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The growth and characterization of 3C-SiC films deposited on sapphire by thermal chemical vapor deposition

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***Abstract*- This paper presents the growth of 3C-SiC epilayers on c-plane sapphire by thermal CVD method with and without the AlN buffer layer. The films grown were characterized by X-ray diffraction with 2-Theta, Omega scan and Phi-scan. AFM analysis and room temperature Photoluminance (PL) were performed to study the surface morphology and structure. The results suggest that the high oriented SiC(111) epilayers were achieved on sapphire by thermal CVD. The SiC films grown contained twin domain cubic structure with triangular shape morphologies either with or without AlN buffer layer were confirmed by AFM image and XRD phi-scan diffractions. The AlN buffer layer has a significant effect to improve the crystalline quality of SiC epilayer.**

I. INTRODUCTION

Silicon carbide (SiC) is regarded as one of the most promising material for high temperature, high power, radiation-resistant electronics applications due to its wide bandgap(2.3~3.3eV) and high breakdown electric field (3-5MV/cm, 10 times that of silicon) characteristics [1-3]. Although commercial hexagonal SiC wafer with 4H and 6H polytype are available, 3C-SiC is often taken into account owing to that it has one of the largest electron mobility(~800cm2/Vs) and smallest band-gap (2.3eV) with more isotropic than all the polytypes [4,5]. In addition, for the nanoelectronics applications, recently 3C-SiC(111) is considered to be a promising template for large-scale epitaxial growth of graphene [6,7]. But till now, no 3C-SiC substrate is commercial available. Heteroepitaxial growth of 3C-SiC has been mainly performed on silicon substrates [8, 9]. However, the crystalline quality of 3C-SiC is still limited not only due to the large lattice mismatch with silicon (~20%) but also the low melting point (<1400℃) of Si substrate.

To achieve high quality SiC epitaxy, a suitable substrate with high melting point is required. In this study, the c-plane sapphire wafers are adopted as substrates to grow 3C-SiC in the thermal CVD system. Sapphire wafer is the most popular substrate for epitaxy growth of III-Nitride, oxide and Si etc., due to its high thermal stability and relatively low cost. Although sapphire inherits excellent nature as substrate, growth of SiC directly on sapphire by CVD would easily result in peeling off. [10]. Alumina nitride (AlN) layer is usually considered to be a good buffer layer on sapphire substrate for III-Nitride growth. Many literatures have shown that the AlN buffer layer has a significant effect in improvement of the quality of epilayers [11, 12]. Accordingly, to improve crystalline quality of SiC film on sapphire, the effect of AlN buffer layer on the growth of SiC are characterized and studied.

II. EXPERIMENTAL

In this study, commercially available 2inches size c-plane sapphire wafers with double side polished were used as substrates for SiC growth. The growth of SiC films were carried out on our homemade thermal chemical vapor deposition (CVD) systems with horizontal cold wall quartz tube and the SiH_4–C_3H_8–H_2 gaseous system was employed for the reaction gases. The substrate was then placed on a graphite susceptor coated with SiC that was heated by radio frequency induction. The mixed gases of SiH_4 (5% diluted in H_2) and C_3H_8 (99.99%) were carried by H_2 (99.999%) into the thermal CVD chamber for the growth of SiC on sapphire using either with AlN buffer layer or without. The steps of the three-step process for SiC growth include carbonization, diffusion and growth by thermal CVD. The sequences of the steps and growth parameters are illustrated in Figure 1 and Table1, respectively. The AlN thin buffer layer about 100nm of thickness was deposited in Veeco D-180 MOCVD system at 1050℃.

The structure and characteristics of SiC films were studied by x-ray diffraction (XRD) with rocking curve and phi-scan. The surface morphologies of film grown were examined by atomic force microscopy (AFM). Room temperature PL was performed to characterize the structural poly type from luminescence.

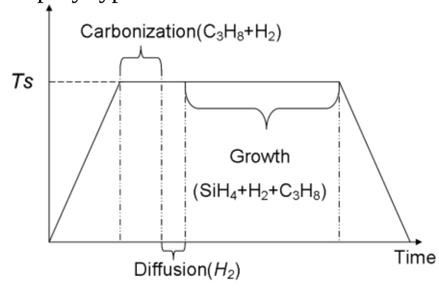

Fig.1.Schematic showing the three-step process for the growth of SiC on the substrate.

TABLE 1

Experimental parameters for the growth of high quality SiC films using three-step process.

	Carbonization	Diffusion	Growth
H_2 (sccm)	100	100	100
C_3H_8 (sccm)	10	0	3
SiH_4(sccm)	0	0	20
Temperature(℃)	1390	1390	1390
Time (min)	5	1.5	30

III. RESULTS AND DISCUSSION

Both of the SiC films grown on Sapphire with and without AlN buffer layer were light transparent with green color and no peeled off was observed for 2 inch diameter wafers. Fig.2 shows the X-ray 2-Theta diffraction spectrum of SiC films grown on sapphire substrate with and without AlN buffer layer. The "*"sign in the figures indicates the signal from sapphire substrate. Although it is difficult to distinguish the 6H or 3C structure only from XRD 2-Theta scan, we temporarily index as 3C structure and confirm by AFM and PL. In Fig. 2(a), the peak of SiC (111) and SiC (222) are located at 2θ=35.62° and 75.36°, respectively. In Fig.2 (b), the 2θ=35.63° and 75.36° are indexed as SiC (111) and SiC (222); 2θ=36.08° and 76.55° are indexed as AlN (002) and AlN(004), respectively. Except for the SiC(111) family, no other peak is can be observed both in Fig.2(a) and 2(b). It suggests that high oriented SiC(111) epilayers were achieved on sapphire by thermal CVD. However, relatively weak diffractions from Si (111) were detected both in the films. But the Si (111) diffraction gets reduced as AlN buffer layer is adopted.

To characterize the crystalline quality of SiC grown films, the XRD omega scan mode (rocking curve) were performed. As shown in Fig.3, the full width half maximum (FWHM) of rocking curve correlated to the SiC grown with and without AlN buffer layer are estimated to be 110.5 arcmin and 191.5 arcmin, respectively. The FWHM of rocking curve of AlN layer on sapphire is 34.3 arcmin (not shown here). From the data in Fig.3, it suggests that the AlN buffer indeed plays an important role to enhance the crystalline quality of SiC grown.

Fig. 4 show the AFM images of SiC films grown on sapphire with and without the AlN buffer layer. Both in the Fig.4(a) and 4(b) exhibit the specific triangular shape of the SiC surface implying that the structure of SiC film should be 3C cubic structure with (111) plane. The different grain sizes of the SiC grown on AlN and Al_2O_3 (sapphire) are observed. Average grain size of 270nm (Fig.4(a)) and 400nm (Fig.4(b)) of SiC grown on Al_2O_3 and AlN are estimated. From the result suggests that the AlN buffer layer provide a better nucleation for SiC crystal growth in 3D mode. Moreover, the root mean square (rms) of surface roughness of Fig. 4(a) and 4(b) are 12.6nm and 38.5nm, respectively. Before SiC growth, the rms of AlN/sapphire is estimated to be 10.2nm. Accordingly, the increased rms of SiC on AlN/sapphire might be not only due to the larger SiC grain size but also the AlN morphology.

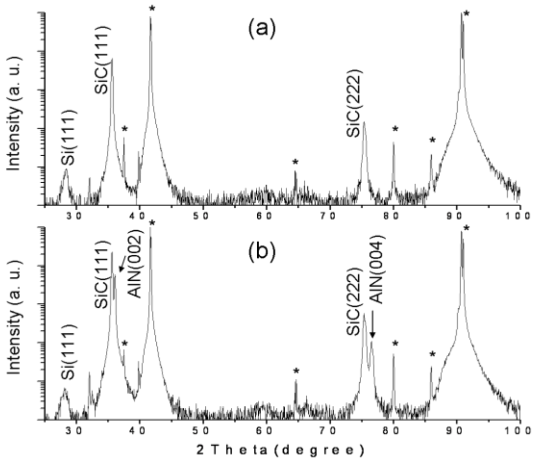

Fig.2. XRD spectrum of (a) SiC without AlN buffer layer and (b) SiC with AlN buffer layer grown on c-plane sapphire. The signal diffracted from sapphire substrate are indicated by "* "sign.

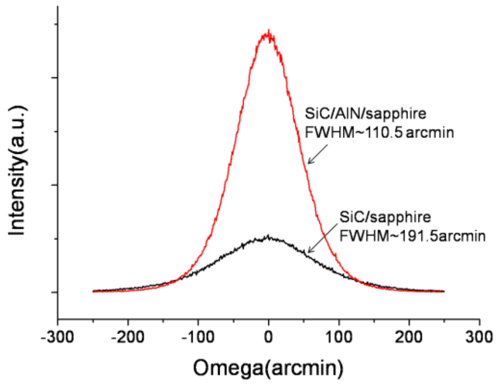

Fig.3. X-ray diffraction omega scans of SiC films grown on sapphire with and without AlN buffer layers.

In order to examine the structure of SiC in this study, we further measured the room temperature PL on the SiC samples. Fig. 5 shows the PL spectrum of SiC film grown with and without AlN buffer on sapphire. As shown in Fig.5, the peak values of 2.283eV and 2.271eV are observed, these are correlated to the SiC grown with and without AlN buffer layer. The higher intensity of SiC grown on AlN buffer should arise from higher crystalline quality. Because the bandgap of 3C-SiC is around 2.3eV, the structure of the SiC films in this study is confirmed to be cubic phase from the peaks of PL.

To understand the growth relationship of SiC on c-sapphire and AlN/c-sapphire, the phi-scan of XRD was performed. Fig, 6(a) shows the XRD phi-scan diffraction spectrum of SiC grown on c-sapphire with SiC (111), and sapphire (104). In Fig.6(a), there are 3 peaks correlated to sapphire. The diffractions from sapphire exhibit 3 fold symmetry due to the $R3\overline{C}$ space group. However, there are 6 peaks from 3C-SiC(111) in Fig.6(a). Based on the AFM images and PL analysis, the structure of SiC should be cubic. Therefore, the 6 peaks from SiC should come from the twin domains growth of 3C-SiC (111). As indicated in Fig. 6(a), the "▲" and "★"represents the two different anti-phase domain in SiC respectively. The Peaks difference between sapphire and SiC is +/-30°. Besides, the phi-scan angle difference between two domains is 60° suggesting that the twin domains of SiC (111) are 60° rotational symmetry.

In addition, Fig.6(b) shows the XRD phi-scan of SiC grown on AlN/c-plane sapphire with SiC (111), AlN (102) and sapphire (104) diffractions. In Fig.6(b), there are 6 peaks from AlN are detected. That is because AlN belongs to $P6_3mc$ which leads to 6 fold symmetry. The same as in fig.6(a), the "▲" and "★" represents the dual domains of SiC. The peaks difference between sapphire and SiC are also +/-30°. The growth relationships between SiC(111) and c-sapphire are the same either with and without AlN buffer layer. Furthermore, the AlN buffer layer grown on the sapphire substrate shows +/-30° difference with sapphire and 0° difference with SiC of phi-angle in Fig.6(b). It suggests that the relationship between AlN and SiC are coherent and AlN buffer layer would affect the crystal growth of SiC. From the demonstration, the existence of twin domains growth of 3C-SiC(111) on AlN or on sapphire is evident.

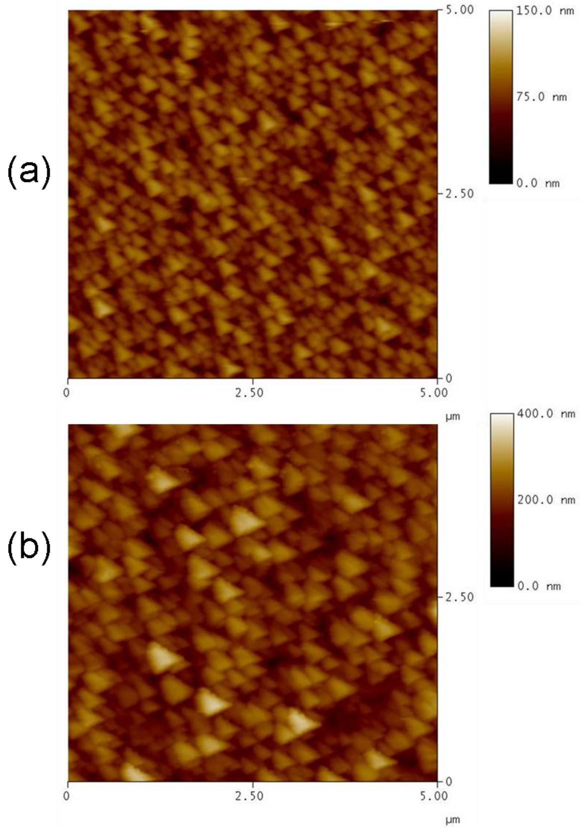

Fig.4. AFM images of (a) SiC without AlN buffer layer and (b) SiC with AlN buffer layer grown on c-sapphire by thermal CVD. The size of the area scanned is 5um x 5um.

IV. CONCLUSION

High quality SiC epilayers were grown on sapphires with and without AlN buffer layer by thermal CVD with the SiH_4–C_3H_8–H_2 gaseous system. From XRD spectrum, highly oriented (111) plane SiC films are obtained. The FWHM in rocking curve demonstrates that the crystalline quality of SiC film can be improved by introducing the AlN buffer layer on sapphire. AFM images exhibit specific triangle shape morphology suggest that the grown SiC epilayers exhibit cubic structure of (111) plane either with or without AlN buffer layer. The room temperature PL spectrum confirms the 3C-SiC structure in the grown film from luminescence peaks. The twin domain growth in 3C-SiC was confirmed by XRD phi-scan. The growth relationship of SiC on the template is determined as +/-30° offset with sapphire and 0° with AlN.

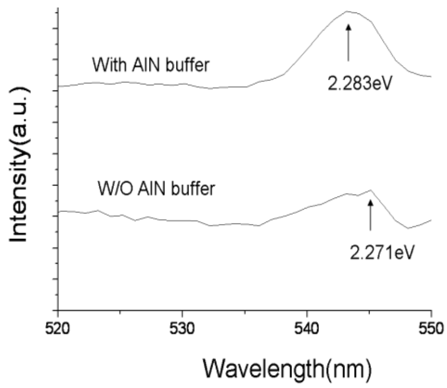

Fig.5. The room temperature PL spectrum of SiC grown with and without AlN buffer layer.

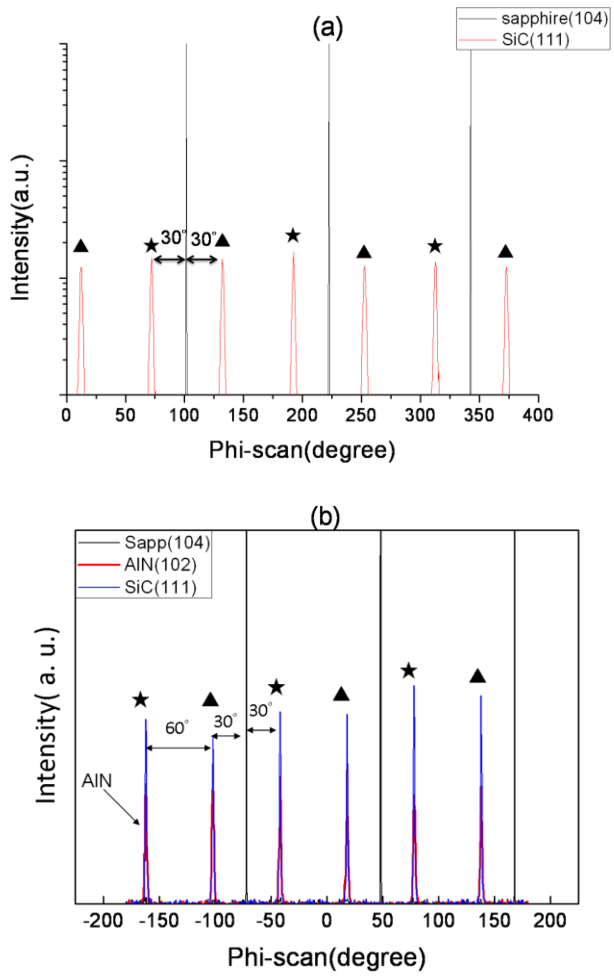

Fig.6.XRD phi-scan spectrum of SiC grown by thermal CVD on (a) c-plane sapphire and on (b) AlN/c-sapphire with SiC(111), AlN(102) and sapphire(104) diffractions.

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