Journal of Korean Association of Crystal Growth
Vol. 9, No. 2 (1999) 212-216

SiC(3C)/Si Photodetector

Kook-Sang Park, Kee-Suk Nahm* Jung-Yun Kim

Semiconductor Physics Research Center, Chonju 561-756, Korea
**School of Chemical Engineering and Technology, Chonbuk National University, Chonju 561-756, Korea*
Department of Physics, Dankook University, Chonan 330-714, Korea
(Received March 10, 1999)

SiC(3C)/Si 수광소자

박국상, 남기석*, 김정윤
반도체 물성 연구소, 전주, 561-756
*전북대학교 공업화학과, 전주, 561-756
단국대학교 물리학과, 천안, 330-714
(1999년 3월 10일 접수)

Abstract SiC(3C) photodiodes (PDs) were fabricated on p-type Si(111) substrates using chemical vapor deposition (CVD) technique by pyrolyzing tetramethylsilane (TMS) with H_2 carrier gas. Electrical properties of SiC (3C) were investigated by Hall measurement and current-voltage (I-V) characteristics. SiC(3C) layers exhibited n-type conductivity. Ohmic contact was formed by thermal evaporation of Al metal through a shadow-mask. The optical gain (G_{op}) of the SiC(3C)/Si PD was measured as a function of the incident wavelength. For the analysis of the photovoltaic detection of the SiC(3C) n/p PD, the spectral response (SR) has calculated by using the electrical parameters of the SiC(3C) layer and the geometric structure of the PD. The peak response calculated for properly chosen parameters was about 0.75 near 550 nm. We expect a good photoresponse in the SiC (3C) heterostructure for the wavelength range of 400~600 nm. The SiC(3C) photodiode can detect blue and near ultraviolet (UV) radiation.

요　약 SiC(3C) 광다이오드는 p-형 Si 위에 tetramethylsilane (TMS)를 열분해하여 화학기상증착법으로 성장된 SiC(3C) 에피층을 성장하여 제작되었다. SiC(3C)의 전기적 특성은 홀 측정(Hall measurement) 및 전류-전압(I-V) 특성으로 조사되었다. SiC(3C) 에피층의 전도형은 n-형이었다. 저항성 접촉은 마스크 (shadow-mask)를 통해서 Al을 열증착하여 형성하였다. SiC(3C) 광다이오드의 광학적 이득(optical gain)은 입사파장의 함수로서 측정되었다. SiC(3C)/Si n/p 광다이오드의 광검지(photovoltaic detection)를 해석하기 위하여 SiC(3C) 에피층의 Spectral response(SR)를 전기적 변수(electrical parameter) 및 광다이오드의 기하학적 구조(geometric structure)를 고려하여 계산하였다. 적절히 선정된 변수들로부터 계산된 SR의 최대값은 550 nm에서 약 0.75이었고, 파장영역 400~600 nm 사이에서 청색 및 근자외선 광검지기로서 매우 유용하다.

1. Introduction

Silicon carbide (SiC) is expected to be a useful electronic semiconductor not only for electronic devices operated at high-temperatures, but also for high-speed electronic devices due to its large saturated drift-velocity of electrons. Moreover, both n- and p-type conductivities can be easily controlled by doping impurities in SiC. The electrical and optical properties with controllable doping make SiC semiconductor very attractive.

3C-polytype SiC (SiC(3C)) has been applied to optoelectronic devices. The SiC(3C) photodiode (PD) can be utilized for the detection of blue and ultraviolet (UV) radiation. SiC has high optical absorption in blue range and sufficient diffusion lengths for the collection of generated charge carriers. Infrared (IR) radiation does not interrupt that the SiC PDs detect near UV radiation in an IR background. In addition, the hardness of SiC can reduce the surface damage due to high-energy particles and photons, and cosmic ray. SiC photodiodes have many applications such as UV monitoring for industrial processes and UV curing, UV spectroscopy, air-quality monitoring equipment, and sun-exposure monitoring using a personal UV detector.

In the past, most SiC applications to optoelectronic devices have been prepared on expensive SiC(6H) wafers. It is well known that the electronic properties of SiC(3C) are better than those of SiC(6H). However, SiC(3C) single crystals produced by sublimation method are very small. SiC(3C) epilayer on Si wafers (SiC(3C)/Si) has been obtained using vapor-phase epitaxy (VPE) [1, 2]. Control of the conduction type (n- or p-type) and the carrier concentration is possible by in-situ doping [3, 4]. The SiC(3C)/Si heterostructure is promising for monolithic integration of SiC devices [5, 6]. A SiC(3C) pin PD was fabricated on Si wafers using rapid thermal chemical vapor deposition [7]. However, there has been few on the analysis of the spectral response (SR) compared with the experimental results of the SiC(3C)/Si PD. The wavelength at which the peak response occurred could be controlled by varying the electronic properties of PD such as carrier mobilities, diffusion lengths of electron and hole, the doping concentrations of the n- and the p-layers, and the geometric structure of the PD. The analysis of the SR is useful for design of SiC PDs sensitive to near UV radiation.

In this work, SiC(3C) PDs were fabricated by growing SiC(3C) on p-type Si(111). The optical gain (G_{op}) and current-voltage (I-V) characteristics of the SiC(3C)/Si PDs were measured under the bias voltage as functions of incident wavelength. The photocurrent density (PC_d) of SiC(3C) PD was measured as a function of incident wavelength in the range of 400~600 nm. The SR of the n/p PD calculated by using the diffusion model of the minority carriers (DMMC) for analyzing of PC_d. The calculated SR of the SiC(3C)/Si was compared with the measured current density.

2. Experiment

SiC(3C)/Si were epitaxially grown on p-type Si (111) by pyrolyzing TMS using CVD method. 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 mmϕ deep hole in the down-stream end of the susceptor with an optical pyrometer through the window at the chamber end. The CVD growth was carried out at 1250℃ with the flow of TMS (3.0 sccm) and H_2 (1.5 slm) After growing the SiC(3C) layer of 1.0 μm, Al metal was thermally evaporated to form ohmic contacts on SiC(3C), and annealed for 10 minutes at 500℃. Figure 1 shows the geometric structure of the SiC(3C)/Si PD.

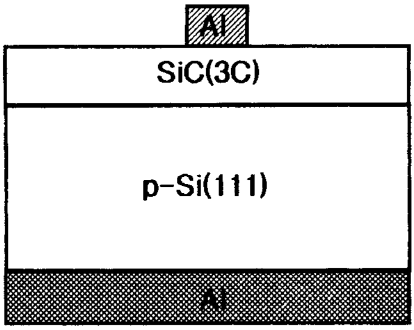

Fig. 1. The geometric structure of the SiC(3C)/Si photodiode.

A spectrophotometer (Model 139) manufactured by Keithley Instruments Inc. with a Ar-ion Laser was used to measure the PC_d of the experimental devices. The photoresponses of the devices were measured under the bias voltage. The measurement of dark current was carried out using an electrometer (Model 602). This system could be used for measurements in the wavelength region from 200 nm to 800 nm. This measurement system consisted of a light source, a chopper, a monochromator, a lock-in amplifier, a digital electrometer, and a computer for the spectrum analysis.

3. Results and discussions

The electrical property of SiC(3C) layer was obtained by using the Hall measurements. SiC(3C) layers exhibited n-type conductivity. The carrier concentration of SiC(3C) layer was usually 5.0×10^{18} cm^{-3} for the thickness of about 1.0 μm at room temperature. The electrical mobility was about 70 cm^2/Vs with a carrier concentration of 5.0×10^{18} cm^{-3}.

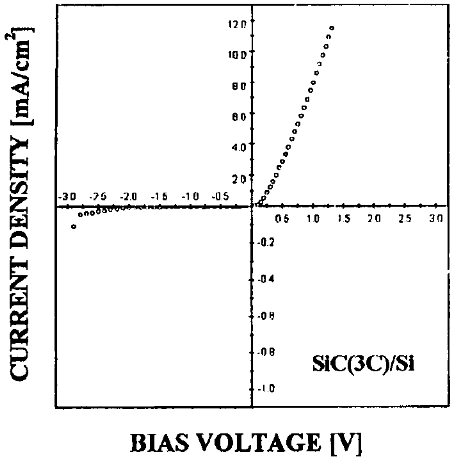

Fig. 2. The current-voltage (I-V) characteristics of the SiC(3C)/Si(p) diode.

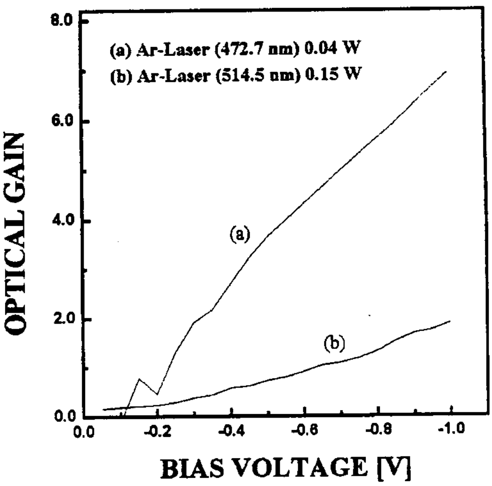

Fig. 4. The optical gain of the photodiode under reverse biases.

Figure 2 shows I-V characteristics of the SiC(3C)/Si(p) diode. The I-V characteristics suggests that SiC(3C)/Si(p) structure forms n/p junction. At 25℃, the turn-on voltage of the diode under forward bias can be as low as 0.2 V due partly to narrow bandgap of the Si material (1.1 eV). The ideality factor of SiC(3C) diode was 1.8. Saturation current of the SiC(3C) diode under reverse bias voltage of -1.0 V was below 10 μA. The dark current increases with increasing under the reverse bias. The mechanism of the reverse bias current may result from the recombination via interface states of SiC(3C)/Si diode.

Figure 3 shows the dark and photo I-V curves of the PD under the reverse bias voltage at different Ar-ion Laser power levels and wavelengths. The photocurrent increases with decreasing the wavelength of incident light. The G_{op} of the PD under reverse biases at incident Ar-ion Laser powers of 0.04 W and 0.15 W is shown in Fig. 4. The G_{op} of the PD was calculated from [8]

$$G = [(I_{Ph} - I_D)/(P_{in} \times \lambda)] \times [hc/q],$$

where I_{Ph} is the photocurrent, I_D the dark current, P_{in} the total energy of the incident light, λ the wavelegth of the incident light, h the Planck's constant, c the speed of light, and q the electron

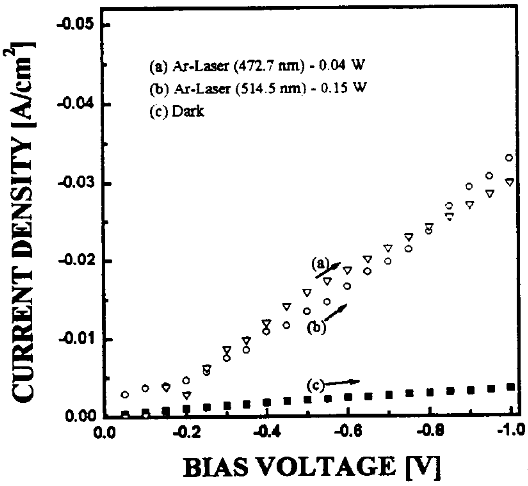

Fig. 3. The dark and photo I-V curves of the SiC(3C) photodiode.

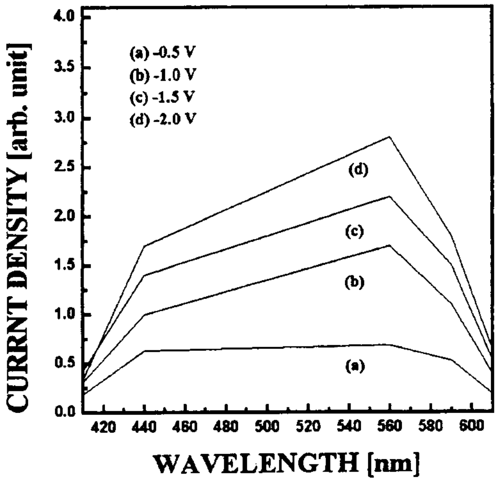

Fig. 5. The calculated spectral response of the SiC (3C) photodiode.

charge. The G_{op} increases with increasing reverse bias due to the increased impact ionization effect of the photogenerated carriers in the light absorption layer [7]. Figure 5 shows the PC_d of a SiC(3C) PD as a function of incident wavelength. The SiC(3C)/Si PD show a good photoresponse for the wavelength range of 450~600 nm.

The DMMC was used for the calculation of the SR of a SiC(3C) n/p photodiode [9]. This model includes the photon absorption within each layer of SiC(3C) and the collection of charges generated by photon absorption. For a steady-state condition, the total SR is given by the sum of the SR components in the n-layer, p-layer and depletion region. The absorption coefficients of SiC(3C) was used for the calculation of the SR. The total SR and the individual contributions of the SR from each of the three layers of a SiC(3C) PD were calculated using the device parameters listed in Tables 1 and 2. Figure 6 shows the calculated total SR of the SiC (3C) PD in the incident wavelength range of 400~800 nm. The SR of the n-layer can be shown in blue range owing to the wide bandgap of SiC(3C). The extreme SR of SiC(3C) is about 0.75 in the wavelength of 550 nm. At photon energies in the blue range, most of the carriers are generated in the p-layer due to the low absorption coefficients. The contribution from the depletion region is considerable in the 400 nm to 600 nm range, and it becomes as large as the other contributions. The distribution of the PCd is similar to that of the SR calculated using the DMMC in the n/p junction in the range of 450~600 nm. The DMMC in the p/n junction could be applied to the analysis of the photoresponse of the SiC(3C) PD.

Table 1
Geometric structures for the calculation of spectral response: (a) thickness (μm), (b) concentration (cm^{-3})

Device	n-layer	p-layer
(a)	1.0	500
(b)	5.0×10^{18}	5.0×10^{16}

Table 2
Photodiode parameters for SiC(3C) and Si at 300 K

	$N_d(cm^{-3})$	$\mu_p(cm^2/Vs)$	$\tau_p(sec)$	$L_p(cm)$
n-SiC	5.0×10^{18}	20	20×10^{-9}	0.5×10^{-4}
	$N_a(cm^{-3})$	$\mu_n(cm^2/Vs)$	$\tau_n(sec)$	$L_n(cm)$
p-Si	5.0×10^{16}	500	1.0×10^{-6}	50×10^{-4}

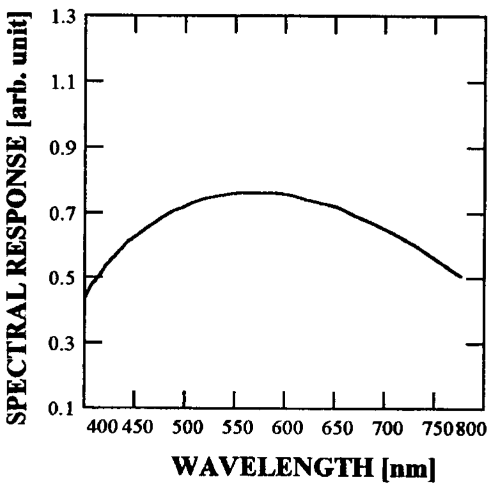

Fig. 6. The measured photocurrent density of a SiC (3C) photodiode.

4. Conclusions

SiC(3C) PDs were fabricated on p-type Si(111) substrates using chemical vapor deposition (CVD) technique by pyrolyzing TMS with H_2 carrier gas. The growth rate of SiC(3C) layer was about 1.0 μm/h under the our growing condition. The SiC(3C) layers have a preferred orientation of the SiC(3C) (111) plane. Electrical property of SiC(3C) was investigated by Hall measurement and I-V characteristics. SiC(3C) layers exhibited n-type conductivity. The electrical mobility was about 70 cm^2/Vs with a carrier concentration of 5.0×10^{18} cm^{-3}. Ohmic contact was formed by thermal evaporation of Al metal through a shadow-mask. SiC(3C)/Si(p) structure formed n/p junction. The turn-on voltage of the diode under forward bias can be as low as 0.2 V due partly to narrow bandgap of the Si. The ideality factor of SiC(3C) diode was 1.8. Saturation current of the diode under reverse bias voltage of -1.0 V was below 10 μA. The dark current increases with increasing under the reverse bias. The G_{op} of the SiC (3C) PD was measured as a function of the bias voltage with incident wavelength. The G_{op} increases with increasing reverse bias due to the increased impact ionization effect of the photogenerated carriers. For the analysis of the photovoltaic detection of the SiC(3C) n/p PD, the SR has calculated by using the electrical parameters of the SiC(3C) layer and the geometric structure of the PD. The peak response calculated for properly chosen parameters was about 0.75 near 550 nm. We expect a good photoresponse in the SiC(3C) heterostructure for the wavelength range of 450~600 nm. The SiC(3C) PD can detect blue-radiation. The distribution of the PC_d was well explained by the the diffusion model including the optical absorption of the depletion region.

Acknowledgement

The authors wish to acknowledge the financial support of the Korea Research Foundation made in the post-doctor program year of (1997) through the Semiconductor Physics Research Center (SPRC) at Chonbuk National University.

References

[1] K. Takahashi, S. Nishino and J. Saraie, J. Crys. Grow. 115 (1991) 617.
[2] C.A. Zorman, A.J. Fleischman, A.S. Dewa, M. Mehregany, C. Jacob, S. Nishino and P. Pirouz, J. Appl. Phys. 78 (1995) 5136.
[3] J.A. Edmond, K. Das and R.F. Davis, J. Appl. Phys. 63 (1988) 922.
[4] K.S. Park, K.C. Kim, K.S. Nahm and H.K. Na, J. Kor. Asso. of Cryst. Grow. 9 (1999) 39.
[5] S. Yoshida, H. Daimon, M. Yamanaka, E. Sakuma, S. Misawa and K. Endo, J. Appl. Phys. 60 (1986) 2989.
[6] M. Yganathan, W.J. Choyke and R.P. Devaty, J. Appl. Phys. 80 (1996) 1763.
[7] K.-H. Wu, Y.-K Fang, J.-H. Zhou and J.-J Ho, Jpn. J. Appl. Phys. 36 (1997) 5151.
[8] S.M. Sze, Physics of Semiconductor Devices 2nd., Chap. 13 (Wiley, New York, 1981) p. 749.
[9] K.S. Park and K.A. Lee, J. Kor. Phys. Soc. 29 (1996) 225.