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Characterization of N-doped SiC(3C) epilayer by CVD on Si(111)

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화학기상증착으로 Si(111) 위에 성장된 N-SiC(3C) 에피층의 특성

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Abstract Nitrogen-doped SiC(3C) (N-SiC(3C)) epilayers were grown on Si(111) substrate at 1250℃ using chemical vapor deposition (CVD) technique by pyrolyzing tetramethylsilane (TMS) in H_2 carrier gas. SiC(3C) layer was doped using NH_3 during the CVD growth to be n-type conduction. Physical properties of N-SiC(3C) were investigated by Fourier transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD) patterns, Raman spectroscopy, cross-sectional transmission electron microscopy (XTEM), Hall measurement, and current-voltage (I-V) characteristics of the N-SiC(3C)/Si(p) diode. N-SiC(3C) layers exhibited n-type conductivity. The n-type doping of SiC(3C) could be controlled by nitrogen dopant using NH_3 at low temperature.

요 약 N-도핑된 3C-SiC (N-SiC(3C))을 화학기상증착(CVD)으로 1250℃에서 Si(111) 기판 위에 tetramethylsilane(TMS)를 열분해하여 성장하였다. 수송가스는 H_2이었고, N-SiC(3C) 에피층은 CVD로 성장되는 동안 NH_3에 의하여 n-형으로 도핑되었다. N-SiC(3C)의 물리적 특성은 적외선 분광(FTIR), X-선 회절(XRD), 라만 스펙트럼(Raman spectrum), 단면 투과전자영상(XTEM), Hall 측정 및 p/n 다이오드의 전류-전압(I-V) 특성에 의하여 조사되었다. N-도핑된 SiC(3C) 에피층의 전도형은 n-형이었고, 전도형은 NH_3를 사용한 N-dopant에 의하여 저온에서 잘 조절될 수 있다.

1. Introduction

SiC is regarded as a hopeful material to overcome the limitation of physical properties of Si. SiC has been the leading material for high-power/frequency and high-temperature electronic applications and short wavelength optical applications due to the advances in the crystal growth and doping ability for both n- and p-types [1, 2]. SiC(3C) has a wide bandgap of 2.2 eV at room temperature and has the highest electron mobility and saturation velocity among the different SiC polytypes. SiC(3C) single crystals are hardly grown by sublimation method. Hence SiC(3C) heteroepitaxial growth on Si substrate (SiC(3C)/Si) has been extensively studied for the device applications [3]. Large area SiC(3C) provides the best prospect in fabricating hybrid devices that integrate SiC technology with the more mature silicon technology [4].

One of the problems associated with SiC(3C)/Si epitaxial growth is the large differences in thermal expansion coefficients and lattice constants between epitaxial layer and substrate which leave numerous defects in the grown layers. This difficulty of the

SiC(3C)/Si epitaxial growth has been considerably overcome by carbonizing the Si surface or by growing the buffer layer before CVD [5]. SiC(3C) was epitaxially grown at low temperature of below 1150℃ without buffer layer formation by using acceptor doping agents [6].

SiC(3C) layers were grown to be unintentionally n-type by the reaction of gases during the CVD [7]. The n-type conductions of the other SiC polytypes have been controlled by using N_2 during epitaxial growth [8]. N_2 gas can be pyrolyzed at very high temperature. However, the n-doping concentration of SiC(3C) should be controlled in the low temperature. NH_3 can be used for the n-doping of SiC(3C).

In this work, we grew N-SiC(3C) thin films on Si (111) using NH_3 as the doping gas during CVD growth with the source gas of TMS. N-SiC(3C) thin films were characterized by Fourier transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD) patterns, Raman spectroscopy, cross-sectional transmission electron microscopy (XTEM), Hall measurement, and current-voltage (I-V) characteristics of the N-SiC(3C)/Si(p) diode.

2. Experiments

SiC(3C)/Si were epitaxially grown on p-type Si (111) by pyrolyzing TMS using CVD method. CVD system consisted of a horizontal reactor with a susceptor heated by a RF induction power supply. The horizontal reactor was a quartz tube with an inner diameter of 30 mmΦ. The susceptor was made of graphite and heated by RF generator of 15 kW with a frequency of 100 kHz. The substrate temperature was estimated by measuring the temperature inside a 20 mm deep hole in the downstream end of the susceptor with an optical pyrometer through the window at the chamber end. Figure 1 shows the temperature and gas flow programs for the CVD growth of SiC. Prior to the SiC growth, the surface of Si substrate was cleaned at 1000℃ for 10 minutes under H_2 flow to remove the native oxide layer. The CVD growth was carried out at 1250℃ with the flow of 3.0 sccm TMS and 1.5 slm H_2. NH_3 was added to the source gases for the n-doping of SiC(3C), where the feeding rate of NH_3 was 1.0 sccm. To prepare free films of SiC(3C), Si substrates were etched out using a $HF:HNO_3$ (1:1), and then SiC(3C) free films were rinsed in deionized water.

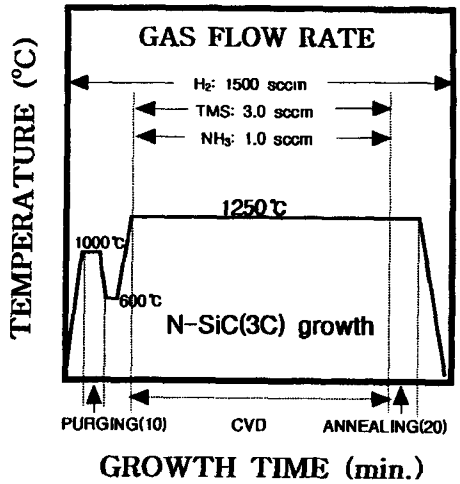

Fig. 1. The temperature and gas flow program for the CVD growth.

To identify n-type conduction of SiC(3C), N-SiC (3C)/Si(p-type) junctions were fabricated. After growing 0.3 μm thick SiC(3C)/Si, Al metal was evaporated to form ohmic contacts on SiC(3C) and Si(111) substrate, and annealed for 5 minutes, at 500℃.

3. Results and discussion

The chemical bonds of SiC(3C) layer were identified by FTIR spectroscopy. Figure 2 shows the FTIR transmission spectra of (a) undoped SiC(3C)/Si and (b) N-SiC(3C)/Si. The absorption mode typical

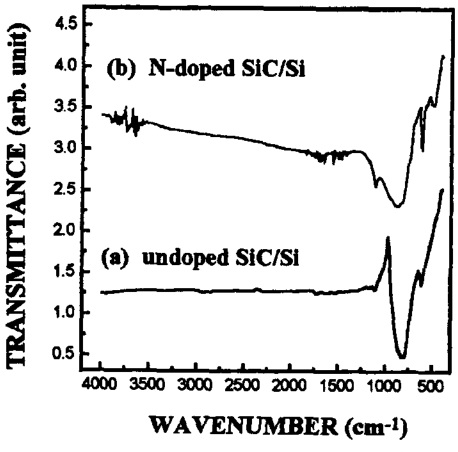

Fig. 2. The FTIR transmission spectra of (a) undoped SiC(3C)/Si and (b) N-SiC(3C)/Si.

of SiC(3C) layer was observed. The SiC groups show an absorption band at 780 cm^{-1}, which attributed to Si-C stretching vibration or to Si-C-H_3 wagging vibrations [9, 10]. The absorption peak at 2925 cm^{-1} is close to anti-stretching C-H_2 modes. A number of absorption peaks between 1400 cm^{-1} and 1700 cm^{-1} is due to C-H_n bending modes. Another peaks at around 612 cm^{-1} and 1110 cm^{-1} are due to Si-H_n deformation mode and Si-O mode, respectively. In Fig. 2 (b), the absorption band at 900 cm^{-1} due to Si-N stretching mode forms a broad absorption band by adding Si-C band at 780 cm^{-1}. The grown SiC(3C) was doped to be n-type by using NH_3.

The polytype of grown SiC layer was identified with X-ray diffraction (XRD) pattern. Figure 3 shows the XRD pattern of N-SiC(3C)/Si using the X-ray with filtered Cu-Kα. There would be a SiC(3C) (111) peak parallel to the Si substrate surface at 35.35° in the 2θ scale. The lattice constant of SiC(3C) was 4.394 Å. The peaks of the SiC(3C) (200), (220) and (311) planes would not appear at 41.39°, 59.96° and 71.74°, respectively. This results suggest that the N-SiC(3C)/Si layers have a preferred orientation of the SiC(3C) (111) plane.

The crystal structure of SiC(3C)/Si was also confirmed by Raman spectroscopy. Figure 4 shows the Raman spectrum of N-SiC(3C)/Si. The Raman spectrum was measured in back scattering geometry using a wavelength of 488 nm from a Ar-ion Laser at room temperature. The Raman peaks of N-SiC(3C) were observed at 780 cm^{-1} and 970 cm^{-1} for the transverse optical (TO) and the longitudinal optical (LO) phonon, respectively. TO and LO peaks are typical peaks observed from 3C-SiC crystalline. A shoulder peak around 970 cm^{-1} originates from excess silicon out-diffused from the Si surface of the SiC (3C)/Si interface [11].

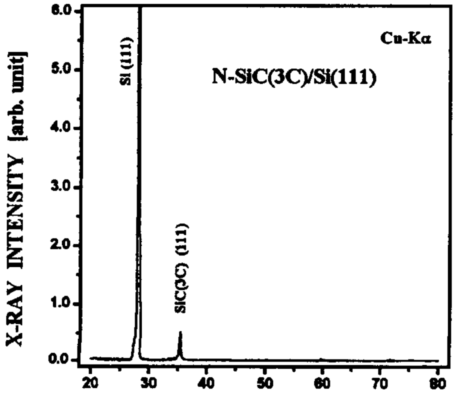

Fig. 3 The XRD pattern of the N-SiC(3C)/Si.

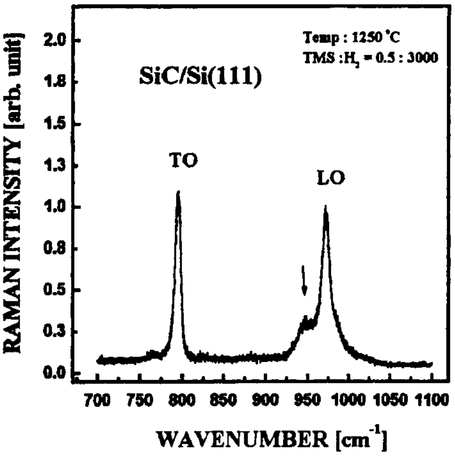

Fig. 4. The Raman spectrum of the N-SiC(3C)/Si.

The SiC/Si interface of the grown SiC(3C) layer was evaluated with the XTEM as shown in Fig. 5. The growth rate of SiC(3C) layer was about 10 nm/min under the our growing condition by CVD. Voids were observed in the SiC(3C)/Si interface, because the reaction occurs in depth by inter-diffusion of carbon and Si atoms.

To determine the electrical properties of undoped SiC(3C) and N-SiC(3C) layers, Hall measurement was carried out by the van der Pauw method. The SiC(3C) layers were grown on the semiconductor on insulator (SOI) substrate. Undoped SiC(3C) layers exhibited n-type conductivity. The carrier concentration of undoped SiC(3C) layers was usually 1.0×10^{16} cm^{-3} for the thicknesses of about 0.8 μm. N-SiC(3C) layers exhibited n-type conductivity. The mobility

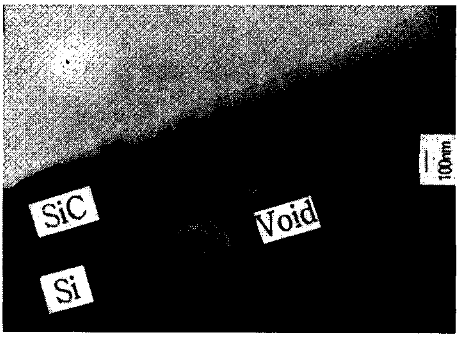

Fig. 5. The XTEM of SiC(3C)/Si.

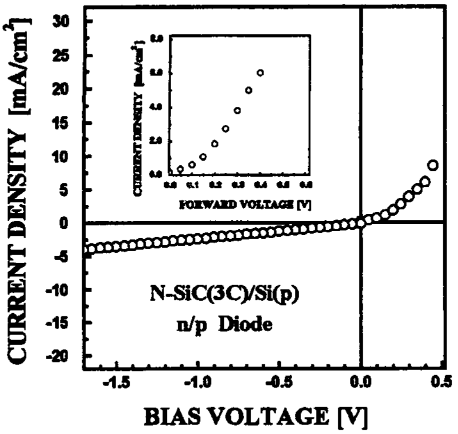

Fig. 6. Current-voltage (I-V) characteristics of N-SiC(3C)/Si(p) diode.

of N-SiC(3C) was about 70 cm^2/Vs with a carrier concentration of 5.0×10^{18} cm^{-3}.

Figure 6 shows I-V characteristics of the N-SiC(3C)/Si(p) diode. The I-V characteristics under forward bias voltage suggests that N-SiC(3C)/Si(p-type) forms n/p junction. N-SiC(3C) layers exhibited n-type conductivity. At 25°C, the turn-on voltage of the diode under forward bias can be as low as 0.3 V due partly to narrow bandgap of the Si material (1.1 eV). Leakage current under reverse bias voltage was very high. The mechanism of the reverse bias current may result from the recombination via interface states of N-SiC(3C)/Si.

4. Conclusions

SiC(3C) layers on Si(111) were grown by pyrolyzing TMS using a CVD method. N-SiC(3C) was doped to be n-type by using NH$_3$. The growth rate of SiC(3C) layer was about 10 nm/min under the our growing condition by CVD, which was evaluated with the XTEM. The chemical bonds of SiC(3C) layer were identified by FTIR spectroscopy. The absorption mode typical of SiC(3C) layer was observed. A highly oriented SiC(3C) crystalline was grown by CVD. The N-SiC(3C)/Si layers have a preferred orientation of the SiC(3C) (111) plane. N-SiC(3C) layers exhibited n-type conductivity. The mobility of N-SiC(3C) epilayer was about 70 cm^2/Vs with a carrier concentration of 5.0×10^{18} cm^{-3}. N-SiC(3C)/Si(p-type) structure formed n/p junction. Leakage current under reverse bias voltage was very high. The mechanism of the reverse bias current may result from the recombination via interface states of N-SiC(3C)/Si. The n-type doping in SiC (3C) could be controlled by nitrogen dopant using NH$_3$ in the low temperature.

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