Reduced temperature growth of crystalline 3C-SiC films on 6H-SiC by chemical vapor deposition from silacyclobutane

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3C- on 6H-SiC (0001) epitaxial growth from the single-source organosilane precursor silacylobutane (c-$C_3H_6SiH_2$) has been investigated over the temperature range of 800–1100 °C. Spectrophotometry was used to determine an optical absorption edge of ~2.27 eV for the films grown at 900 °C, corresponding approximately to the energy band gap of 3C-SiC. The crystallinity, structure, strain, and dislocation density in the 3C-SiC thin films were determined using double crystal x-ray diffractometry (DCXRD). The films grown at 800–1000 °C were found to be exclusively 3C-SiC. The films grown at 1100 °C were a mixture of 3C, 4H, and 6H polytypes of SiC. All films shown an excellent surface morphology. The optimum films are obtained at 900 °C, exhibiting structural properties nearly equal to those of the substrate: narrow DCXRD peak width (~17 arcsec) and low dislocation density ($\sim 3\times10^6$ cm^2). © *1995 American Institute of Physics.*

I. INTRODUCTION

SiC exhibits superior physical properties[1] as a semiconductor material for various high temperature and high power electron devices[2] requiring a wide band gap energy, high breakdown electric field, high thermal conductivity, etc. Among the various SiC polytypes, 3C-SiC with a band gap of ~2.3 eV is believed to have the highest electron mobility, while the 6H-SiC polytype with a band gap of ~3.0 eV, is currently available as a commercial substrate. Epitaxial growth of (111) 3C-SiC on c-plane (0001) 6H-SiC is the material system of choice because of the very small (<0.1%) lattice mismatch between film and substrate. In addition to providing 3C-SiC epilayers for homojunction applications, the growth of 3C-SiC on 6h-SiC also produces a junction with a ~0.7 eV band gap energy difference for heterojunction device applications. Previous reports of crystalline 3C-SiC grown on 6H-SiC have mostly utilized chemical vapor deposition (CVD) with two gas precursors,[3–7] which requires high growth temperature (~1150–1450 °C) and independent flow control of each precursor. Reduction of growth temperature has been an important goal in the fabrication of SiC devices in order to reduce the defects caused by high temperature processing. The successful growth of crystalline 3C-SiC films on Si (100) and (111) at the reduced temperatures of 800–900 °C from the single-source organosilane precursor silacylobutane (c-$C_3H_6SiH_2$, SCB) has been previously reported[8,9]The cyclic structure of the SCB molecule contains sufficient strain energy[10,11] to significantly reduce its decomposition temperature and, hence, the temperature required for SiC deposition. In this article, the chemical vapor deposition of 3C-SiC on 6H-SiC substrates is reported on using SCB over the temperature range of 800–1100 °C.

II. EXPERIMENTAL CONDITIONS

The substrates used in the experiments are on-axis n-type 6H-SiC (0001) ("research" grade) from Cree Research Inc. The deposition experiments were carried out in a computer-controlled rapid thermal (RT) CVD system, which was previously described[12] in detail. Prior to growth, *in situ* cleaning was performed in an HCl/H_2 atmosphere at 1200 °C. Next, SiC films were grown by SCB at temperatures ranging from 800 to 1100 °C. The typical growth conditions were: reaction time of 10 min, flow conditions of 1.9 l/min H_2 and 1 sccm of SCB, chamber pressure of 5 Torr.

Several analysis and characterization techniques were employed to study the grown SiC films. Ultraviolet (UV) and visible spectrophotometry were applied to determine the band gap energy. Double crystal x-ray diffraction (DCXRD) was performed to study the crystallinity, structure, strain, and dislocation density in the SiC thin films.[13,14] The angular resolution of the DCXRD measurements is 1 arcsec. The surface morphology was investigated by optical microscopy and scanning electron microscopy (SEM).

III. RESULTS AND DISCUSSION

The SiC films grown at all temperatures have a brownish color and exhibit a mirrorlike surface with an excellent morphology, as observed under the optical microscope. The surface is also observed to be very smooth under the SEM at high magnification. A Cary 2400 UV and visible spectrophotometer was used to determine the absorption edge. The optical band gap of the 6H-SiC substrate is found to be ~3.0

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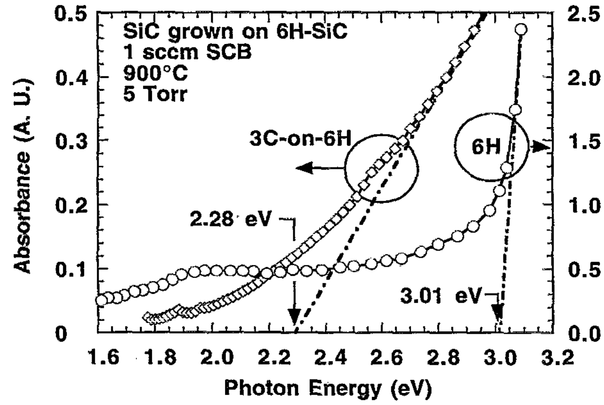

FIG. 1. Optical absorption spectra of 6H-SiC substrate and of sample with film grown at 900 °C with SCB on a 6H-SiC substrate.

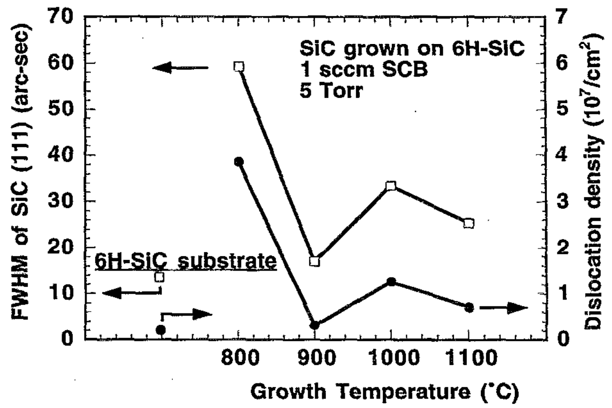

FIG. 2. Effect on film growth temperature on the full width at half maximum (FWHM) signal of SiC ⟨111⟩ double crystal x-ray diffraction (DCXRD) peak and on the corresponding dislocation density. Values for as-received 6H-SiC substrate also shown.

eV. With a 6H-SiC sample as the reference, the optical absorption edge of SiC films grown at 800, 900, and 1000 °C was measured to be about 2.2–2.3 eV, corresponding approximately to the energy band gap of 3C-SiC. In Fig. 1 is shown the optical absorbance of a SiC film grown at 900 °C, indicating an effective band gap energy of 2.28 eV.

Results from DCXRD measurements of 3C-SiC films grown on 6H-SiC by SCB at 900 °C are given in Table I. The two main DCXRD peaks monitored are the 3C-SiC⟨111⟩ and 6H-SiC ⟨0006⟩ reflections. Their theoretical angular separation is ~55 arcsec. The 3C structure of the grown SiC film was confirmed by the presence of the asymmetric [115], [224], and [024] reflections, which can be obtained at unique angular positions of the sample only if the surface is the (111) plane. The films grown at 800–1000 °C exhibited a complete overlap of the 3C-SiC ⟨111⟩ and 6H-SiC ⟨0006⟩ reflections at a Bragg angle of $\theta \approx 17.8°$. To the best of our knowledge this represents the first report of true epitaxial growth of 3C-SiC on 6H-SiC substrates. In these cases, we have taken the peaks occurring at 17.8° to be indicative of the properties of SiC film.

A very significant reduction in the dislocation density has been achieved for 3C-SiC grown on 6H-SiC (0001). These films exhibit a dislocation density in the low-10^6 to high-10^7 cm^2 range. These values are comparable to that measured for the 6H-SiC substrate itself (~2×10^6 cm^2). The full width at half maximum (FWHM) of the SiC (111) DCXRD peak and the corresponding dislocation density of the films are plotted as a function of growth temperature in Fig. 2. The FWHM of the ⟨111⟩ peak obtained from the film grown at 900 °C is ~17 arcsec, which is only slightly larger than the FWHM of the ⟨0006⟩ peak from the as-received substrate (~15.5 arcsec). In addition, it should be pointed out that these films were grown on as-received, on-axis 6H substrates, without an epilayer. It is expected that epitaxial growth with SCB at these low temperature on substrates whose polishing damage layer is removed (or with an epilayer present) will produce SiC films with even better characteristics. For comparison, DCXRD results obtained from 3C-SiC film on Si (100) also obtained from Cree Research is included.

Interestingly, the SiC film grown on 6H-SiC at 1100 °C is visually observed to be more transparent than SiC films grown at lower temperatures, indicating the possibility of other polytype formation. This is confirmed by the DCXRD spectrum shown in Fig. 3, which exhibits reflections from 3C, 4H, and 6H polytypes. The angular separation between

TABLE I. Double-crystal XRD results from 3C-SiC films grown on 6H-SiC with SCB. The FWHM of the major XRD peak is indicated along with the corresponding crystal axis. The strain, perpendicular and parallel to the film, is indicated whether compressive (C) or tensile (T).

Sample	FWHM of the films (arcsec)	Strain ⊥(%)	Strain ∥ (%)	Dislocation density of the films (/cm^2)
3C- 6H-SiC @900 °C	16.93 ⟨111⟩	0.3C	0.09C	3.15×10^6
3C- 6H-SiC @1100 °C	25.39 ⟨111⟩	0.18C	0.07C	7.14×10^6
SiC/Si(100)[a]	299 ⟨002⟩	0.04C	0.10T	9.83×10^8

[a]Sample from Cree Research (6-μm-thick SiC).

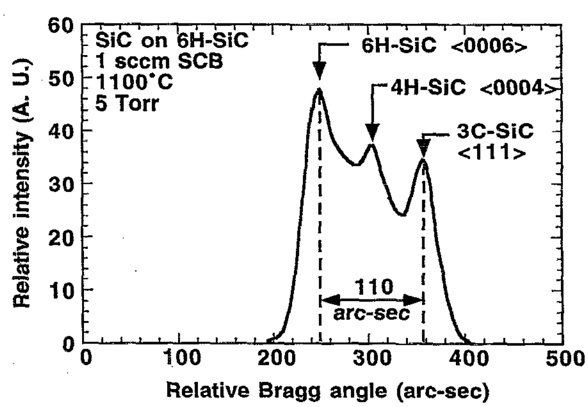

FIG. 3. DCXRD spectrum of sample with 3C-SiC film grown with SCB at 1100 °C on 6H-SiC substrate.

the 3C-SiC⟨111⟩ and 6H-SiC ⟨0006⟩ peaks is ~110 arcsec, which still shows only a small lattice mismatch between the epilayer and the substrate.

IV. SUMMARY

In summary, 3C-SiC thin films have been grown on 6H-SiC (0001) using the cyclic organosilane precursor SCB. Crystalline films have been obtained at growth temperatures as low as 800 °C. The optimum growth temperature appears to be around 900 °C, resulting in a film with structural properties nearly the same as those of the substrate: a very narrow DCXRD peak (~17 arcsec) and a dislocation density of $\sim 3\times 10^6/cm^2$. The results obtained indicate that the use of SCB as precursor for growth of 3C- on 6H-SiC is very promising for low-temperature deposition of crystalline films.

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