ISSN 0852-4777

INVESTIGATION OF ANNEALING EFFECT ON THE FORWARD BIAS AND LEAKAGE CURRENT CHANGES OF P-TYPE 6H-SIC SCHOTTKY DIODES WITH SIO_2 RAMP PROFILE AFTER IRRADIATED UP TO 1.75 MGY

(Application For Nuclear Fuel Elements Facilities)

Usman Sudjadi
Center For Nuclear Fuel Technology, BATAN
Puspiptek Area, Serpong, Tangerang

ABSTRACT

INVESTIGATION OF ANNEALING EFFECT ON THE FORWARD BIAS AND LEAKAGE CURRENT CHANGES OF P-TYPE 6H-SIC SCHOTTKY DIODES WITH SIO_2 RAMP PROFILE AFTER IRRADIATED UP TO 1.75 MGY. Annealing effect on the electrical properties change of P-type 6H-SiC Schottky diodes with SiO_2 ramp profile after irradiated up to 1.75 MGy at RT (Room Temperature) were investigated. A perpendicular edge termination based on oxide ramp profile around the Schottky contact is used on Al Schottky rectifier fabricated on a 10 μm p-type 6H-SiC epi-layer on p-type 6H-SiC substrate (3.5^0 off, Si face), Na: $5.9 \times 10^{15}/cm^2$. The samples were irradiated with gamma-ray up to 1.75 MGy after that the samples annealed at 100 ^{0}C - 500 ^{0}C for 30 minute, respectively. The electrical characteristics of the diodes are evaluated before and after irradiated, before and after irradiated plus annealed. The results have shown that the forward current increases with increasing annealing temperatur.
Keywords: Annealing effect, forwards bias, leakage current, 6H-SiC, Schottky diode

ABSTRAK

EFEK PEMANASAN PADA PERUBAHAN SIFAT-SIFAT KELISTRIKAN DARI DIODE – DIODE SCHOTTKY 6H-SIC TIPE P DENGAN SIO2 RAMP PROFILE SETELAH DIIRRADIASI DI ATAS1,75 MGY*. Efek pemanasan pada perubahan sifat-sifat kelistrikan dari diode – diode Schottky 6H-SiC tipe P dengan SiO_2 ramp profile setelah diirradiasi di atas1,75 MGy pada temperatur ruang telah diteliti. Sebuah terminasi oxide dengan sudut tegak lurus untuk ramp profile di sekeliling kontak Schottky telah digunakan pada Al penyearah Schottky, difabrikasi pada sebuah 10 μm 6H-SiC pada tipe P epi-layer, pada 6H-SiC tipe P substrate ($3,5^0$ off, Si face), Na: $5,9 \times 10^{15}/cm^2$. Cuplikan diirradiasi dengan sinar gamma di atas 1,75 MGy setelah itu cuplikan masing-masing dipanaskan pada suhu 100 ^{0}C - 500 ^{0}C selama 30 menit. Karakteristik kelistrikan dari diode-diode dievaluasi sebelum dan sesudah diirradiasi. Dievaluasi juga sebelum dan sesudah diirradiasi dan dipanaskan. Hasil-hasilnya menunjukkan bahwa arus maju menaik dengan kenaikan temperatur pemanasan.*

Kata Kunci: *Efek pemanasan, tegangan bias maju, kebocoran arus, 6H-SiC, diode Schottky.*

INTRODUCTION

It is well known that silicon carbide (SiC) is a promising candidate for high power and high frequency electronic devices because of its excellent thermal and electrical properties such as stability at high temperature, wide band gap, high breakdown field, and high thermal conductivity. In addition, since SiC has a strong radiation resistance, it is also expected to be widely applied in electronic devices **used in harsh radiation** environments such as space, **nuclear power plants**, **accelerator facilities**, and so on. This material can made for sensor and electronic devices components to detecting high level gamma radiation, and can applied in the nuclear fuel elements facilities or laboratory for example in the hotcell. Metal-silicon carbide (SiC) interfaces play very important roles in many high-performance devices in optoelectronics, high-temperature, high-frequency, and power applications[1]. Annealing effects on the SiC Schottky diodes were studied by several researchers. G. Brezeanu et al.[2] have annealed Nickel-6H-SiC Schottky barrier diodes with simple termination of the planar at 800-1000^{0}C. The results shown that reverse characteristics, near–ideal parallel plane breakdown at a voltage of 800 V and very low leakage current after vacuum of Schottky contact at 900 ^{0}C for 2 min. A-remarkable weak reverse current-voltage dependence for V_R > 100 V has been obtained. The forward characteristics of the Ni/6H-SiC SBD agreed very well with thermo-ionic emission theory. The 800^{0}C vacuum annealing led to devices with ideality factors near one and specific on resistance higher than theoretical value due to ohmic backside contact. By increasing the annealing temperature to 1000^{0}C, the R_{on} is reduced but dramatic degradation of the breakdown voltage was observed. The samples of Ni/6H-SiC Schottky diodes of G. Brezeanu et al were not irradiated with gamma-ray. O. Noblanc et al.[3] have investigated about physical and electrical characterization of Wolfram Nickel (WN) Schottky contacts on 4H-SiC. They have deposited WN by reactive sputtering on 4H-SiC to make Schottky rectifiers. The physical properties of the interface have studied by XPS and TEM for as-deposited, 800 and 1200^{0}C annealed samples. The two former samples reveal steep interface with metallic layer made of W and W_2N phases. No dissociation of the SiC was evidenced in these conditions. In the later one, tungsten silicide and tungsten carbide were evidenced. The rectifying properties were studied by I(V) measurements. Barrier height of 0.94 eV was measured for annealed samples up to 950^{0}C and thermal stability was observed up to 350^{0}C. The samples of O. Noblanc et al were not irradiated with gamma-ray [3]. To understand the properties change in the interface of metal and semiconductor contact after irradiated and annealed. This paper reported the annealing effect on the electrical properties change of P-type 6H-SiC Schottky diodes with SiO_2 ramp profile after irradiated up to 1.75 MGy at RT.

EXPERIMENTS

The samples used in this experiment were 10 µm thick epilayer grown on p-type 6H-SiC substrate (Cree Inc.). The doping concentration of epilayer is 5.9 x 10^{15} cm^{-3}. First of all, the SiC samples were cleaned using acetone for 10 minutes and sub-sequently ethanol with ultrasonic. Then, the surface contamination and natural oxide of samples were etched using $HCl:HNO_3$=3:1 for 5 minutes followed by 50%$HF:H_2O$=1:5 for 5 minutes [4,5]. The thickness of oxide ramp is

1000 Å. Circular contact windows (300 μm, 250 μm, and 150 μm) in oxide were defined using a shadow mask. Ohmic contact on the backside of the samples was obtained by the evaporation of Al (200 Å) and annealing at 850 ^{o}C for 5 minute in a vacuum ambient for first layer Ohmic contact, after that evaporated again with Al 1000 Å (not annealed) for second layer Ohmic contact. The samples were irradiated with γ-rays (^{60}Co source) up to 1.8 MGy at a rate of 4.35 – 8.7 kGy/h at room temperature (RT). During the irradiation, no bias was applied to diodes. After that the sample were annealed at 100 ^{0}C, 200 ^{0}C, 300 ^{0}C, 400 ^{0}C, and 500 ^{0}C, for 30 minute, respectively. The current – voltage (I–V) characteristics of the Schottky diodes were measured at RT in a dark condition before and after γ- ray irradiation. The current voltage characteristics of the Schottky diodes were measured also before and after gamma-ray irradiated plus annealed [6,7].

RESULTS AND DISCUSSION

The forward current versus forward bias with difference annealing of p-type 6H-SiC Schottky diodes with 300 μm circular diameter is shown in Fig. 1: with increasing annealing temperature the forward current increases. The sample in Fig 1 annealed at 100 C, 200 C, 300 C, 400 C, and 500 C, for 30 minute, respectively. Fig. 2 shows the forward current versus forward bias with difference of p-type 6H-SiC Schottky diodes with 250 μm circular diameters.This sample annealed 150 C, 250 C, 300 C, and 500 C, for 30 minute, respectively. The leakage current versus annealing temperature of p-type 6H-SiC Schottky diodes with 150 μm circular diameter is shown in Fig. 3: with increasing annealing temperature the forward current increases. The sample in Fig. 3 annealed at 100 C, 300 C, 400 C, and 500 C, for 30 minute, respectively. The forward current versus forward bias with difference annealing of p-type 6H-SiC Schottky diodes with 300 μm circular diameter is shown in Fig. 4. The sample in Fig 4 annealed at 100 C, 200 C, 300 C, 400 C, and 500 C, for 30 minute, respectively. Fig. 5 shows the leakage current versus annealing temperature with difference of p-type 6H-SiC Schottky diodes with 250 μm circular diameters.This sample annealed at 150 C, 250 C, 300 C, and 500 C, for 30 minute, respectively. The leakage current versus annealing temperature of p-type 6H-SiC Schottky diodes with 150 μm circular diameter is shown in Fig. 6. The sample in Fig. 6 annealed at 100 C, 300 C, 400 C, and 500 C, for 30 minute, respectively. Figs. 1-3 show that with increasing annealing temperature the forward current increases. Figures 4, 5, and 6 are shows also that with increasing annealing temperature, the leakage current increases. G. Brezeanu et al. [2] have reported that the typical J_F – V_F characteristics of a Schottky barrier diode with oxide ramp profile are shown that, 800 ^{0}C annealed sample revealed that the current conduction mechanism follows the thermionic emission theory for at least six orders of magnitude into current density levels. However, at high levels, the series resistance comes into effect and this contributes to an additional voltage drop across the diode. The forward voltage drop is

$$V_F = (nkT/q)\ln(J_F/A^*T^2) + \Phi_{Bn} + R_{on} J_F$$

Where k is the Boltzman's constant, T is the temperature and A^* is the Richardson's constant. These results have also reported that the current conduction mechanism also follows the thermionic emission theory.

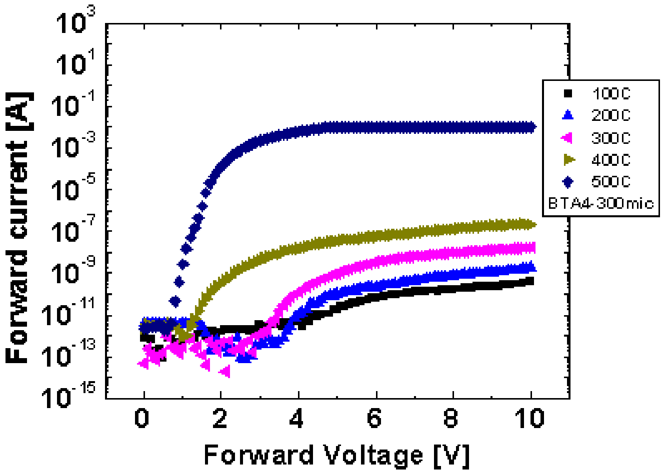

Figure. 1 Forward current versus forward voltage with difference annealing temperature (Φ = 300 μm)

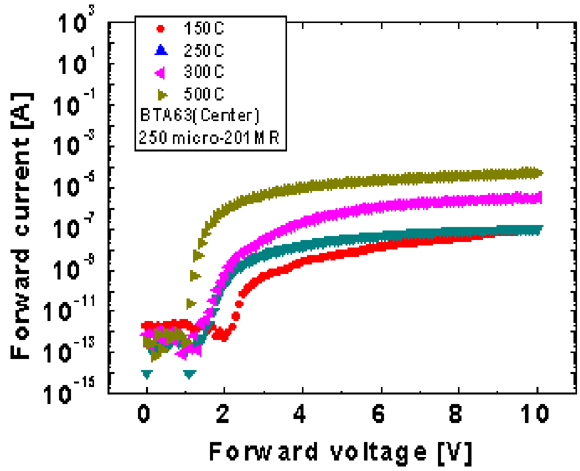

Figure 2. Forward current versus forward voltage with difference annealing temperature (Φ = 250 μm)

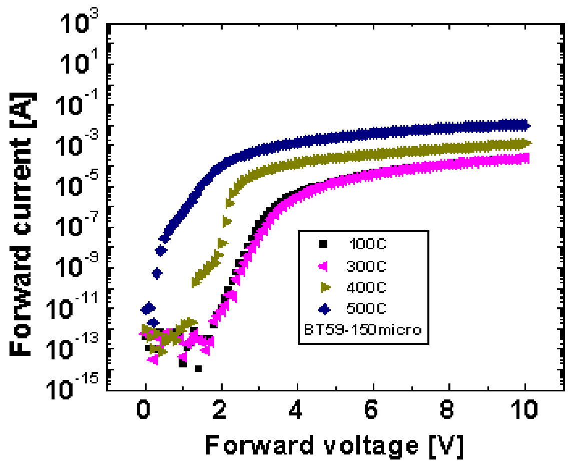

Figure 3. Forward current versus forward voltage with difference annealing temperature (Φ = 150 μm)

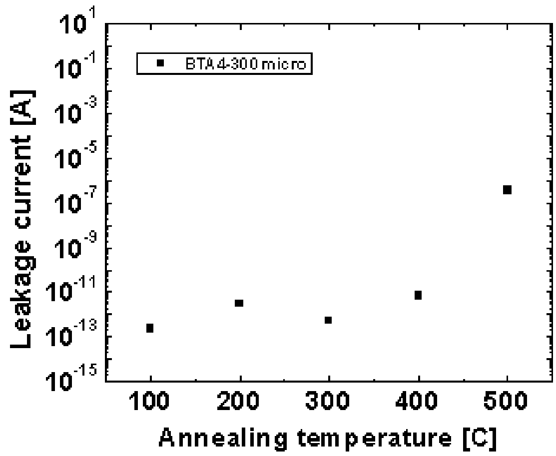

Figure 4. Leakage current versus annealing temperature (Φ=300μm)

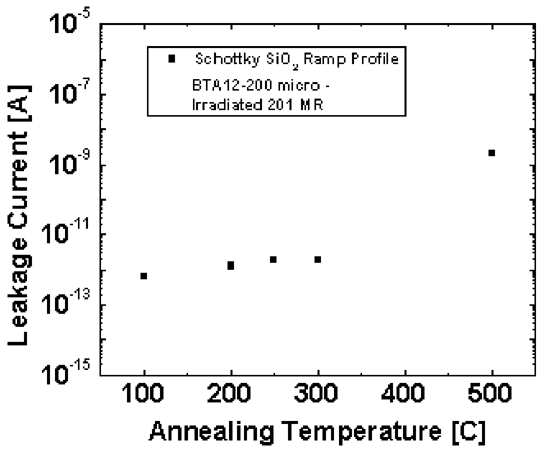

Figure 5. Leakage current versus annealing temperature (Φ=200μm)

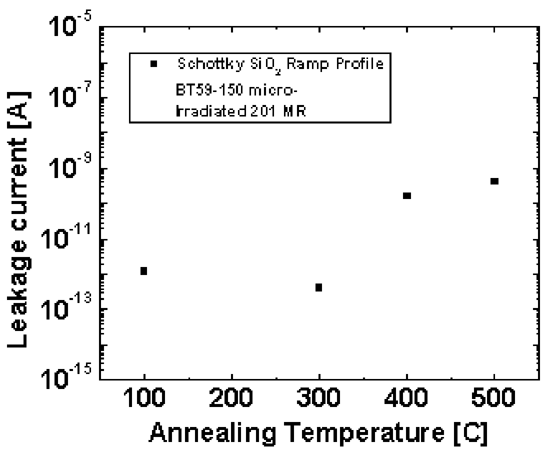

Figure 6. Leakage current versus annealing temperature (Φ=150μm)

ISSN 0852-4777

CONCLUTION

According of experiment results of investigation of annealing effect on the electrical properties change of P-type 6H-SiC Schottky diodes with SiO_2 ramp profile after irradiated up to 1.75 MGy at RT (Room Temperature), can concluded that the forward current increases with increasing annealing temperature.

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