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Growth of 3C-SiC Films on On-axis 6H-SiC Substrates by LPCVD

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Cubic SiC (3C-SiC) films were deposited on on-axis 6H-SiC (0001) substrates by low-pressure chemical vapor deposition (LPCVD). The result of X-ray diffraction patterns shows that the 3C-SiC films were of good crystalline quality. The influence of the growth parameters (flow rates of the gas sources and growth temperature) on the growth rate of the SiC films is discussed. The results show that the transport of silane or its reaction products is the limiting factor for the growth. The surface morphology of the SiC films was observed by atomic force microscope imaging. From these results it can be concluded that the growth of the films is in agreement with a Stranski-Krastanov growth mode.

Key words: 3C-SiC, on-axis 6H-SiC, LPCVD, Growth mode

I. INTRODUCTION

Silicon carbide (SiC) is a promising semiconductor material for microelectronic devices owing to its superior electrical properties [1,2]. Concerning the fabrication of devices, special attention has been paid to the growth of 3C-SiC or 6H-SiC films on 6H-SiC substrates [3,4] using chemical vapor deposition (CVD) technique. Despite easy realization of 6H-SiC films on off-angle 6H-SiC substrates, these off-angles cause several problems in areas such as wafer supply and device performance [5]. Moreover, 3C-SiC has larger electron mobility than 6H-SiC [6], giving it some advantages in the domain of devices. As far as 3C-SiC films grown on 6H-SiC substrates by CVD were concerned, Kong *et al.* investigated the substrate/film interface, and the effect of substrate etching on the film polytype was proposed [7,8]. However, neither detail of the effect of the growth parameters on the growth rate nor the explanation of growth mode was fully provided and clarified. In this work, single crystal 3C-SiC films were prepared on on-axis 6H-SiC (0001) substrates by low-pressure chemical vapor deposition (LPCVD). The crystalline quality, growth rate, surface morphology and growth mode of the films were investigated.

II. EXPERIMENTS

On-axis 6H-SiC (0001) wafers with a size of 5 mm×5 mm×0.26 mm were used as substrates. Silane (SiH_4) and propane (C_3H_8) were used as gas sources, and H_2 as carrier gas. Before introducing SiH_4 and C_3H_8, the substrates were thermally etched for 20 min at 1400 °C in 1.5 L/min H_2 in order to remove the native oxide and to reduce the surface damage. During the deposition process, the pressure in the reaction chamber was kept at 1.3 kPa, the H_2 flow rate was maintained at 1.5 L/min, the flow rates of SiH_4 and C_3H_8 were 0.5-15 and 5-12 mL/min, respectively, and the growth duration was 1.5 h.

X-ray diffraction (XRD) and rocking curves of the SiC films were measured by an X'Pert double crystal diffractometer. Reflection high-energy electron diffraction (RHEED) images were obtained in the molecular beam epitaxy (MBE) vacuum chamber. The surface morphology of the SiC films was characterized by atomic force microscopy (AFM). The thickness of the SiC films was evaluated by cross section views using a field emission scanning electron microscope (FESEM).

III. RESULTS AND DISCUSSION

For SiC films grown on SiC substrates, RHEED is a powerful tool to determine the polytype kind of SiC epilayers [9]. Figure 1 shows a RHEED pattern for a

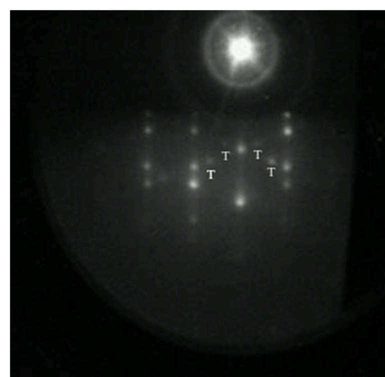

FIG. 1 RHEED pattern of a typical SiC film.

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typical SiC film, which is very indicative of cubic SiC (3C-SiC) polytype of the film [9]. The bright spots and additional weaker spots (denoted by letter T) are due to the presence of SiC islands and twins on the surface of the film [10], respectively.

Figure 2(a) shows the XRD pattern of the typical SiC substrate. For comparison, the XRD pattern of the typical SiC film grown at 1500 °C with flow rates of SiH_4 5 mL/min and C_3H_8 6 mL/min is also shown in Fig.2(b). In Fig.2(a), the peaks at 2θ=35.73° and 75.51° can be easily indexed with a hexagonal SiC (0006) plane and SiC (00012) plane, respectively. As indicated by Fig.2(b), two peaks at 2θ=35.57° and 75.37° appeared due to the diffraction from (111) plane and (222) plane of 3C-SiC, respectively. No other significant features are observed except for the four peaks, which indicate that the film has good crystalline quality. Rocking curves are used to assess the crystalline quality. Insets in Fig.2(a) and (b) are rocking curves of the (0006) plane of 6H-SiC substrate and (111) plane of 3C-SiC film, respectively. The values of full-width at half-maximum (FWHM) of the rocking curves of the 6H-SiC substrate and the 3C-SiC film are 0.06° and 0.08°, respectively, showing that both the substrate and the film are single crystals.

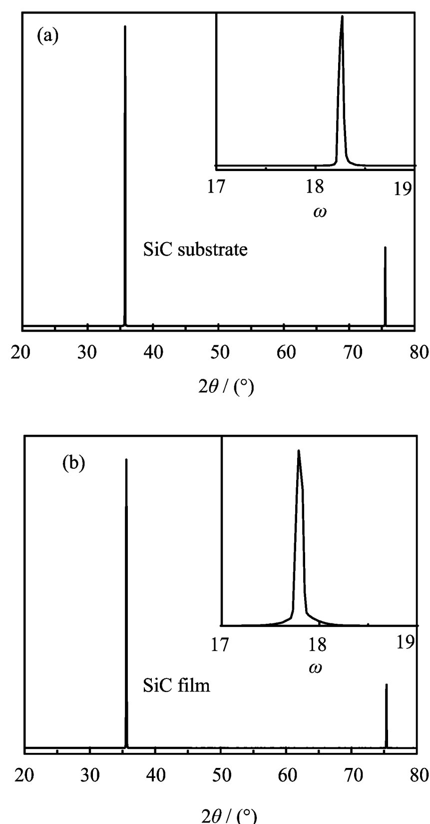

FIG. 2 XRD patterns of (a) the typical SiC substrate and (b) the typical SiC film. Inset in each figure is rocking curve of the 6H-SiC (0006) and the 3C-SiC (111), respectively.

The effect of growth parameters (flow rates of the gas sources and growth temperature) on the growth rate of the SiC films is seen in Fig.3. Figure 3(a) shows the dependence of the thickness of the SiC films on the SiH_4 flow rate when the flow rate of C_3H_8 was 6 mL/min and deposition temperature was 1500 °C. It can be seen that initially the thickness of the films increases with increasing SiH_4 flow rate. Then the thickness of the films decreases when the flow rate of SiH_4 exceeds 5 mL/min. The thickness of the SiC films is almost unaffected by the variation of C_3H_8 flow rate in the range of 6-12 mL/min with SiH_4 flow rate of 5 mL/min and deposition temperature of 1500 °C, as shown in Fig.3(b). The thickness of the films as a function of the flow rates of the gas sources is different from that of the CVD system working at atmospheric pressure reported by the literature [11], in which the thickness of the films increased with increasing C_3H_8 flow rate. The reason for the difference may be related to growth mechanism. For the current case, the films were grown by a vapor-solid (VS) mechanism [12], while in the literature [11] a vapor-liquid-solid (VLS) mechanism was obtained due to excessive silicon in the vapor. Between T=1400 °C and T=1550 °C, the thickness of the films is independent of deposition temperature with a SiH_4 flow rate of 0.6 mL/min and C_3H_8 flow rate of 6 mL/min (unshown here). The reason is that the growth rate is limited by the diffusion of active species in the boundary layer [13]. The decrease of the film thickness with further increasing SiH_4 flow rate is related to the gas phase nucleation from silicon hydrides [14]. The gas phase nucleation, involving Si-cluster formation, is due to excessive concentration of Si vapor generated from SiH_4 decomposition. The formed Si-clusters are carried away by the gas stream instead of being deposited on the substrate, considerably reducing the efficiency of SiH_4 utilization [14]. From Fig.3(a), it can be concluded that the gas phase nucleation began to occur when the flow rate of

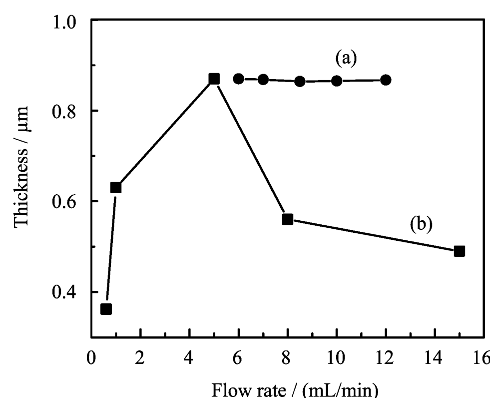

FIG. 3 Thickness of 3C-SiC films as a function of flow rates of gas sources with deposition temperature of 1500 °C. The lines are guides for eyes. (a) C_3H_8 6-12 mL/min, SiH_4 5 mL/min; (b) C_3H_8 6 mL/min, SiH_4 0.5-15 mL/min.

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SiH_4 exceeded 5 mL/min. The strong dependence of the growth rate on the silane flow rate and its relative insensitivity to the propane flow rate indicates that the transport of silane or its reaction products is the limiting factor for the growth.

Figure 4(a) and (b) show the tapping mode AFM images of 3 μm ×3 μm scan size of a typical 6H-SiC substrate and a typical 3C-SiC film, respectively. The substrate reveals faint ridges and random scratches caused by the polishing process. These ridges and scratches disappeared after subsequent growth of the film on the substrate. Many islands were observed on the surface of the film. The value of the rms (root mean square) roughness of the substrate surface is about 2 nm, while the corresponding value of the film surface is 8 nm. Generally speaking, for 3C-SiC films grown on on-axis 6H-SiC substrates, the growth mode is two-dimensional nucleation [15]. For this work, at the initial stage of the growth, a two-dimensional growth mode can be obtained due to very little lattice mismatch between 3C-SiC and 6H-SiC and good crystalline quality of the films as shown by the XRD rocking curves. With the development of the growth, the diffusion length of the adatoms decreased and the adatoms were not effectively migrated, but nucleated as isolated islands on the terrace of the wetting layer. Therefore, three-dimensional (3D) island growth mode took place. From the bright diffraction spots in the RHEED patterns, the 3D growth mode of the films can also be confirmed [16]. Therefore it is inferred that the growth mode is in agreement with a Stranski-Krastanov (S-K) growth mode [16] during the whole stage of the growth, which means two-dimensional growth (2D) followed by 3D-islands growth.

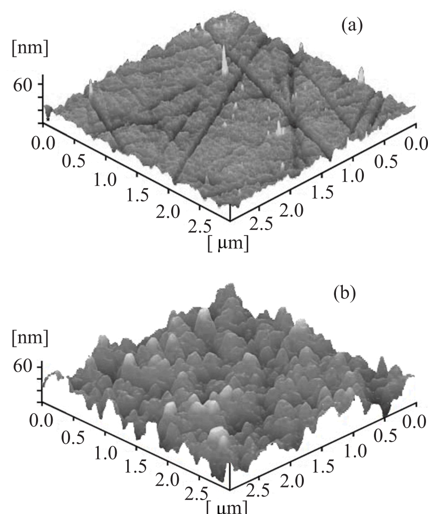

FIG. 4 AFM images of the typical 6H-SiC substrate (a) and the typical 3C-SiC film (b).

IV. CONCLUSION

In conclusion, single crystal 3C-SiC films were prepared on on-axis 6H-SiC (0001) substrates by means of LPCVD. The influence of the growth parameters on the growth rate of the SiC films is discussed. It was found that the transport of silane or its reaction products is the limiting factor for the growth. The surface morphology of the films was observed by AFM. On the basis of these results, the S-K growth mode of the films was inferred.

V. ACKNOWLEDGMENT

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