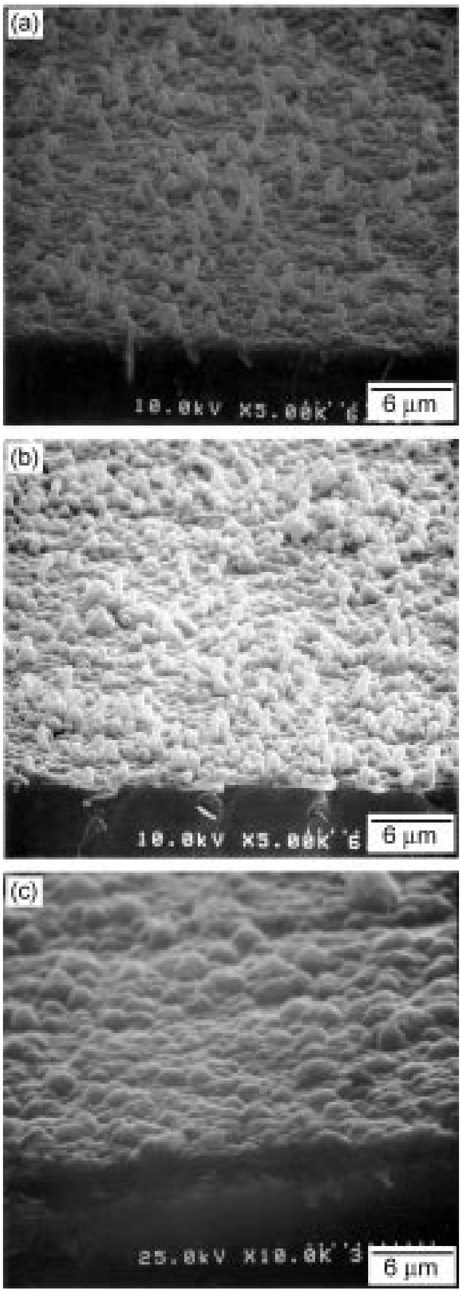

Fig. 6. SEM images of the deposits which were produced on Si substrates polished with #2000 SiC abrasive paper at different deposition temperatures. (a) 1000°C, (b) 1050°C, (c) 1100°C (α=50).

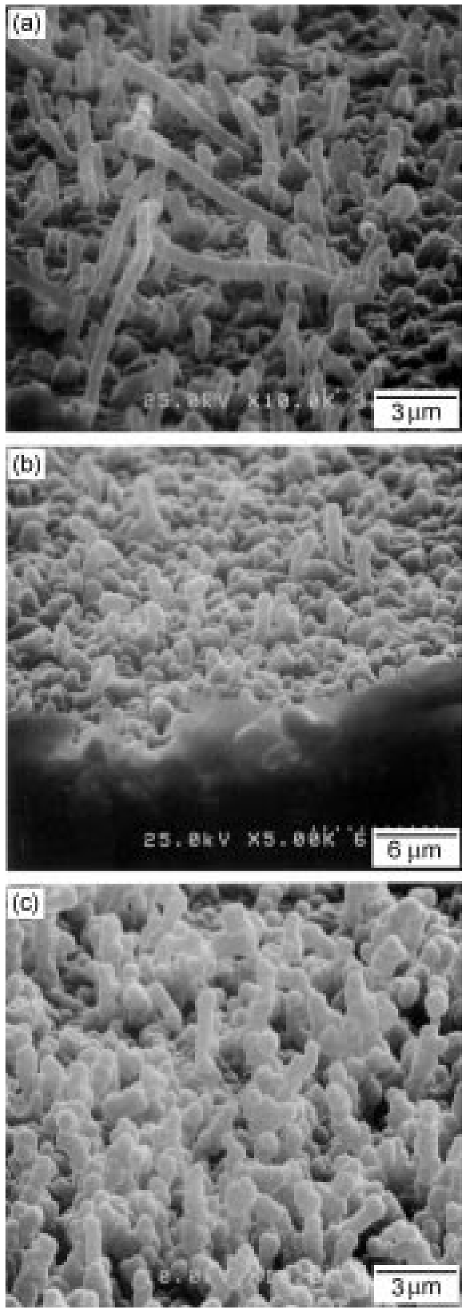

Fig. 7. SEM images of the deposits which were produced on Si substrates polished with #1000 SiC abrasive paper at different deposition temperatures. (a) 1000°C, (b) 1050°C, (c) 1100°C (α=50).

Conclusions

Silicon carbide whiskers were grown on graphite substrates at temperatures from 1000ºC to 1100ºC and input gas ratio (H_2/MTS) of 30 and 50. Under the same conditions, whiskers were grown at 1000ºC and 1100 ºC. A film type deposit was grown at 1050ºC on a silicon substrate. Also, silicon carbides were deposited on silicon substrates that had been abraded with #2000 and #1000 SiC abrasive paper.

The whole growth behavior changed from axial growth to radial growth around 1050ºC. It is thought that 1050ºC is the transition region of the growth mechanism. The whiskers or films were grown on different substrates at 1100ºC. When we see, from the surface defect point of view, the growth property of deposits was a little affected from surface defects under 1050ºC and the growth property of deposits was much affected over 1050ºC.

Acknowledgement

This work was supported by the Korea Science and

Engineering Foundation (KOSEF) through the Ceramic Processing Research Center at Hanyang University.

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