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Effects of carbonization and substrate temperature on the growth of 3C–SiC on Si(1 1 1) by SSMBE

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Abstract

The growth of 3C–SiC on Si(1 1 1) substrate was performed at different carbonization temperatures and substrate temperatures by solid-source molecular beam epitaxy (SSMBE). The properties of SiC film were analyzed with in situ reflection high energy electron diffraction (RHEED), X-ray diffraction (XRD), atomic force microscopy (AFM) and X-ray photoelectron spectroscopy (XPS). The best carbonization temperature of 810 °C was found to be optimal for the surface carbonization. The quality of SiC film grown on Si at substrate temperature of 1000 °C is best. The worse crystalline quality for the sample grown at higher temperature was attributed to the large mismatch of thermal expansion coefficient between SiC and Si which caused more dislocation when sample was cooled down to room temperature from higher substrate temperature. Furthermore, the larger size of single pit and the total area of the pits make the quality of SiC films grown at higher temperature worse. More Si atoms for the sample grown at lower temperature were responsible for the degradation of crystalline quality for the sample grown at lower temperature.

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Keywords: 3C–SiC; Si(1 1 1); SSMBE; Carbonization; Substrate temperature

1. Introduction

SiC is a wide band gap IV–IV compound semiconductor, which has now absorbed more attention due to great technological interest in device operating at high temperature, high power, high frequency and in harsh environment [1–3]. Because of the advantages of epitaxy of SiC on Si such as low cost, large-size substrate, good electrical conduction, many persons try to grow SiC on Si substrate. However, many factors affect the quality of films. Among them, carbonization and substrate temperature are thought to be especially important for the growth of SiC thin films.

Zekentes et al. [4] have studied the effect of carbonization on the growth of SiC by GSMBE and found the best carbonization temperature. But very few persons study it in detail by SSMBE.

On the other hand, Madapura et al. [5] and Kim Kwang Chul et al. [6] have investigated the substrate temperature effect on the quality of films by CVD. Kim Kinam [7] and Chen [8] have studied the effect based on PLD. Pfennighaus, etc. [9] have studied the relation between the quality of film and substrate temperature in the range of 780– 900 °C by SSMBE. In this paper, we study the effect of carbonization on the growth of SiC and try to find the best carbonization temperature. Furthermore we also investigate the effect of substrate temperature on the growth of SiC in the extended temperature range by SSMBE.

2. Experimental

Two groups of SiC samples were grown on Si(1 1 1) by using the electron gun evaporators for Si and C with base pressure of 5×10^{-8} Pa in a SSMBE system. During the growth, the samples were characterized in situ by RHEED at accelerating voltage of 22 kV and the deposition rates of Si and C were measured by quartz crystal oscillators (MAXTEK TM-350) with the precision of 1 Å.

Si(1 1 1) substrates (p-type) were cleaned for 5 min with carbon tetrachloride, acetone and alcohol, then treated with H_2SO_4:H_2O_2 (1:1), and dipped in 10% buffer HF solution for 3 min to remove the surface native oxides. After dried in a flux of N_2, the samples were placed into the chamber immediately.

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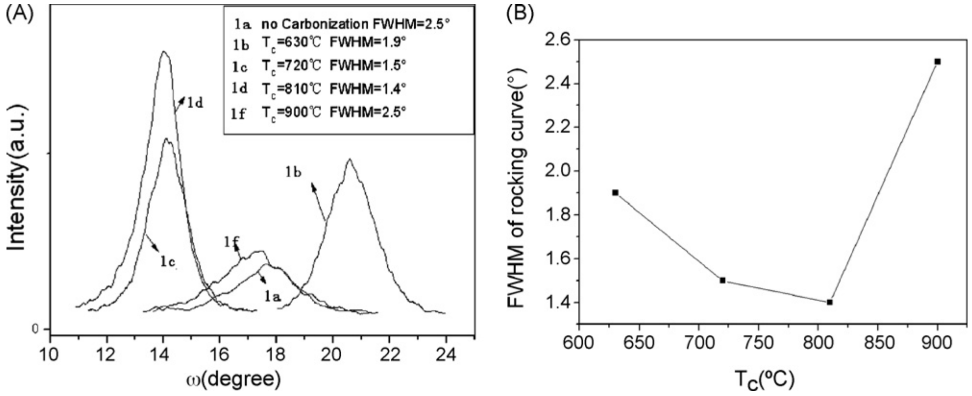

Fig. 1. (A) Rocking curves of SiC samples without and with different carbonization temperatures. (B) Variation of FWHM of the rocking curve as a function of T_C.

Afterwards, a Si buffer layer with the thickness of 100 Å was grown on the substrate with the temperature of 700 °C.

In order to study the effect of carbonization, a group of samples were fabricated. One sample was not carbonized and the others were carbonized for 30 min with carbonization rate of 1 Å/min at different carbonization temperatures (T_C) of 630, 720, 810, and 900 °C, respectively. The SiC films were grown on the carbonized samples as well as non-carbonized sample for 100 min with the deposition rate of 3 Å/min at the same substrate temperature of 1100 °C.

Another group of samples were all carbonized at 720 °C and then grown for 200 min with the deposition rate of 3 Å/min at different T_S of 900, 1000, 1100 °C, respectively to study the effect of substrate temperature.

The film crystallinity was characterized by XRD spectra of the θ–2θ scans which were obtained using a MXPAHF diffractometer with Cu Kα source. The chemical component of film was analyzed by XPS spectra by using an ARUPS10 spectrometer with Mg Kα (1253.6 eV) source. The film morphology was measured by AFM performed in tapping mode with a Dimension TM3100 Digital instruments apparatus.

3. Results and discussion

3.1. Effect of substrate carbonization on the growth of SiC

Fig. 1(A) shows the rocking curves of the five samples without and with carbonization at different temperatures. The variation of FWHM of the rocking curve as a function of T_C is shown in Fig. 1(B). We can see that all the values of FWHM of the rocking curve of carbonized samples are smaller than that of the sample without carbonization, except for the sample carbonized at 900 °C. It is obvious that carbonization can improve the crystalline quality of SiC film, which shows that carbonization can reform mismatch and strain between substrates and films [10–12]. From Fig. 1(B), we can see the values of FWHM of rocking curve become smaller when T_C increases from 630 to 810 °C and bigger with an increase of T_C from 810 to 900 °C. Therefore, there is a smallest value at 810 °C. This is consistent with the result of Zekentes et al. [4].

Higher carbonized temperature affects the nucleation at the early stage of SiC film growth, which causes a worse buffer layer and then makes the quality of SiC film worse. Due to low activation energy of atoms at lower carbonization temperature, difficulty of nucleation is responsible for the degradation of crystalline quality SiC film later [13–15].

3.2. Effect of substrate temperature on SiC growth

Fig. 2 shows the RHEED patterns of Si substrate (A) and SiC samples with different substrate temperatures: (B) 900 °C, (C) 1000 °C, (D) 1100 °C, respectively. Si(7 × 7)reconstruction shown in Fig. 2(A) indicates a clean Si substrate surface. In Fig. 2(B), besides SiC streak, some Si faint streaks could still be observed, indicating that there are a few Si atoms on the surface. However in Fig. 2(C) we just can see SiC streaks could be observed. Compared with the spots in Fig. 2(C), asymmetric spots are observed in Fig. 2(D), which indicates that the surface of SiC film grown at T_S of 1100 °C becomes rough. The RHEED patterns indicate the quality of film grown at 1000 °C is better than that of films grown at 900 and 1100 °C.

Fig. 3 shows the XRD spectra of samples with different substrate temperatures (900, 1000 and 1100 °C). The rocking curves of the three samples are shown in the inset. From the

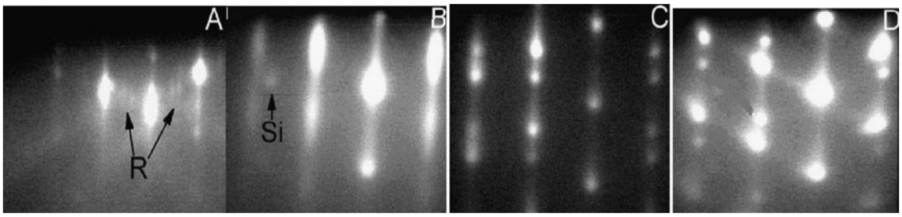

Fig. 2. RHEED patterns of Si substrate (A) and SiC samples with different substrate temperatures: (B) 900 °C, (C) 1000 °C and (D) 1100 °C, respectively.