Vol 18 No 5, May 2009
1674-1056/2009/18(05)/1931-04

Chinese Physics B

© 2009 Chin. Phys. Soc.
and IOP Publishing Ltd

High energy electron radiation effect on Ni and Ti/4H-SiC Schottky barrier diodes at room temperature*

Zhang Lin(张 林), Zhang Yi-Men(张义门), Zhang Yu-Ming(张玉明),
Han Chao(韩 超), and Ma Yong-Ji(马永吉)

Microelectronic School, Key Laboratory of Ministry of Education for Wide Band-Gap Semiconductor Materials and Devices, Xidian University, Xi'an 710071, *China*

(Received 29 October 2008; revised manuscript received 11 November 2008)

This paper reports that Ni and Ti/4H-SiC Schottky barrier diodes (SBDs) were fabricated and irradiated with 1 MeV electrons up to a dose of 3.43×10^{14} e/cm^2. After radiation, the Schottky barrier height ϕ_B of the Ni/4H-SiC SBD increased from 1.20 eV to 1.21 eV, but decreased from 0.95 eV to 0.94 eV for the Ti/4H-SiC SBD. The degradation of ϕ_B could be explained by interface states of changed Schottky contacts. The on-state resistance R_S of both diodes increased with the dose, which can be ascribed to the radiation defects. The reverse current of the Ni/4H-SiC SBD slightly increased, but for the Ti/4H-SiC SBD it basically remained the same. At room temperature, ϕ_B of the diodes recovered completely after one week, and the R_S partly recovered.

Keywords: silicon carbide, Schottky barrier diode, electron radiation, annealing effect
PACC: 6180, 8750G, 7850G, 7340S

1. Introduction

Silicon carbide (SiC) has outstanding properties such as wide bandgap, higher thermal conductivity, high breakdown field and high radiation tolerance, and has been used to fabricate high operating temperature, high power, and high radiation hardness devices.[1] The SiC Schottky barrier diode (SBD) can be made by a simple process and has superior performances to sustain high critical breakdown electric field and high temperature operation, high switching speed and low power loss, and has been used as a high voltage rectifier, ultraviolet and radiation detector. Also, SiC SBD is a key component of many SiC-based power devices like metal semiconductor field effect transistors (MESFET) and static induction transistors (SIT).[2]

There is great interest in the response of SiC SBD to high-energy particle radiation because of the potential applications in space, nuclear power industry and military areas. High-energy particles such as proton, neutron and electron radiation can create vacancies, interstitials, and their associated defects. These radiation-induced defects act as traps and generation-recombination centres in the SiC material. So they make the resistivity increase in the SiC and enhance the recombination current, leading to the degradation of SiC devices. However, the radiation defects will not disappear without high temperature annealing.[3−5] In the past several years, high energy proton[6,7] and neutron[8,9] radiation effects on SiC SBD have been reported, but the high energy electron radiation effect has rarely been investigated.

In this paper, the radiation effect on Ni and Ti/4H-SiC SBDs is investigated with 1 MeV electron irradiation. Then the annealing effect of the diodes at room temperature is observed.

2. Experiment

The 4H-SiC wafer was prepared by homoepitaxial growth with a commercial low-pressure, hot wall chemical vapour deposition (CVD) (LP-HW-CVD) reactor (Epigress VP508 system) using the $SiH_4/C_3H_8/H_2$ system. The n type SiC epitaxial layer was grown on the Si-face (0001) 4H-SiC substrate with 8 °C off axis, which was purchased from SiCrystal AG. The growth process lasted for 2 hours at 1580 °C. A typical growth rate was 5 μm/h, and the thickness of the epilayer was approximately 10 μm. The epi-

*Project supported by the National Natural Science Foundation of China (Grant No 60606022), the Xian Applied Materials Foundation of China (Grant No XA-AM-200702) and the Advanced Research Foundation of China (Grant No 9140A08050508).

layer was formed by an unintentionally doped process, with measured net carrier concentration about 6.4×10^{14} cm^{-3}.

The Ni/Pt (450/50 nm) was deposited on the backside of the SiC wafer by electron beam evaporation and annealed at 1000 °C in N_2 ambience for 2 min to form ohmic contacts, followed by electron beam evaporated Cr/Au (50/200 nm). Circular Schottky contact was deposited by electron beam evaporation Ni/Cr/Au or Ti/Cr/Au (200/50/200 nm) and patterned by lift off. The Ti and Ni metals in this investigation were chosen because they are the most widely used metals for Schottky contacts in SiC devices. The cross section of the Ni or Ti/4H-SiC SBD is shown in Fig.1. Then the sample was sliced into a single device by laser cutting for packaging with aluminium wire bonding.

The radiation experiment was performed at room temperature with the ELV-8 type electron accelerator at the Northwest Institute of Nuclear Technology. The highest total dose was up to 3.43×10^{14} e/cm^2 with a dose rate of 6.85×10^{10} e/(cm$^2 \cdot$s). Meanwhile, all diodes were with zero bias during irradiation.

The I–V characteristics were measured by using an HP4156A precision semiconductor parameter analyser and an Agilent Technology 34980A Multifunction Switch/Measurement Unit. During the experiment, there was no obvious sample temperature rise to be observed.

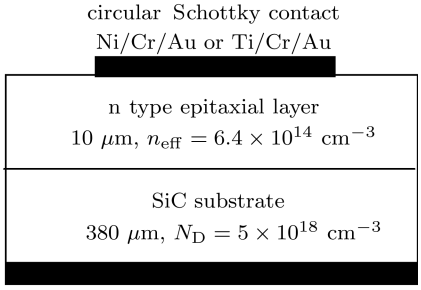


Fig.1. Schematic cross section of the Ni or Ti/4H-SiC SBD.

3. Results and discussions

3.1. Forward characteristics

During measurements of the samples, it was found that noticeable and repeatable results were obtained, in which the Ni and Ti/4H-SiC SBDs showed different degradation trends. The forward current of the Ni/4H-SiC SBD decreased after radiation, but the forward current of the Ti/4H-SiC SBD increased at low bias voltage (< 0.7 V) and decreased at higher forward voltage. The forward currents of Ni and Ti/4H-SiC SBDs at 2.0 V decreased by 50.3% and 42.1% respectively. Figure 2 shows forward characteristics of the Ni and Ti/4H-SiC SBDs before and after radiation.

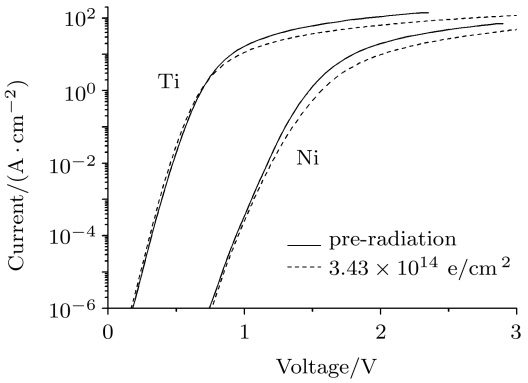


Fig.2. Forward I–V characteristics of the 4H-SiC SBDs before and after radiation.

Based on thermionic emission theory, the forward current $I_{\rm F}$ running through the SiC SBD can be expressed as:[2]

$$I_{\rm F} = I_{\rm S}\left\{\exp\left[\frac{q}{nkT}(V - I_{\rm F}R_{\rm S})\right] - 1\right\}, \quad (1)$$

$$I_{\rm S} = AA^*T^2\exp(-q\phi_{\rm B}/kT), \quad (2)$$

where n is the ideality factor, $I_{\rm S}$ is the reverse saturation current, $R_{\rm S}$ is the on-state resistance, $\phi_{\rm B}$ is the Schottky barrier height and A^* is the Richardson's constant (146 A $\cdot$ cm$^{-2} \cdot$ K^{-2}).

Ignoring the voltage drop at the linear region of current, we can obtain n from Eq.(1),

$$n = \frac{q}{kT}\frac{\partial V}{\partial \ln I}, \quad I = \frac{I_{\rm F}}{I_{\rm S}}. \quad (3)$$

At a high forward voltage, $R_{\rm S}$ can be given by

$$R_{\rm S} = \left(1 - \frac{\partial \ln I_{\rm F}}{\partial V}\frac{nkT}{q}\right) \Big/ \left(\frac{\partial I_{\rm F}}{\partial V}\right). \quad (4)$$

With calculation from Eq.(2), $\phi_{\rm B}$ and n of the Ni/4H-SiC SBD are changed from 1.20 eV to 1.21 eV and 1.56 to 1.51, and that of Ti/4H-SiC SBD decreased from 0.95 eV to 0.94 eV and 1.14 to 1.12 respectively.

Figure 3 shows the $R_{\rm S}$ as a function of the electron dose. After radiation, $R_{\rm S}$ is increased from 15.6 Ω to 21.6 Ω for Ni/4H-SiC SBD, and increased from 8.16 Ω to 13.7 Ω for Ti/4H-SiC SBD. The increase of $R_{\rm S}$ can be explained by the carrier removal effect and the mobility removal effect of the electron radiation.[10]

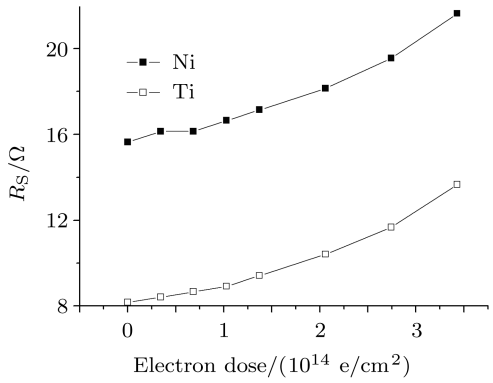


Fig.3. R_S vs electron dose.

3.2. Reverse characteristics

Figure 4 shows reverse characteristics of the Ni and Ti/4H-SiC SBDs before and after radiation. The reverse current of the Ni/4H-SiC SBD is slightly increased from 1.24×10^{-4}A$\cdot$cm^{-2} to 1.59×10^{-4}A$\cdot$cm^{-2} at –200 V after radiation. The generation-recombination centres created by the high energy electrons are the main mechanism for the increased reverse current.[6] But the reverse current of the Ti/4H-SiC SBD basically remained the same; perhaps this is because the reverse current is much bigger than the recombination current component introduced by radiation defects.

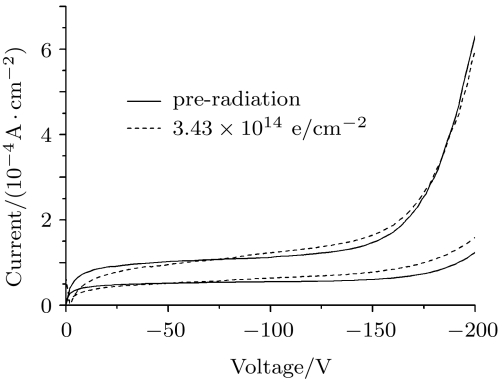


Fig.4. Reverse I–V characteristics of the 4H-SiC SBDs before and after radiation.

3.3. Annealing effect

After radiation, the diodes were annealed for two weeks at room temperature. The measurement results showed that the reverse characteristics did not have obvious changes in two weeks, but an obvious recovery effect of the forward characteristics was observed. Annealing results are showed in Fig.5. After one week, ϕ_B of the Ni and Ti/4H-SiC SBDs had completely recovered to the value before radiation, and R_S had partly recovered. The annealing of ϕ_B showed that the degradation could be explained by interface states of their Schottky contacts changed by electron radiation.[11,12] The mechanism of the recovered effect on R_S needs further study. But considering the radiation induced defects in SiC material will not recover without high temperature annealing, the recovery effect of the R_S perhaps for the charged state of the radiation induced traps changed.

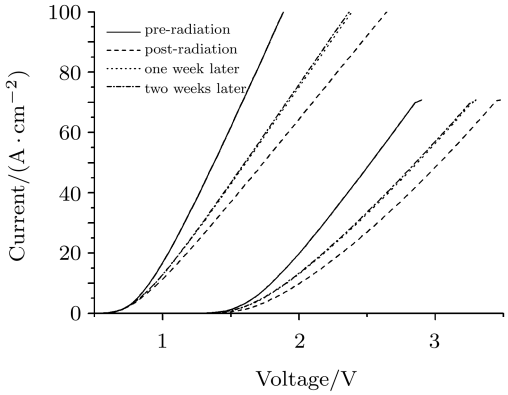


Fig.5. Annealing effect of the 4H-SiC SBDs at room temperature.

4. Conclusion

In this paper, the high energy electron radiation effect on Ni and Ti/4H-SiC SBDs is investigated by electron irradiation with a highest dose up to 3.43×10^{14} e/cm^2 of 1 MeV electrons. After radiation, both diodes have kept a good rectifying characteristic, and show excellent radiation-resistance capability. The ϕ_B of the Ni/4H-SiC SBD is slightly increased, but slightly decreased for the Ti/4H-SiC SBD. The R_S values of both diodes are increased with the electron dose. The reverse current of the Ni/4H-SiC SBD is slightly increased, but basically remained the same for the Ti/4H-SiC SBD. At room temperature, visible recovery effects of ϕ_B and R_S have been observed.

References

[1] Zhang Y M 1998 *Study of Silicon Carbide Materials and Devices* (Ph.D Dissertation) (Xi'an: Microelectronics Institute, Xi'an Jiaotong Uiversity) p1-p9 (in Chinese)

[2] Wang S G, Yang L A and Zhang Y M 2003 *Chin. Phys.* **12** 322

[3] Alfieri G, Monakhov E V and Svensson B G 2005 *J. Appl. Phys.* **98** 113524

[4] Storasta L, Bergman J P and Janzén E 2004 *J. Appl. Phys.* **96** 4909

[5] Katsunori Danno and Tsunenobu Kimoto 2006 *J. Appl. Phys.* **100** 113728

[6] Nigam S, Kim Jihyun and Ren F 2002 *Appl. Phys. Lett.* **81** 2385

[7] Luo Z Y and Chen T B 2004 *IEEE Trans. Nuclear Science* **51** 3748

[8] Nava F, Castaldini A and Cavallini A 2006 *IEEE Trans. Nuclear Science* **53** 2977

[9] Sciortino S, Hartjes F and Lagomarsino S 2005 *Nuclear Instruments and Methods in Physics Research* A **552** 138

[10] Shang Y C, Zhang Y M and Zhang Y M 2000 *Nuclear Electronics & Detection Technology* **120** 424 (in Chinese)

[11] Wang S G, Zhang Y M and Zhang Y M 2003 *Chin. Phys.* **12** 94

[12] Lv H L, Zhang Y M and Zhang Y M 2008 *J. Semiconductors* **29** 458