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# Controlled-growth and characterization of 3C-SiC and 6H-SiC films on C-plane sapphire substrates by LPCVD

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**Abstract**

SiC films have been deposited on C-plane (0 0 0 1) sapphire substrates by low pressure chemical vapor deposition (LPCVD). The 3C-SiC and 6H-SiC polytype kinds of the films grown at two different growth parameters (growth temperature and flow rate of silane) were verified by Raman spectra analysis. The results of XRD patterns and rocking curves show the films are of good crystalline quality. The microstructure of the films was measured by high resolution transmission electron microscopy (HRTEM). Field emission scanning electron microscope (FESEM) and atomic force microscope (AFM) were used to evaluate the surface morphology. The chemical bond and composition of the films were characterized by X-ray photoelectron spectra (XPS). All of these results further confirm that the SiC films are of good quality.


*Keywords:* SiC films; Sapphire substrate; CVD; Structure

## 1. Introduction

Silicon carbide (SiC) is a rapidly developing semiconductor material for power devices owing to its superior physical and chemical properties [1]. For most high power applications, devices supported by insulating substrates are necessary to reduce the parasitic effect and to increase the maximum power capability [2], The high thermal conductivity of SiC is good for high temperature growth of SiC film on insulating substrate [3]. Sapphire is an insulating substrate with high melting point and stable chemical properties. Using CVD technique and C-plane sapphire substrates, it was suggested that 6H-SiC film could be easily grown on an A1N buffer, and 3C-SiC film grown with an ArF excimer laser-assisted was also reported [4,5]. By adjusting pulse frequency, three kinds of SiC polytype can be grown on sapphire substrates by pulse-laser deposition technique [6]. However, no reports about the growth of different SiC polytype kinds have been found by adjusting growth parameters in CVD technique. In this paper, single crystalline 3C-SiC and 6H-SiC films have been grown on sapphire substrates by low-pressure chemical vapor deposition (LPCVD) through variation of growth parameters without the A1N buffer. The crystalline quality, microstructure, surface morphology, chemical bond and composition of the films were investigated.

## 2. Experimental

C-face (0 0 0 1) sapphires with size of 10 mm × 5 mm × 350 μm were used as substrates. Silane ($SiH_4$) and propane ($C_3H_8$) were used as gas sources, and hydrogen ($H_2$) as carrier gas. Before introducing the gas sources, the substrates were thermally etched for 10 min at 1300 °C in 1.5 slm $H_2$ in order to clean the surface. During the deposition process, the pressure in the reaction chamber was held at $1.3 \times 10^3$ Pa, $H_2$ flow rate was maintained at 1.5 slm. Two samples, denoted as $S_1$ and $S_2$, were deposited at temperature of 1450 and 1400 °C, respectively. For sample $S_1$, the flow rates of $SiH_4$ and $C_3H_8$ were 3.8 and 17 sccm, respectively. For sample $S_2$, the corresponding parameters were 8.5 and 17 sccm. The thickness of samples $S_1$ and $S_2$ is about 65 and 110 nm, respectively.

X-ray diffraction (XRD) and rocking curves of the films were measured by X'Pert double crystal diffractometer (Hybrid). Raman scattering spectra were performed by an Ar-ion laser with the wavelength of 514.5 nm in back scatter configuration. The surface morphologies of the SiC films were characterized by field emission scanning electron microscope (FESEM) and atomic force microscope (AFM). X-ray photoelectron spectra (XPS) were recorded using Mg Kα X-ray as the excitation source. The test of microstructure by high resolution transmission electron microscopy (HRTEM) was performed, before which the SiC films were separated from the sapphire substrates by fast cooling in liquid nitrogen.

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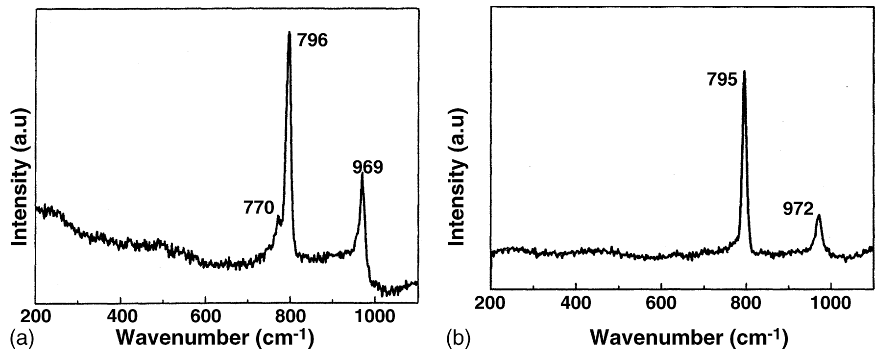


Fig. 1. Raman spectra of (a) samples $S_1$ and (b) $S_2$.

## 3. Results and discussion

According to the characteristic peaks of SiC polytype in Raman spectrum, the kind of SiC polytype can be affirmed [4,7]. Fig. 1(a) and (b) shows the Raman spectrum for samples $S_1$ and $S_2$, respectively. In Fig. 1(a), the peak located at 969 $cm^{-1}$ is a longitudinal optical (LO) phonon mode with the $A_1$ symmetry and two transverse optical (TO) phonon modes at about 796 and 770 $cm^{-1}$ with the $E_2$ symmetry are also observed. This result indicates that the film belong to 6H-SiC polytype. As shown from Fig. 1(b), two characteristic peaks of cubic SiC (3C-SiC) at about 795 and 972 $cm^{-1}$ are attributed to the transverse optical phonon mode (TO) and the longitudinal optical phonon mode (LO) of the SiC, respectively. Sample $S_1$ was deposited at a relatively low flow rate of silane and higher deposition temperature, while sample $S_2$ was grown at higher flow rate of silane and relatively low deposition temperature. The fact that different growth parameters lead to different SiC polytype kind can be explained in terms of supersaturation. At low flow rate of silane and higher deposition temperature, the impinging atoms have higher mobility and can migrate on the surface of the sapphire substrate quickly, so the stacking sequence of ABCACB (6H-SiC) is easily formed. However, higher flow rate of silane and relatively low deposition temperature bring on higher supersaturation, which suppresses the migration velocity of impinging atoms and favors the formation of 3C-SiC polytype (ABCABC) [8]. From the viewpoint of phase diagram given by Knippenberg [9], 6H-SiC is a stable phase than 3C-SiC, and its growth temperature is higher than that of 3C-SiC. These experimental results are in agreement with the phase diagram theory.

Fig. 2(a) and (b) shows the XRD pattern of samples $S_1$ and $S_2$, respectively. From Fig. 2(a), the peaks at $2\theta = 35.57°$ and $75.41°$ can be easily indexed with a hexagonal SiC (0 0 0 6) plane and (0 0 0 1 2) plane which is the second order diffraction of SiC (0 0 0 6). As indicated in Fig. 2(b), two peaks at $2\theta = 35.55°$ and $75.29°$ can also be observed, indicating cubic SiC (1 1 1) and (2 2 2) plane, respectively. The strongest peaks located at about 41.7° in Fig. 2(a) and (b) are due to the diffraction from hexagonal $Al_2O_3$ (0 0 0 6) planes. No other diffraction peaks appeared except for the four peaks, which indicate the SiC films have good crystalline structure and (0 0 0 6) plane and (1 1 1) plane of the films are parallel to the surface of the sapphire substrates. Rocking curves are used to assess the crystalline quality. Insets in Fig. 2(a) and (b) are rocking curves of (0 0 0 6) plane and (1 1 1) plane of the films, respectively. The values of full-width at half-maximum (FWHM) of the rocking curve of samples $S_1$ and $S_2$ are 0.6° and 1.1°, respectively, which indicates that the SiC films are of good crystalline quality.

The TED (transmission electron diffraction) pattern and HRTEM image of samples $S_1$ and $S_2$ are shown in Figs. 3 and 4, respectively. From the inset in Fig. 3, it can be seen that the measurements of interplanar spacings and interplanar angles are consistent with the [0 0 0 1] diffraction pattern of 6H-SiC. The six dots close to the transmitted beam in six-fold symmetry correspond to diffraction spots of $\{1\,1\,\bar{2}\,0\}$ planes of 6H-SiC. Single crystal of 6H-SiC film can also be confirmed from this pattern. It can also be seen that the lattice spacing is 0.15 nm from the HRTEM image in Fig. 3, which corresponds to $\{1\,1\,\bar{2}\,0\}$ planes of 6H-SiC. From the inset in Fig. 4, one can see that the measurements of interplanar spacings and interplanar angles are in

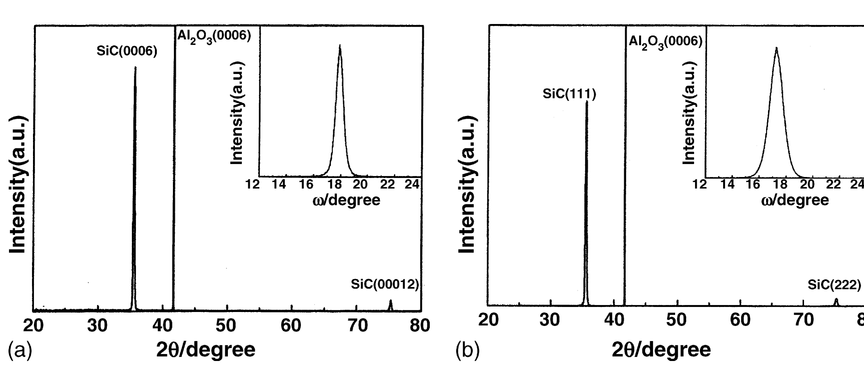


Fig. 2. XRD patterns of (a) samples $S_1$ and (b) $S_2$. Inset in each figure is rocking curve.