Multi-wafer 3C-SiC thin films grown on Si (100) in a vertical HWLPCVD reactor*

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Abstract: We report the latest results of the 3C-SiC layer growth on Si (100) substrates by employing a novel home-made horizontal hot wall low pressure chemical vapour deposition (HWLPCVD) system with a rotating susceptor that was designed to support up to three 50 mm-diameter wafers. 3C-SiC film properties of the intra-wafer and the wafer-to-wafer, including crystalline morphologies and electronics, are characterized systematically. Intra-wafer layer thickness and sheet resistance uniformity (σ/mean) of $\sim$3.40% and $\sim$5.37% have been achieved in the 3×50 mm configuration. Within a run, the deviations of wafer-to-wafer thickness and sheet resistance are less than 4% and 4.24%, respectively.

Key words: 3C-SiC; vertical multi-wafer HWLPCVD; heteroepitaxial growth; uniformity

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1. Introduction

Silicon Carbide (SiC) is an important electronic and structural material suitable for high-power, high temperature electronic devices and micro-electromechanical system (MEMS) devices in harsh environments due to its excellent stability[1, 2]. In addition, among SiC polytypes, cubic silicon carbide (3C-SiC) is the only type that can be grown on the Si substrate, giving it a remarkable advantage in the low-cost fabrication of large diameter wafers[3]. However, device applications using 3C-SiC grown on Si substrate have lagged, owing to the difficulty in realizing a high throughput of high quality material with high intra-wafer and wafer-to-wafer uniformity.

3C-SiC growth with good uniformity and excellent crystallinity is a key technology for SiC electronic and MEMS devices[4]. Heteroepitaxial growth of multi-wafers with good characteristics has been reported in different reactors using different gas system[5]. Chemical vapor deposition (CVD) is always considered as the most effective method of growing high-quality SiC films, which has been performed using a variety of precursors and various deposition conditions. One of the desirable qualities of CVD film growth is uniformity. For a multi-wafer CVD system, high intra-wafer uniformity and high wafer-to-wafer uniformity are both important to ensure the properties of all final devices made from these films. As for SiC film growth, the traditional growth method was performed with the standard reactants of SiH_4 and either C_3H_8 or C_2H_4 in H_2 as the carrier gas by using a hot-wall low pressure chemical vapor deposition (HWLPCVD), which is often selected over atmospheric pressure CVD (APCVD) because the large diffusion coefficients at lower pressures tend to obtain more uniform films[6,7].

In our experiments, 3C-SiC films have been deposited in a novel home-made multi-wafer hot-wall LPCVD reactor (Fig. 1) with a rotating susceptor, which can hold up to three 50-mm-diameter wafers. Specifics regarding the LPCVD reactor setup are also detailed in an earlier paper[8]. Gas flow distribution is more controllable and uniform in such a configuration; also, temperature can be higher, thereby yielding SiC epilayers with high uniformity.

2. Experimental procedure

N-doped polycrystalline 3C-SiC films were grown on Si (100) substrates in our home-made vertical hot-wall LPCVD reactor, a schematic illustration of which is shown in Fig. 1. The reactor chamber consists of watercooled cylindrical quartz tube, positioned vertically with the gas flows coming from the top, perpendicular to the susceptor[9]. The chamber has a SiC-coated graphite susceptor, wrapped with graphite foam for thermal insulation. Substrates are placed in the gas-flow channel of the susceptor and uniformly heated by a radio-frequency (RF)-induction.

Si wafers 1, 2 and 3 were placed inside a rotating susceptor, as shown in Fig. 1. Before being loaded into the reaction tube, Si wafers were soaked in HF diluted solution for 5 min to remove the native oxidation from the surface. The growing process consisted of two stages. In the first stage, 4.5 sccm C_2H_4 diluted in 10 slm H_2 was used for carbonization and introduced into the growth chamber at 1000 ℃. Then the chamber temperature increased slowly to 1250 ℃ in 10 min. As for the second step, trichlorosilane ($SiHCl_3$) and thylene (C_2H_4) were used as silicon and carbon sources, and ammonia (NH_3) as the N dopant gas, respectively. The sources were diluted and carried

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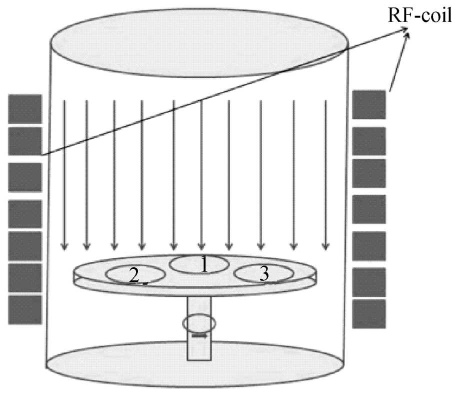

Fig. 1. Schematic picture of the home-made vertical multi-wafer hot-wall CVD reactor.

by pure H_2 gas, and then fed into the growth chamber. Heteroepitaxial growth was performed at 1250 ℃ with fluxes of H_2, NH_3, $SiHCl_3$ and C_2H_4 being 10 slm, 0.18 sccm, 4.5 sccm and 4.5 sccm, respectively. The deposition pressure was held at 40 Torr and the growth process lasted 120 min for these films. After the growth stage, the samples were cooled down in H_2 ambient.

After growth, the grown films were characterized and analyzed by X-ray diffraction (XRD), Raman scattering, scanning electron microscopy (SEM), and sheet resistance measurement (SRM), separately. XRD was performed to analyze the film structures by using a Philips diffractometer with CuKα radiation and θ–2θ geometry. Cross-sectional SEM was used to estimate the film thickness by observing the cross-sectional shape. SRM was obtained by Napson NC-40 non-contact sheet resistance measurement instrument. XRD and SEM measurements were taken at five points: one was located in the wafer center and the others at the periphery (12.5 mm from center). The value of the uniformity was calculated by uniformity = σ/mean, where σ and mean refer to the standard deviation and the mean value[9].

3. Results and discussion

The surfaces of SiC films were mirror-like and XRD was used to investigate the crystallinity of the 3C-SiC films. Figure 2 shows the X-ray diffraction patterns of the 3C-SiC films within a run. For one wafer, the five points shown in the pictures were measured. The data were from the five areas across the wafer (shown in the inset). The 200 peak of 3C-SiC was clearly visible in each scan. The substrates were highly oriented (100) silicon films. Figures 2(a)–2(c) show that the deposited SiC films are also highly oriented along the (200) direction. The spectra were highly uniform, peak positions were almost the same, and the FWHM were narrow, less than 0.4°. The spectra exhibited a strong SiC (200) texture, therefore SiC films showed an orientation much the same as that of the Si (100) substrate, which indicated that the films were of homocrystalline cubic 3C-SiC. These indicated that the films were highly-oriented and had almost the same crystallinity, which also proved that the three wafers were highly uniform. The growth rate is about 5–6 μm/h, and it should be noted that if the growth rate was higher than a certain value, the

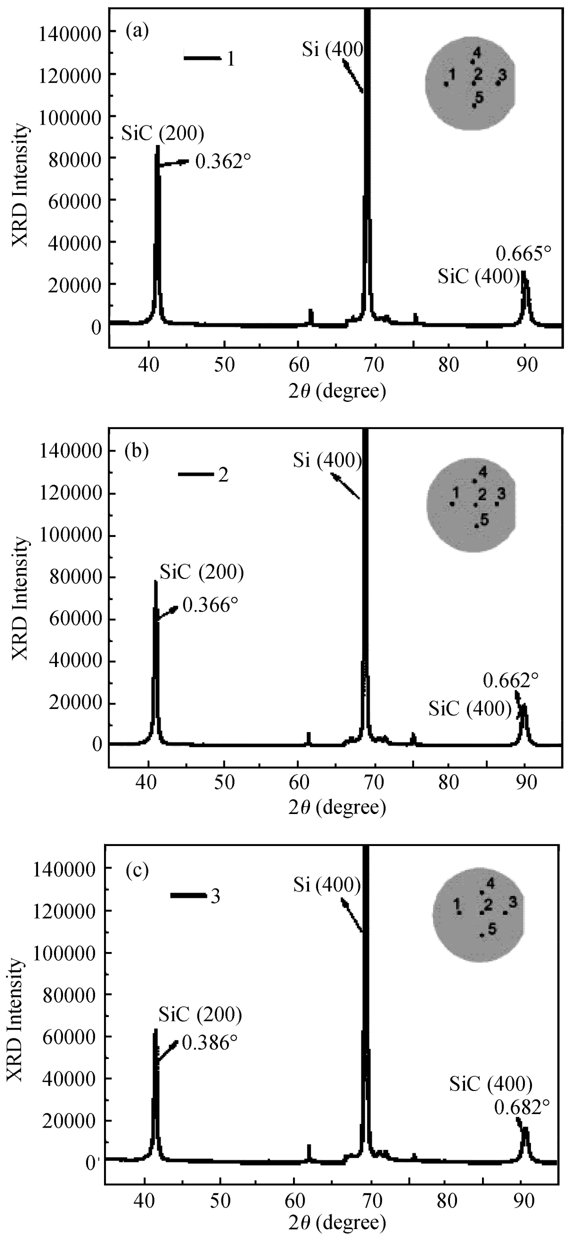

Fig. 2. (a, b, c) XRD spectra of 3C-SiC films grown on Si (100) substrate. The peak positions of wafers (a, b, c) were 41.4°, 41.5° and 41.5°, respectively.

SiC (111) texture would appear together with the SiC (100) texture in the heteroepitaxial 3C-SiC films. Therefore, an extremely weak peak of SiC (222) texture at 75.5° appears, and it may be caused by the tilt SiC planes when islands coalesce, where the APD is formed, as reported before[8]. A peak at 61.8° arises due to the diffraction from the Si (400) plane.

The quality of the films was supported by Raman measurements. Figure 3 shows the typical Raman spectra obtained for the 3C-SiC films on Si (100). Predominantly one sharp line of 796 cm^{-1} corresponding to the transversal (TO) mode of 3C-SiC can be observed clearly in the three wafers. The peak of 970.3 cm^{-1} corresponding to the longitudinal (LO) mode of 3C-SiC also proved that the films were cubic 3C-SiC. This result was consistent with the X-ray results and also showed a good SiC crystalline structure[10].

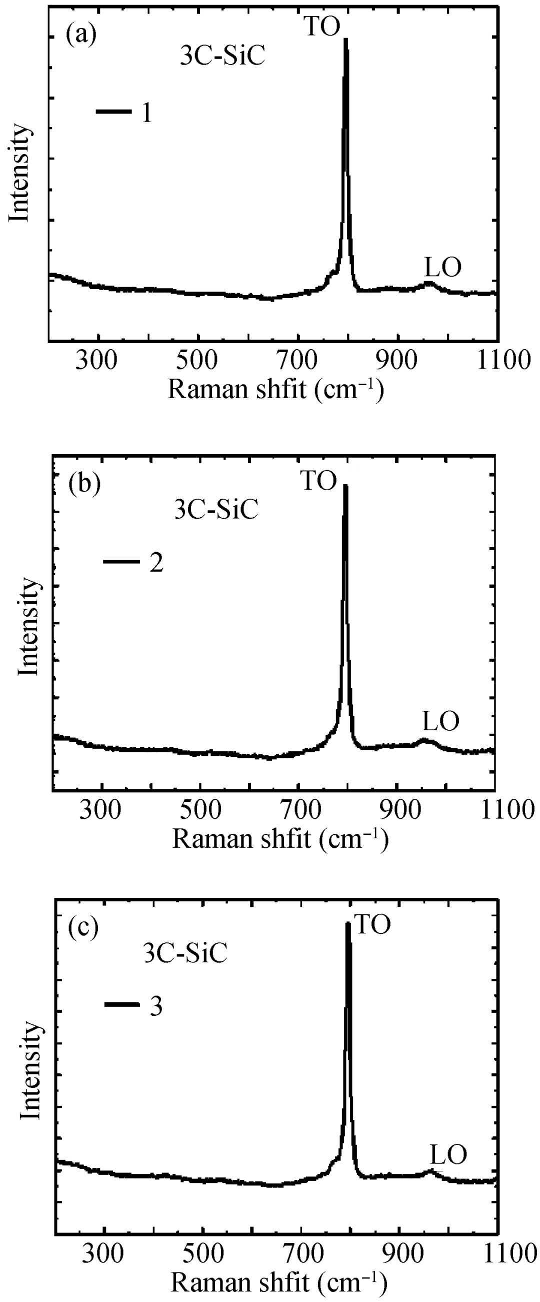

Fig. 3. Raman spectra of the wafers 1, 2 and 3 within a run, respectively.

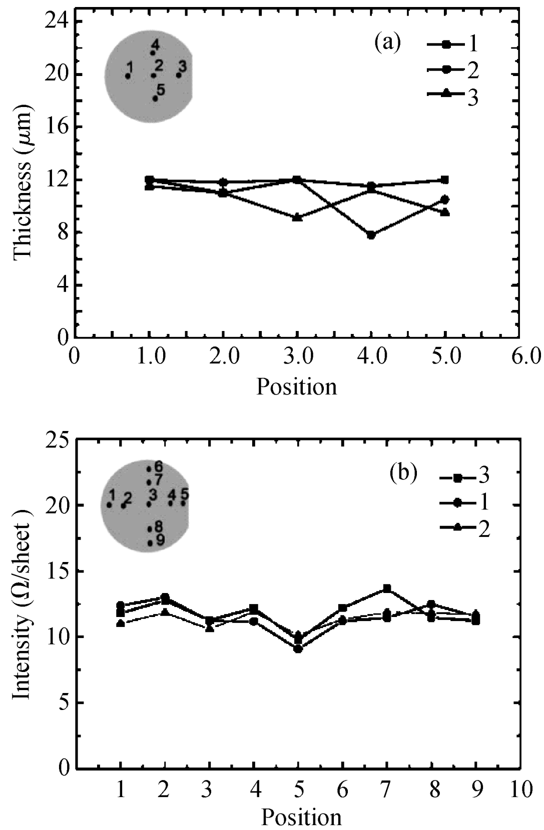

Fig. 4. Thickness uniformities and sheet resistance uniformities of 3C-SiC films grown on Si (100) substrates. (a) Thickness and uniformities (σ/M) of 3C-SiC samples 1, 2 and 3, respectively, within a run. (b) Sheet resistances and uniformities of the three 3C-SiC samples.

Thickness uniformity was analyzed by investigating the three wafers within a run. SEM measurement of each wafer was taken at five positions mentioned in the second part. The detailed positions and the results can be seen in Fig. 4(a). The thickness uniformity of each wafer was calculated by the following method,

$$\text{uniformity} = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}(x_i - m)^2}{N}}}{m} \times 100\%, \quad m = \frac{\sum_{i=1}^{N} x_i}{N},$$

where x_i is the thickness of the i-th position and N is the total sample counts. For these three wafers, $N = 5$. For the films with a thickness of about 11 μm, the intra-wafer uniformity and the wafer-to-wafer uniformity were about 3.40% and 4.00%, respectively, which indicated that good thickness uniformity was obtained in the multi-wafer 3C-SiC heteroepitaxial thin films. Meanwhile, compared to the results reported before (the intra-wafer thickness uniformity was 6%–7%), the properties of our system have been greatly optimized.

Sheet resistance measurement of each wafer was carried out at nine positions, as seen in Fig. 4(b). Position 3 was the centre of the wafer. The other eight positions were evenly distributed along two perpendicular diameters, and positions 2, 4, 7 and 8 were at the middle of the radii. Sheet resistance, which presents the resistance in the current direction of a square-shaped thin film, can be expressed as $R_K = \rho/d$, where ρ is the film resistivity and d is the film thickness. Sheet resistance (R_K) uniformity can be used to represent the doping uniformity of 3C-SiC heteroepitaxial thin films. Figure 4(b) shows R_K uniformities of n-type 3C-SiC thin films. As we can see in Fig. 4(b), for NH_3 doped films, the average value of sheet resistance was about 11 $\Omega/\square$, and the intra-wafer and wafer-to-wafer uniformities are about 5.37% and 4.24%, respectively. These results indicate that the growth process has been doped effectively, and also that the wafers had good uniformity. Compared to the results reported before (the uniformity of the intra-wafer sheet resistance was 6.7%–8%), the study greatly improved the properties of our system.

4. Conclusion

Multi-wafer (3 × 2”) 3C-SiC heteroepitaxial films were grown on Si (100) substrates by using our home-made vertical hot-wall HWLPCVD reactor. The results from SiC layers grown with this multi-wafer system are promising. The film structure has been investigated by XRD analysis and Raman scattering showing high crystal quality. 3C-SiC film properties, including crystalline morphologies, structures and electronics, are characterized and analyzed in the way of intra-wafer and wafer-to-wafer. The uniformity of intra-wafer thickness and sheet resistance of the 3C-SiC films were found to be 3.40% and 5.37%. Within a run, the deviations of wafer-to-wafer thickness and sheet resistance were 4.00% and 4.24%, respectively. These results were better than the results reported before, in which the uniformities of intra-wafer thickness and sheet resistance were 6%–7% and 6.7%–8%[8]. The study laid solid foundations for improving yield output to meet the industry’s increasing demands.

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