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Optical Properties of GaN Films Grown on SiC/Si

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Abstract. 3C SiC grown on Si and on SOI wafers have been used as substrates for GaN growth. The optical properties of GaN/3C SiC are compared to those of GaN grown on the commonly used sapphire substrates and on 6H SiC substrates. Mapping of the PL characteristics over ~ 1 inch substrates indicate a fairly strong edge effect in terms of peak intensity for GaN/3C SiC. Interestingly, the wavelength of the peak intensity was quite uniform over the entire wafer area, with an average value of 365 nm and a standard deviation of ~ 3.3 nm. Mapping of the FWHM of the emission peak exhibited some edge effect, with the lowest values in the center of the wafer. The average PL FWHM was ~ 17 nm, with a standard deviation of ~ 1.4 nm.

1. Introduction

Sapphire has been commonly used as a substrate for GaN growth for a number of years now, mainly due to its wide availability and excellent surface preparation. Sapphire is also extremely stable at the temperatures normally used for GaN growth. However, the large lattice mismatch and the large thermal mismatch between the two materials results in the generation of a high density of defects in the GaN epitaxial layers. Hexagonal SiC (6H) offers a much smaller lattice mismatch (3.5%). Although this mismatch is still too large to allow for thick pseudomorphic GaN film growth, it should help in lowering the defect density in the GaN epi layers. However, the high cost, small size (< 5 cm) and limited availability represent significant practical obstacles to the use of 6H SiC as substrates for GaN growth. We have previously demonstrated the ability to deposit good quality GaN films on 3C SiC layers grown on silicon on insulator (SOI) substrates [1]. In this paper, we discuss the optical properties of GaN films grown on SiC/Si and on SiC/SOI substrates with an emphasis on "uniformity" issues over entire (but small) wafer areas. We also compare the results obtained from GaN/3C SiC to those of GaN films grown under optimized conditions on 6H SiC and sapphire substrates.

2. Experimental Conditions

SiC films were grown in a chemical vapor deposition (CVD) system on Si substrates under conditions identical to those used for growth on the SOI substrates [1]. We have utilized atmospheric pressure carbonization with propane and hydrogen at a temperature of 1200 °C to 1300 °C. The Si substrates were (111) off-axis wafers. The SOI structures had a thin (100 nm) Si (111) device layer, a 1 μm SiO_2 layer and a (100) - oriented Si substrate. GaN films were grown on the SiC layer by MOCVD using trimethylgallium (TMGa) and ammonia precursors at 1000 °C for one hour, producing ~ 1-2 μm thick films. The growth techniques have been described in detail elsewhere [2,3].

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3. Thin Film Characteristics and Discussion

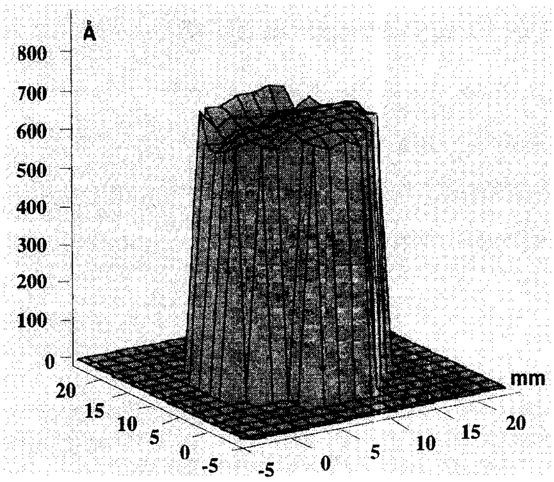

Fig. 1 Thickness uniformity of SiC on Si across a 1 inch wafer.

The thickness uniformity of SiC grown on Si has been mapped using ellipsometry. A typical result is shown in Fig. 1, where an average thickness is obtained over a 1 inch wafer.

SiC films grown on Si and on SOI substrates were routinely characterized by x-ray diffraction (XRD) and were found to give a single peak corresponding to the (111) orientation. Fig. 2 shows XRD spectra from SiC films grown on SOI wafers under two different conditions: (a) B23 was grown at 1200°C for 6 min: (b) B24 was grown at 1250°C for 3 min. B24 exhibits only a strong SiC <111> peak. On the other hand, B23 shows a strong peak from the Si (111) device layer and a weak peak from the Si (100) substrate, in addition to the SiC <111> peak.

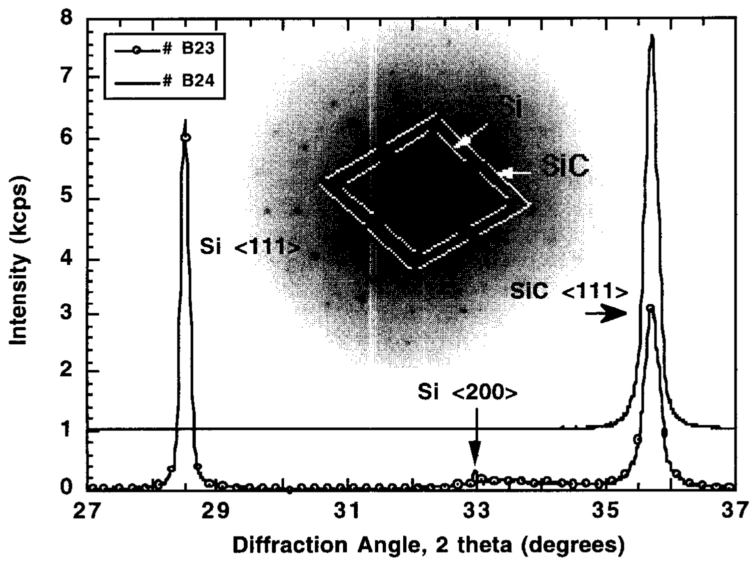

Fig. 2 XRD of SiC SOI structures grown under two different conditions: B23 - 1200°C, 6 min; B24 - 1250°C, 3 min.

This comparison of XRD spectra indicates the importance of growth temperature on the amount of Si that is converted to SiC. The absence of a Si <111> peak in the sample grown at 1250 °C shows that most of the Si device layer has been consumed during the carbonization process. However, there is still some unconsumed Si as the TED pattern in the Fig. 2 insert clearly shows. One can also see a strong orientation relationship between the SiC and the Si indicating oriented SiC growth. Similar data was also obtained from the SiC grown directly on a Si wafer.

Fig. 3 shows XRD scans from GaN films that were grown on a number of substrates including SiC/SOI, SiC/Si, 6H-SiC, and sapphire. The X-ray intensity counts are arbitrary and the curves have been separated for clarity.

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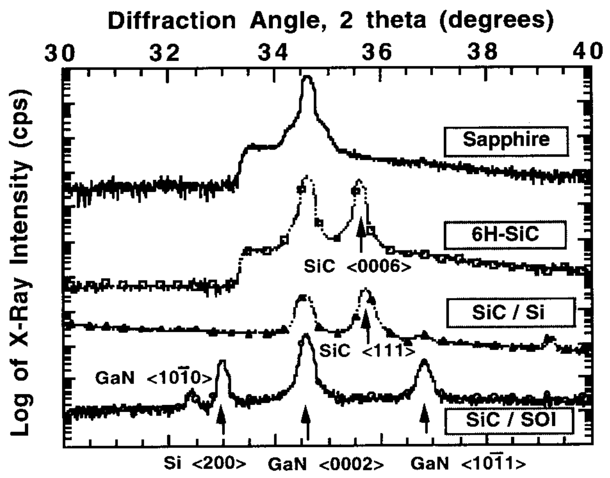

Fig. 3 XRD plots from GaN grown on various substrates.

It can be seen from Fig. 3 that the GaN growth is single crystal on sapphire, 6H, and on the SiC/Si substrates, exhibiting a single (0002) peak. In the case of the SOI substrates, the GaN shows additional peaks at 32.4° and at 36.8°, clearly indicating polycrystalline structure. The samples grown on 6H SiC and on 3C SiC/Si also display the SiC <0006> and <111> peaks, respectively.

Fig. 4 shows a comparison of the PL intensity obtained at room temperature from GaN grown on 3 different substrates. The GaN on sapphire clearly gives the strongest signal which is to be expected given the considerable work that has already been done in optimizing growth on this substrate.

There is a significant difference in intensity levels obtained from GaN films grown on 6H-SiC and GaN on 3C SiC/Si, with the latter showing much stronger light emission. While, one must always be careful in drawing any direct conclusions from such an intensity comparison, it is interesting to note that for approximately the same thickness, under identical measurement conditions, the signal intensity from the GaN grown on 3C SiC/Si is much stronger than from the GaN grown on the 6H substrate. This indicates that the *potential* exists to obtain better quality GaN from growing on a 3C SiC surface under optimized conditions.

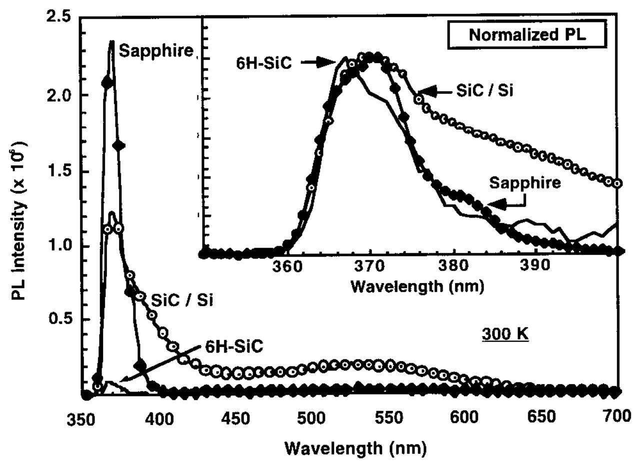

Fig. 4 Photoluminescence Spectra from GaN films grown on several substrates.

The insert in Fig. 4 shows the normalized PL (normalized to the maximum PL intensity for each curve) from the GaN on these 3 substrates. It may be seen that the GaN grown on the SiC/Si has the largest FWHM, which points out that considerable work needs to be done in improving the emission from the GaN/SiC/Si. It is interesting to see that the emission curves from the GaN/6H-SiC and GaN/sapphire are almost coincident. Given the fact that the lattice parameter of 3C-SiC in the (111) orientation is very close to that of 6H-SiC in the <0001> orientation, this implies that an equally good FWHM may theoretically be possible by growing GaN on 3C-SiC/Si (111) as well.

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Mapping of the PL intensity (I_p) over a fairly broad spectral range (350-400 nm) from GaN grown on 3C SiC/Si indicates a fairly strong edge effect: (a) there is a fairly uniform region covering the central part of the wafer; (b) this is followed by a decreasing level of I_p as one approaches the wafer periphery. This edge effect, though still present, is much weaker in GaN grown on commercially obtained 6H SiC substrates and nearly absent for sapphire substrates. We, therefore, attribute the main reason for this effect to the surface conditions of the underlying film or substrate.

Fig. 5 shows a map of the peak wavelength (λ_p) across the 1 in 3C SiC/Si wafer. The average $\langle\lambda_p\rangle$ is ~ 365 nm with a standard deviation of 3.28 nm. Interestingly, for GaN on the 6H surfaces, the $\langle\lambda_p\rangle$ is 364 nm, but with a much smaller standard deviation of 0.14 nm. A map of the full width at half-maximum of the PL peak from the GaN film on SiC/Si is shown in Fig. 6. The average FWHM is ~17.3 nm and its standard deviation is 1.37 nm. The corresponding values for GaN grown on 6H SiC are 11.3 nm for the average FWHM and 0.18 nm for its standard deviation.

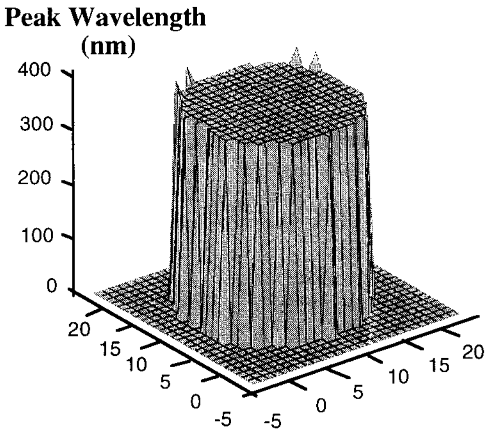

Fig. 5 Map of the peak wavelength of emission from GaN/SiC/Si across a 1 inch wafer.

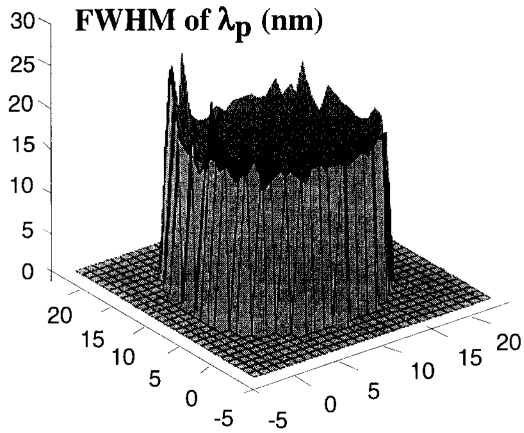

Fig. 6 Map of the FWHM of peak emission from GaN/SiC/Si across a one inch wafer.

4. Summary

From the above results, it is seen that 3C SiC grown on Si (111) or on SOI substrates may eventually serve as a cheaper alternative to currently used sapphire or 6H-SiC substrates. The photoluminescence obtained from the GaN films grown on the economical 3C-SiC/Si substrates, although far from optimized, is still comparable to that obtained from the far more expensive substrates. In addition, the use of SOI substrates may help in obtaining self-supporting GaN layers which can then be used as substrates for GaN homoepitaxial growth.

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