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Uniformity Investigation in 3C-SiC Epitaxial Layers Grown on Si Substrates by Horizontal Hot-Wall CVD

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Abstract: 50mm 3C-SiC epilayers are grown on (100) and (111) Si substrates in a newly developed horizontal low-pressure hot-wall CVD reactor under different growth pressures and flow rates of H_2 carrier gas. The structure, electrical properties, and thickness uniformity of the 3C-SiC epilayers are investigated by X-ray diffraction (XRD), sheet resistance measurement, and spectroscopic ellipsometry. XRD patterns show that the 3C-SiC films have excellent crystallinity. The narrowest full widths at half maximum of the SiC(200) and (111) peaks are 0.41° and 0.21°, respectively. The best electrical uniformity of the 50mm 3C-SiC films obtained by sheet resistance measurement is 2.15%. A σ/mean value of ±5.7% in thickness uniformity is obtained.

Key words: 3C-SiC; heteroepitaxial growth; horizontal hot-wall CVD; uniformity
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1　Introduction

Silicon carbide (SiC) is a wide band gap semiconductor with potential applications in radiation resistant, high power, high frequency, and high temperature devices for the power generation, automotive, aerospace, and petroleum industries[1]. Furthermore, due to its different possible stacking sequences, SiC has more than 250 polytypes, such as 3C-SiC, 4H-SiC, and 6H-SiC. Among them, cubic silicon carbide (3C-SiC) is attractive for its high electron mobility ($1000\mathrm{cm}^2/(\mathrm{V}\cdot\mathrm{s})$) and high electron saturation velocity ($2.7\times10^7\mathrm{cm/s}$)[2]. These electrical properties are great advantage in the development of high-speed electrical devices[3].

SiC bulk substrate is very expensive, limiting the application of SiC epitaxial layers grown on SiC bulk substrates. Therefore, epitaxial SiC film grown on Si substrate has become a promising alternative due to its low cost and compatibility with the conventional Si process. Due to the large lattice mismatch (about 20%) and thermal expansion coefficient mismatch (8%) between SiC and Si, defects such as misfit dislocations, anti-phase boundaries (APBs), and anti-phase domains (APDs) form in 3C-SiC films[4]. Presently, hot-wall chemical vapor deposition (HWCVD) is being widely used among research groups worldwide. Hot-wall CVD, proposed previously for SiC homoepitaxy, is superior to cold-wall CVD because of its high decomposition efficiency of precursor gases and better temperature homogeneity. However, some problems also exist in the SiC epitaxial layers, such as nonuniform thickness and the electrical properties of SiC films. In the work reported in this paper, some fundamental aspects such as flow rate of carrier gas and the effect of growth pressure on growth uniformity have been investigated in a horizontal low-pressure hot-wall CVD reactor.

2　Experiment

3C-SiC films were grown on on-axis Si(100) and (111) substrates in a newly developed 50mm hot-wall CVD reactor. SiC-coated high-purity graphite wrapped by graphite foam for thermal insulation was used as the susceptor. Si substrates were placed in the gas-flow channel of the susceptor and were uniformly heated by RF-induction.

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Hydrogen (H_2) was used as carrier gas, and silane (SiH_4) and ethylene (C_2H_4) as source gases. All growth runs were carried out using a three-step recipe[5]. Because of the large lattice-mismatch between SiC and Si, the carbonized buffer layers were prepared using C_2H_4. C_2H_4 was introduced into the reactor at 600℃. When the temperature reached the growth temperature of 1200℃, SiH_4 was introduced into the reactor and the epitaxial growth started. The typical growth time was 15min. The effect of growth pressure and H_2 flow rate on epitaxial growth was investigated. Table 1 shows the H_2 flow rate and growth pressure in each sample growth. The flow rate of SiH_4 and C_2H_4 were fixed at 1 and 3sccm, respectively. After growth, the samples were cooled down in an H_2 ambient.

Table 1 H_2 flow rate, growth pressure, and growth time during sample growth

Sample No.	H_2 flow rate /slm	Growth pressure /Torr	Growth time /min
1	3	40	15
2	3	200	15
3	3	500	15
4	6	40	137
5	6	200	15
6	6	500	15
7	8	40	15
8	8	200	15
9	8	500	15

The surface morphology of the 3C-SiC epitaxial layers was characterized using a Nomarski microscope. The crystallinity of the epitaxial layers was analyzed by XRD. The film thickness was measured by spectroscopic ellipsometry. The electrical properties were determined by Napson NC-40 non-contact sheet resistance measurement.

3 Results and discussion

Figure 1 shows typical X-ray diffraction patterns from the SiC epitaxial films on No.1(100) and No. 4 (111) Si substrates, respectively. A strong SiC(200) peak at $2\theta = 41.4°$ can be seen in Fig. 1 (a). The full width at half maximum (FWHM) of the (200) peak is 0.53°. This indicates that the 3C-SiC films grown on Si(100) substrates are parallel to the substrate. Similarly, Figure 1(b) shows a strong SiC(111) peak at $2\theta = 35.6°$ and its secondary diffraction (222) peak at $2\theta = 75.5°$. The FWHM of the (111) peak is 0.21°. The above data shows good crystallinity of the 3C-SiC films with substantial (100) and (111) preferential orientation.

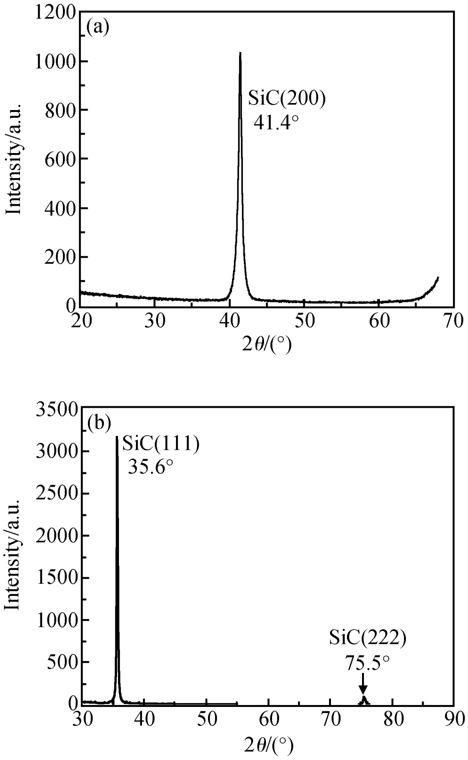

Fig. 1 XRD patterns from SiC epitaxial films on No. 1(100) (a) and No.4(111) (b) Si substrates

Figure 2 shows the XRD patterns of 3C-SiC film from six different areas on samples No.1 and No.4. The inset shows the measured areas on samples No. 1 and No. 4. The FWHMs of the strong SiC(200) peak in Fig. 2(a) are 0.483°, 0.533°, 0.526°, 0.408°, 0.406°, and 0.415°, respectively. The FWHMs of the SiC(111) peak in Fig. 2(b) are 0.213°, 0.209°, 0.208°, 0.223°, 0.225°, and 0.331°, respectively. The 3C-SiC epitaxial films grown on both Si(100) and Si(111) are homogenous in crystallinity uniformity. There is no direct relation between thickness uniformity and the FWHM of the characteristic peaks.

Figure 3 shows the surface appearance of the 3C-SiC samples for different carrier gas flow rates and growth pressures. It has been shown that the velocity of the gas flow at the center is the largest, which leads to the non-uniformity of the 3C-SiC[3]. The growth uniformity is very sensitive to growth conditions, especially in hot-wall CVD[6],

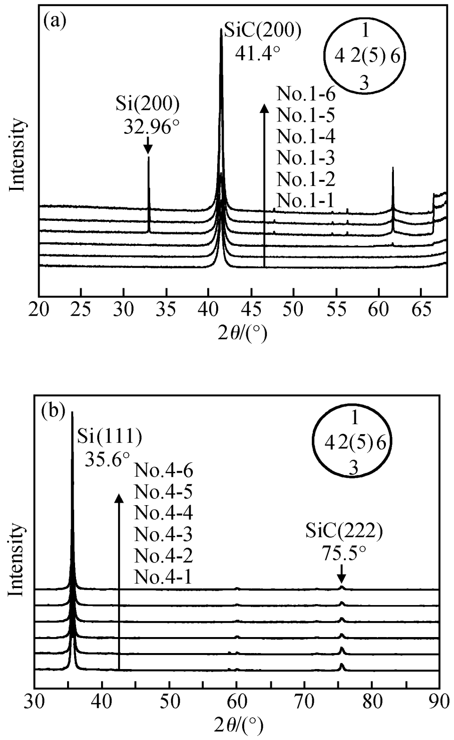

Fig. 2　XRD patterns of 3C-SiC films of different areas on samples No. 1 (a) and No. 4 (b)　The inset shows the measured areas on samples No. 1 and No. 4.

and can be improved by increasing the growth pressure or H_2 flow rate.

From Fig. 3, it can be concluded that sample No. 9 has the best thickness uniformity among these samples. The thickness was determined by spectroscopic ellipsometry. Table 2 shows the thickness of each measured point on sample No. 9.

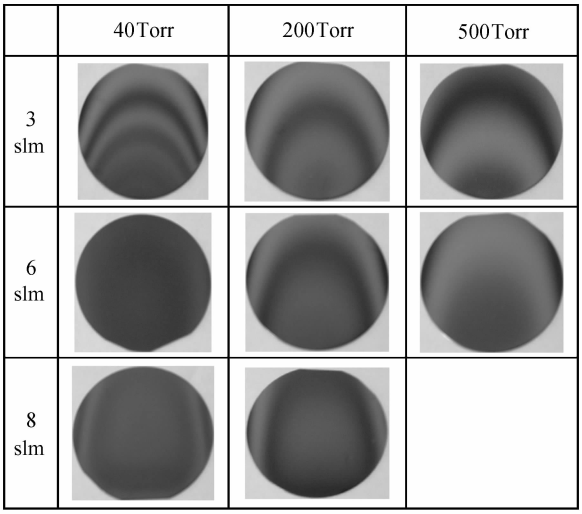

Fig. 3　Surface appearance of the samples obtained at different H_2 flow rates and growth pressures

Table 2　Thickness of each measured point on sample No. 8

Position No.	Thickness/nm
1	124.7
2	132
3	141
4	173.4
5	161
6	167.1
7	162.1
8	132.1
9	164.1
mean	150.8
σ/mean	± 5.7%

Figure 4 shows a typical schematic drawing of the measured point. The arrow shows the direction of gas flow. The thickness ranges from 124.7 to 173.4nm with a mean value of 150.8nm. The deviation is ± 5.7%, expressed as σ/mean. As shown in Table 2, the thickness of the epitaxial layer along the gas flow direction becomes smaller and the thickness on the vertical direction to the gas flow is small at the center and large at the edge.

The sheet resistance was obtained by Napson NC-40 non-contact sheet resistance measurement. The positions of the measured points are similar to those in Fig. 4. The σ/mean values of the sheet resistance of the different measured points are 4.77%, 2.25%, 2.35%, 2.15%, 5.88%, 5.57%, 6.04%, 6.95%, and 12.66%, for samples 1, 2, 3, 4, 5, 6, 7, 8, and 9, respectively. From these data, it can be concluded that homogeneity in sheet resistance can be obtained at a lower H_2 flow rate. Sample No. 9, with the best thickness uniformity has the biggest deviation in σ/mean value. To obtain good uniformity in both thickness and sheet

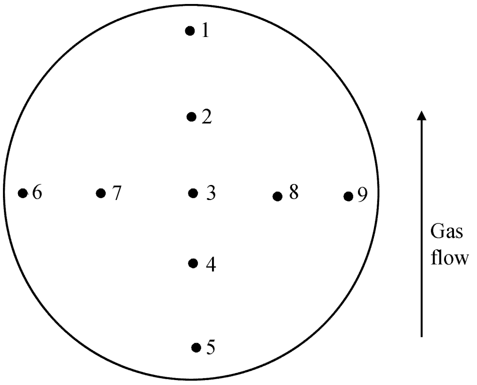

Fig. 4　Schematic drawing of the measured point and the direction of gas flow

resistance, the growth condition has to be compromised. The sheet resistance is related to doping concentration. There is no direct relation between thickness uniformity and doping concentration.

4 Conclusion

Crystalline 3C-SiC was obtained at the growth temperature of 1200℃ on 50mm (100) and (111) Si substrates by using horizontal low-pressure hot-wall CVD. The structure, electrical properties, and thickness uniformity of the 3C-SiC epitaxial layers was investigated. With increasing H_2 flow rate and growth pressure, the thickness uniformity of the 3C-SiC epitaxial films was improved. A σ/mean value of ±5.7% was obtained. The best electrical uniformity of 50mm 3C-SiC films obtained by using sheet resistance measurement was 2.15%. To obtain good uniformity in both thickness and sheet resistance, the growth conditions must be optimized further.

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利用水平热壁 CVD 法生长的 3C-SiC/Si 的均匀性

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摘要： 利用新改进的水平低压热壁 CVD 设备，改变生长时的压力和 H_2 流速，在 50mm 的 Si(100)和(111)衬底上获得了 3C-SiC 外延膜，并对外延膜的结构均匀性、电学均匀性和厚度均匀性进行了分析. X 射线衍射图中出现了强的 3C-SiC 的特征峰，其中 3C-SiC 的(200)和(111)峰的半高宽分别为 0.41°和 0.21°. 3C-SiC 外延膜方块电阻的均匀性最好可达 2.15%. 厚度均匀性可达 ±5.7%(σ/mean 值).

关键词： 3C-SiC；异质外延生长；水平热壁 CVD；均匀性

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