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Growth and Characterization of N-Doped SiC Films from Trimethylsilane

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ABSTRACT: Nitrogen-doped 3C-SiC films grown by chemical vapor deposition on Si (111) substrates using trimethylsilane (SiC_3H_9) have been investigated. The structure of the SiC films is studied by X-Ray diffraction, reflection-mode FTIR. The surface and interface of the grown films were examined by SEM. The effects of N_2 flow rate on the electrical properties of the 3C-SiC films were investigated by Hall effect measurement over a range of temperatures. The highest electron mobility measured at 300 K is 104 $cm^2/V{\cdot}s$ with a corresponding carrier concentration of 2×10^{17} cm^{-3}. The electron carrier concentration in trimethylsilane grown SiC films can be readily controlled by the flow rate of N_2.

1. INTRODUCTION

SiC is a promising material for microelectronic devices and MEMS to be used in extreme conditions such as high power, high temperature, high frequency, high radiation and highly corrosive environments. Current price and wafer size of commercially available SiC substrates limit the number of applications being pursued by industry. Heteroepitaxy of SiC on Si is an attractive alternative to obtain large area SiC pseudo-substrates at low cost. We have been pursuing the use of the novel organosilane precursor trimethylsilane (3MS–SiC_3H_9) as a low cost approach to develop large area 3C-SiC pseudo-substrates [1-2]. This gas is commercially available and relatively safe to handle. Films grown by CVD from 3MS [2] show that crystalline SiC can be obtained on Si(111) at growth temperatures as low as 1100°C. Our previous results show that the chemical and structural properties of SiC films grown using 3MS are similar to those grown at higher temperatures using the $SiH_4/C_3H_8/H_2$ gas system. In this work we studied the effect of *in-situ* N_2 doping on the structural and electrical transport properties of the SiC films using XRD, FTIR and Hall effect measurements.

2. EXPERIMENTAL

Nitrogen-doped SiC films were grown on 3 inch p-type Si(111) substrates with a resistivity of 150-300 Ω-cm. The 3MS purity is 99% (with ~1% toluene). A thin buffer layer was first formed using propane at 1300°C and atmospheric pressure. The propane flow rate was 10 sccm for the carbonization process. In the subsequent SiC growth, 40 sccm 3MS was utilized. H_2 was used as the carrier gas, while N_2 was used as the dopant source. The H_2 flow rate was 2 slm during carbonization and 1 slm during growth. N_2 flow rates from 0.1 to 20 sccm were used during both carbonization and growth. The growth temperature and working pressure were 1200°C and 4 Torr during all 3MS growth, respectively. The crystallinity of the SiC films was characterized by XRD. The SiC film surfaces and interfaces were checked by SEM. The incorporation of N in SiC was investigated by reflection-mode FTIR. Electrical properties of grown SiC films were investigated using Hall effect measurements with a magnetic field up to 1.2 T and a temperature range from 77 to 720 K. Electrical contacts were made by depositing Ni on the four corners of the sample and annealing at 900°C for 10 min. The quality of the electrical contacts was evaluated by checking the linearity of their I-V relation. The magnetic field was set at 1 T for all Hall effect measurements.

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3. RESULTS AND DISCUSSIONS

The XRD spectrum of a 3C-SiC film grown using 10 sccm N_2 at 1200°C for 3 min is shown in Fig. 1. A Si (111) peak at 28.4° and a SiC (111) peak at 35.6° are observed. No other SiC crystal orientations were detected. The FWHM of SiC (111) peak is 0.233°, which is 1.75 times that of the Si (111) peak. The FWHM values of N-doped SiC films are similar to those of films without N_2 doping. This indicates that N_2 doping does not significantly affect the SiC crystal structure by the incorporation of N atoms. The insert in Fig. 1 shows an SEM cross-sectional image of the N-doped SiC/Si. Voids in the Si substrate are clearly observable. The growth rate for this sample was 0.6 μm/min. In general, the SiC growth rate is in the range of 0.3-0.6 μm/min at 40 sccm 3MS and 1200°C, which is much higher than those typically obtained from the $SiH_4/C_3H_8/H_2$ gas system.

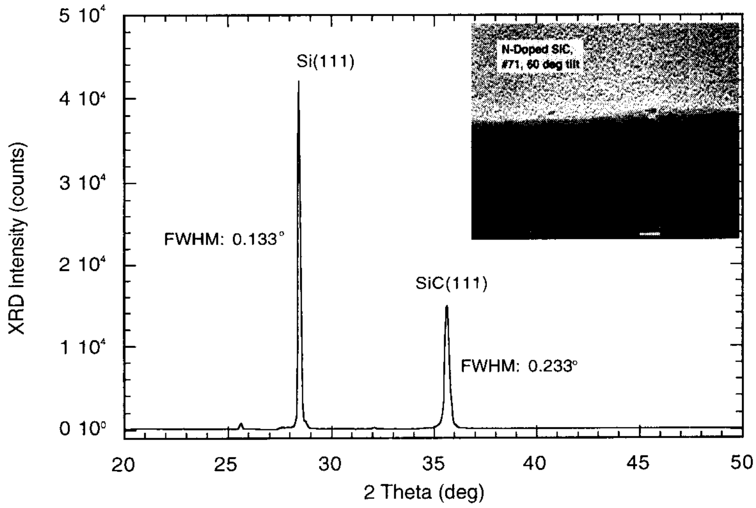

Fig. 1 XRD and SEM of N-doped SiC/Si(111) grown from 3MS at 1200°C.

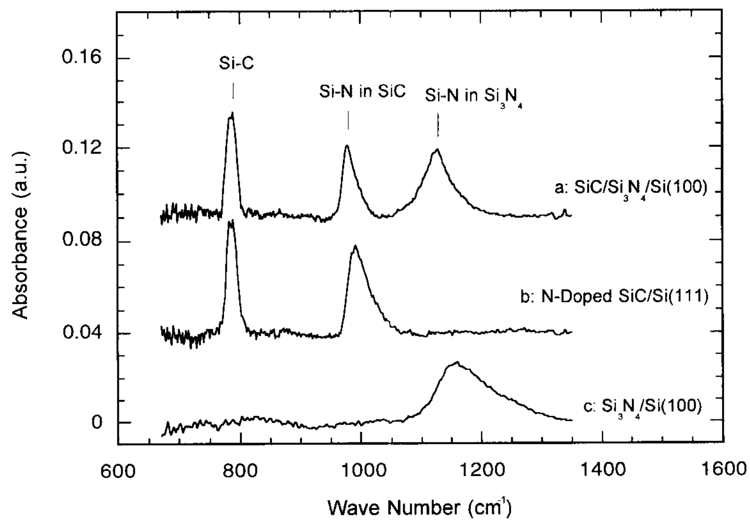

Fig. 2 Reflection-mode FTIR: (a) SiC grown on Si_3N_4/Si (100) at 1200°C and 40 sccm SCB; (b) SiC grown on Si (111) at 1200°C, 40 sccm 3MS and 0.1 sccm N_2 doping; (c) Si_3N_4/Si (100) substrate for SiC growth.

Reflection-mode FTIR was used to study the chemical structure of N-doped SiC. In Fig. 2a and 2b, the peaks at ~785 cm^{-1} are due to the Si-C stretching vibration. The peak at ~1159 cm^{-1} in Fig. 2c should be assigned to Si-N bond vibration in Si_3N_4 layer, as is the peak at ~1128 cm^{-1} in Fig. 2a. The peaks at 980-990 cm^{-1} in Fig. 2a and 2b can be reasonably assigned to Si-N bonds

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formed by N atoms occupying C vacancy sites in the SiC lattice. This possibility is much more likely than that of N atoms occupying Si sites and forming N-C bonds, due to the large difference of N and Si atomic radii. In addition, the C-N bond vibration peaks (in tertiary amine) are reported to be at ~1350 and ~2800 cm^{-1}.[3] Furthermore, we have observed a monotonic increase in the 980 cm^{-1} peak intensity with increasing N_2 flow rate during growth. This indicates that an increasing number of N atoms were incorporated in the C vacancies of the SiC lattice, generating an increasing number of electrons as shown in the following Hall effect measurements.

The electron mobility and carrier concentration of SiC films grown with 3MS are shown in Fig. 3 as a function of N_2 flow rate. Line (a) shows that by varying the N_2 flow rate from 0.1 to 20 sccm, the net electron carrier concentration changed from just above 1×10^{17} cm^{-3} to nearly 1×10^{20} cm^{-3}. The N_2 doping efficiency during SiC growth with 3MS is similar to that obtained with SiH_4/C_3H_8 in the same C:Si ratio of 3 on Si [4] and on 6H SiC [5]. Curve (b) shows the effect of the N_2 flow rate on the mobility. Increasing the doping level decreases the mobility from 104 $cm^2/V\cdot s$ for an electron carrier concentration of 2×10^{17} cm^{-3} to 2 $cm^2/V\cdot s$ when the electron density is 7×10^{19} cm^{-3}.

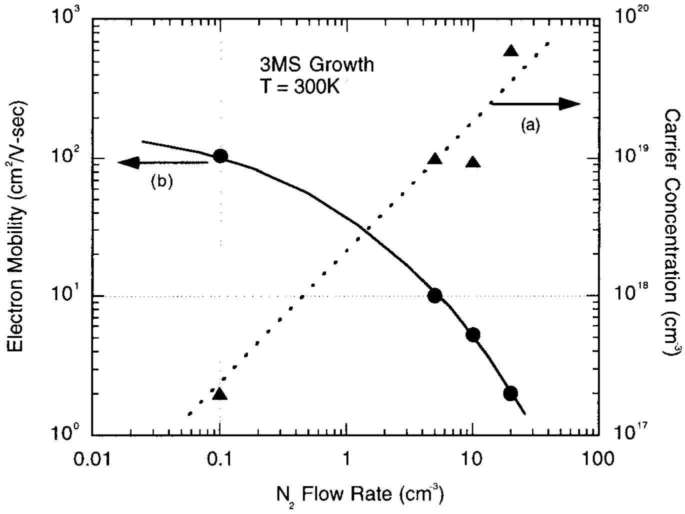

Fig. 3. Electron mobility and carrier concentration as a function of N_2 flow rate for 3MS grown SiC.

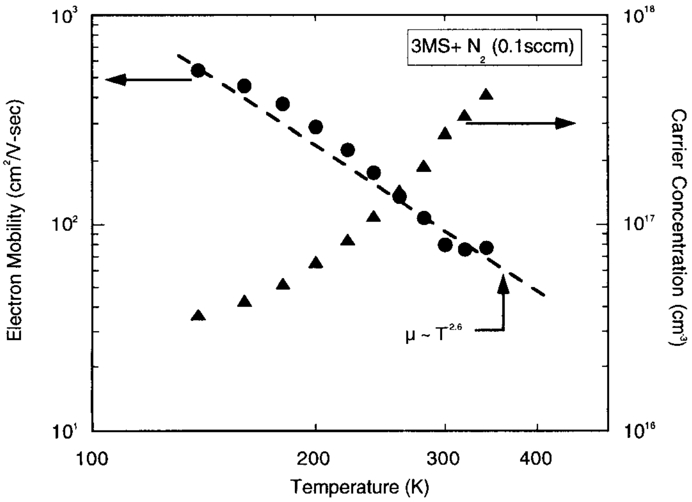

Fig. 4. Temperature dependence of electron mobility and carrier concentration of 3C-SiC films grown from 3MS with *in-situ* N_2 doping. Dashed line shows $\mu \propto T^{-2.6}$ curve fit.

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Fig. 4 shows the temperature dependence of electron mobility and carrier concentration in a SiC film grown with 0.1 sccm N_2 at 1200°C. The Hall electron mobility increases monotonically with decreasing temperature over the range measured. At 139 K, the electron mobility of the SiC film is 538.2 $cm^2/V{\cdot}s$ and it decreases to 76.6 $cm^2/V{\cdot}s$ at 342 K. The corresponding carrier concentrations are $3.63{\times}10^{16}$ and $4.15{\times}10^{17}$ cm^{-3}, respectively. The mobility decreases with a T^{-n} dependence, with n = 2.6. This temperature dependence is probably due to lattice scattering. Similar results have been suggested by Suzuki et al. [4] for SiH_4/C_3H_8-grown SiC films, where they measured a value of n = 2 – 2.2.

Fig. 5 shows the relationship between electron mobility and carrier concentration at room temperature for SiC films grown from 3MS with *in-situ* N_2 doping. The trend of increasing electron mobility with decreasing carrier concentration is reproduced for the 3MS grown SiC films. The trend is comparable to that obtained by Matsunami's group [6] and by Powell et al. [7] on 3C-SiC films grown with the $SiH_4/C_3H_8/H_2$ gas system. So far, the best result measured at 300 K from 3MS grown SiC films is a mobility of 104 $cm^2/V{\cdot}s$ with a carrier concentration of $2{\times}10^{17}$ cm^{-3}. By reducing the electron carrier concentration, significantly higher electron mobility should be obtained.

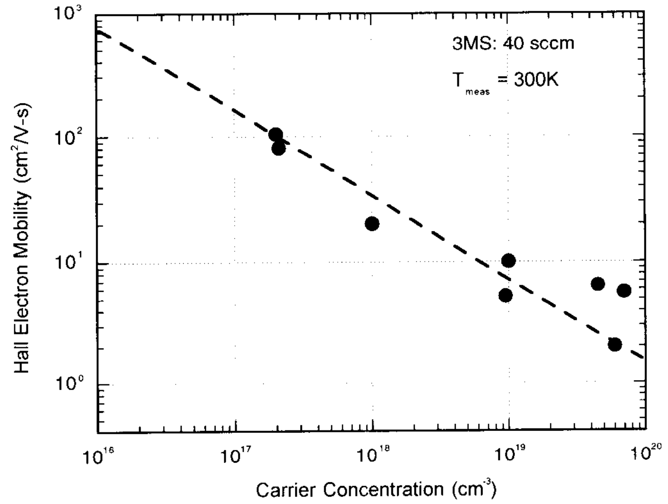

Fig. 5. Electron mobility versus carrier density measured at 300 K from SiC films grown with 3MS on Si(111).

4. SUMMARY

We have grown and characterized N-doped SiC films grown on Si (111) substrates. The 3MS grown SiC films can be readily doped over a wide range with N_2. FTIR study indicates that N atoms occupy the C vacancies in the SiC lattice. A mobility of 104 $cm^2/V{\cdot}s$ has been obtained at 300 K from a 3MS grown SiC film. 3MS is an appealing precursor for 3C-SiC growth given its ability to provide a safe and simple growth process compare with conventional silane precursors.

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