Effect of Carbonization Process Conditions on Surface Morphology of 3C-SiC Films Grown on Si Substrates

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Cubic silicon carbide (3C-SiC) has attracted interest as a commercially viable electronic material because it can be grown on inexpensive silicon (Si) substrates using chemical vapor deposition (CVD), and because it possesses an isotropic electron mobility of 1000 cm^2/V s. However, 3C-SiC grown on Si substrates still contain numerous types of defects generated from the large lattice parameter mismatch between SiC and Si. In this study, we have investigated surface morphology and crystallinity of 3C-SiC films grown on Si substrates using different carbonization processes. Two-inch Si(001) substrates, miscut 2.5º toward the [110] direction, were used in this investigation. Epitaxial growth of 3C-SiC on Si substrates consists of a three-step process; *in-situ* cleaning of wafer surfaces with hydrogen at 1100 ºC, carbonization with propane as a carbon-based precursor gas at 1150 ºC or 1250 ºC, and epitaxial film growth with propane and silane at 1350 ºC.

Comparisons are made between surface morphologies in 3C-SiC films when propane gas is introduced into the growth environment at 700 ºC or 1100 ºC to initiate the carbonization process. This comparison shows 3C-SiC film quality dramatically improves when the cell temperature is lowered to 700 ºC prior to flowing propane into the chamber. Nucleation sites for 3C-SiC are generated by the interaction between the Si surface and carbon atoms via thermal decomposition of the carbon-based precursor gas. The nucleation island growth rate will increase with sequent ramping up to carbonization temperature. As the reaction of carbon and silicon occurs, voids in the silicon are generated, as discussed by Li, et al [1]. Introduction of propane gas at higher temperature enhances void formation, leading to surfaces that are rougher than when propane is introduced at 700 ºC. This has been observed in the current experiment using scanning electron microscopy (SEM).

Carbonization temperature is shown to strongly affect surface defect densities in 3C-SiC films. Surface investigation in 3C-SiC films with carbonization performed at 1150 ºC or 1250 ºC reveals a significant decrease in the density of surface protrusions with decreasing carbonization temperature, with greater than 400/mm^2 for 1250 ºC carbonization, and less than 30/mm^2 for 1150 ºC carbonization. Using SEM and scanning probe microscopy, these protrusions appear to originate from voids caused by Si out-diffusion from the substrates during carbonization process [2]. Si out-diffusion during carbonization is enhanced with an increase of carbonization temperature, resulting in an increased density of surface defects. Comparing different propane gas flow rates of 3 sccm and 15 sccm during carbonization, x-ray diffractometry indicates little influence on crystalline quality as flow rate changes.

[1] J. P. Li and A. J. Steckl, J. Electrochem. Soc., **142**, 634 (1995).
[2] R. Scholz, U. Gosele, E. niemann, and F. Wischmeyer, Appl. Phys. A **64**, 115 (1997).

Table 1. Carbon-based precursor gas-on temperature and carbonization conditions of each sample

Sample No.	Gas-on temperature (°C)	Pressure (mbar)	Carbonization temperature (°C)	C_3H_8 flow rate (sccm)	Time (min)
1	1100	300	1250	3	2
2	1100	300	1150	3	2
3	700	300	1250	3	2
4	700	300	1150	3	2
5	700	300	1150	15	2

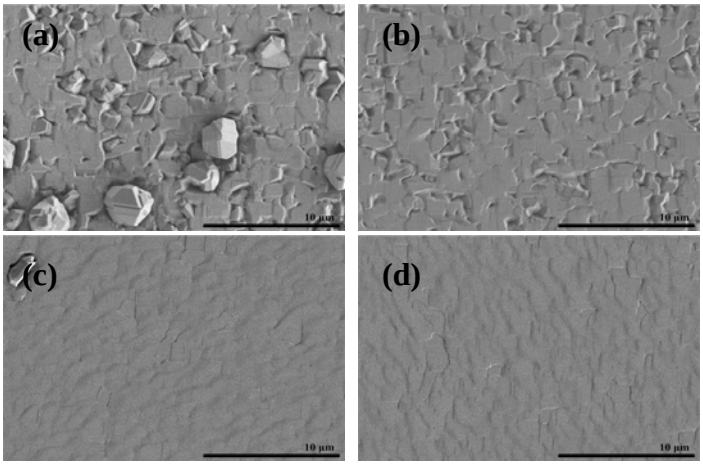

Fig. 1 Plan-view SEM analysis of the 3C-SiC films grown on Si(001) substrates for (a) propane gas on at 1100, (b) sample No. 2, (c) sample No. 3, and (d) sample No. 4.

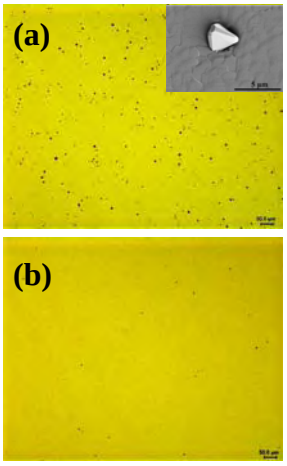

Fig. 2 Observation of the surface morphology of 3C-SiC using Normarski interference optical microscopy for (a) sample No. 3 and (b) sample No. 4. (Inset) SEM image of a protrusion on the surface.

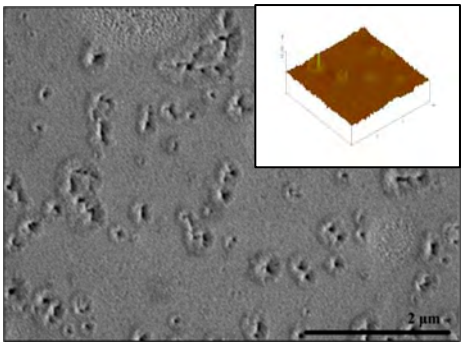

Fig. 3 Plan-view SEM analysis performed on a thin buffer layer grown on Si(001) substrate during carbonization process. (Inset) AFM image showing unsealed voids and hollow-shaped growth on the void edge.

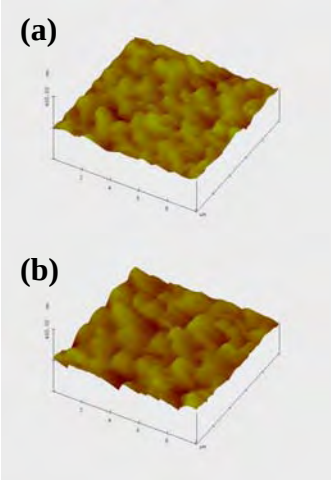

Fig. 4 AFM images showing the surface morphology of 3C-SiC films for (a) sample No. 4 and (b) sample No. 5.

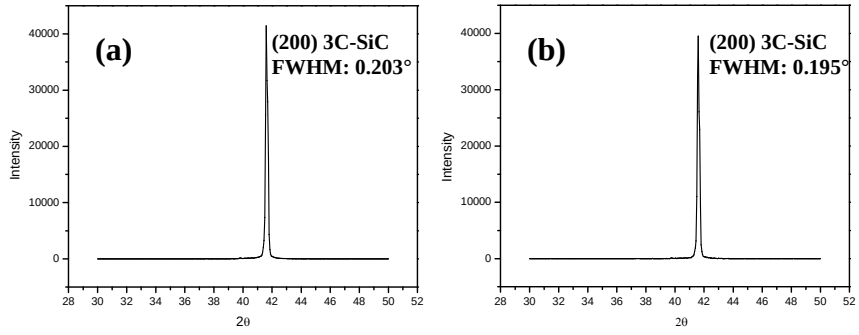

Fig. 5 XRD patterns from 3C-SiC films with two different carbonization temperatures: (a) sample No. 4 (3 sccm propane) and (b) sample No. 5 (15 sccm propane).