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Impact of High Electron Radiation on Electrical properties of 4H-Silicon Carbide Schottky Diodes

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ABSTRACT. In this work, investigates of the electron irradiation effects on the electrical characteristics of 4H-SiC Schottky diodes has been done. Commercial 4H-SiC Schottky diodes were electron irradiated with the dose of 6 MGy, 9 MGy, 12 MGy and 15 MGy using EPS-3000 electron beam machine. Electrical characterization of post irradiation diodes showed that the forward bias (FB) current decreased while reverse bias (RB) leakage current increased. The series resistance was also increased as well as the electron fluence increased. The increases of resistance indicated that the RB leakage current was increased. It was believed that both electron-induce displacement and the formation of generation-recombination (G-R) centres as the cause of the carrier density decreased.

***Keywords**: 4H-silicon carbide, Schottky diode, Electron irradiation, Current-voltage;*

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1. INTRODUCTION

Diode is one of the main component in an electronic circuit. Utilizing diode in harsh radiation environment may create electrical damages to the diode which affects the properties, reliability and lifetime. Therefore, it is very important to investigate radiation sustainability of diode which operated under radiation. Various diodes materials have been studied for application under harsh radiation environment. 4H-Silicon Carbide (4H-SiC) Schottky diodes have been shown to be the most suitable candidate for this purpose due to its high radiation hardness, superior thermal and electrical characteristics such as wide band gap, higher thermal conductivity, high critical breakdown field, saturation electron drift velocity, electron mobility, chemical stability and mechanical strength. Therefore, 4-H Schottky diodes are promising be used for satellite-based systems, high temperature detectors and nuclear power industries [1-3]. Schottky diode is devices that has similar operation to a conventional p-n junction diode, but differs in its structure because consist of metal-semiconductor junction which plays important role [4]. This paper reports on the impact of radiation damage on the device performance of 4H-SiC Schottky diodes, which are irradiated at room temperature with 3 MeV electrons.

2. MATERIALS AND METHODS

Diodes used in this study were high voltage and high-speed switching commercial 4H-SiC Schottky diodes. The electrical characteristic was measured by Keithley instrument 4200 SCS. Electron irradiations were done using EPS-3000 EBM at Malaysian Nuclear Agency. The radiation energy was 3 MeV, while the accumulated radiation dose ranged from 6 MGy to 15 MGy. The repetitive reverse voltage V_{RRM} of commercial 4H-SiC diodes was 600V and Forward Current I_F (AV) was 1.7A. The ideality factor (n) saturation current (I_s) and series resistance (R_s) have been determined by fitting the linear and high injection region of the forward bias I-V curves while barrier height (Φ_b) was calculated.

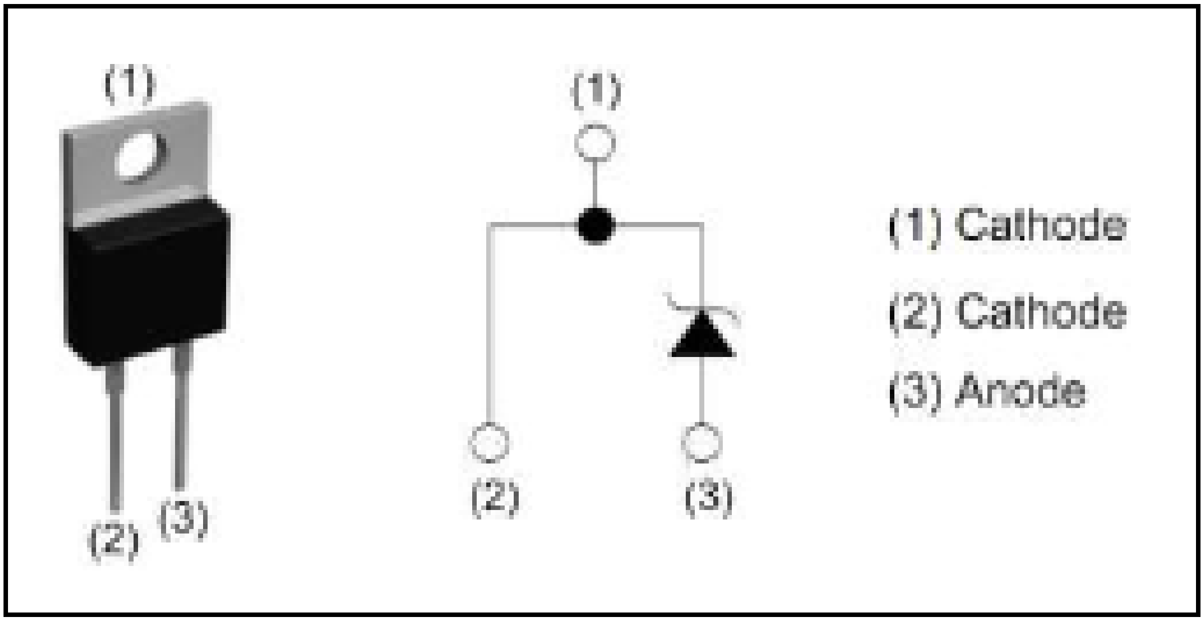


Fig. 1 Outline and inner circuit of commercial 4H-SiC diode

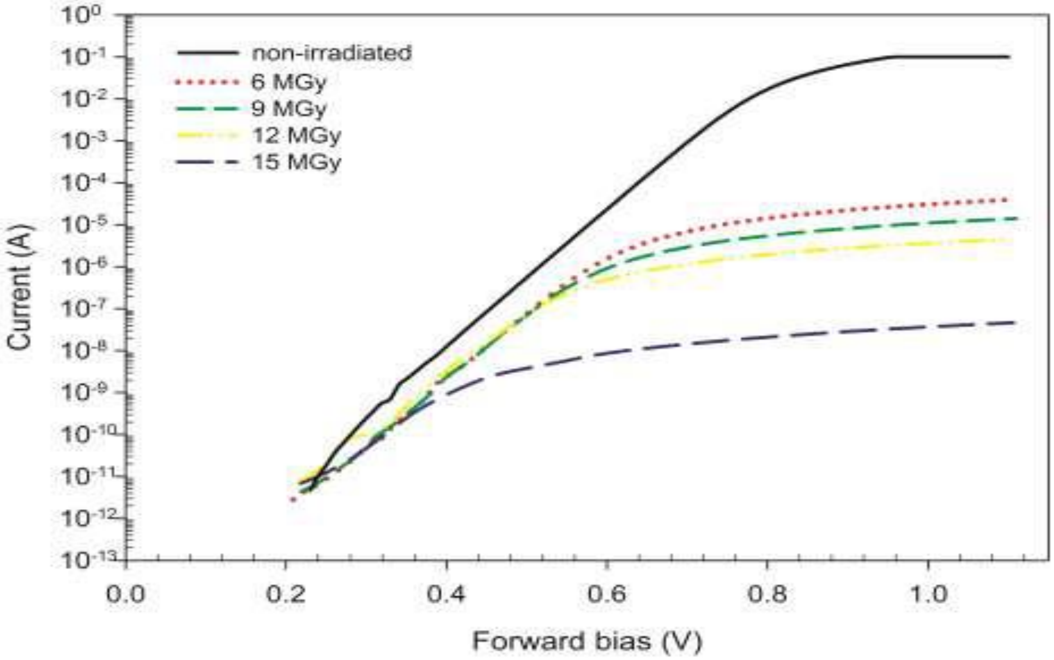
Fig. 1 shows the outline and inner circuit diagram of commercial 4H-SiC diode used in this work. Pre irradiation I-V measurements were carried out for all samples. The series resistance *Rs* was measured by using relationship as follow:

$$R_S = \frac{C}{N_D} \qquad (1)$$

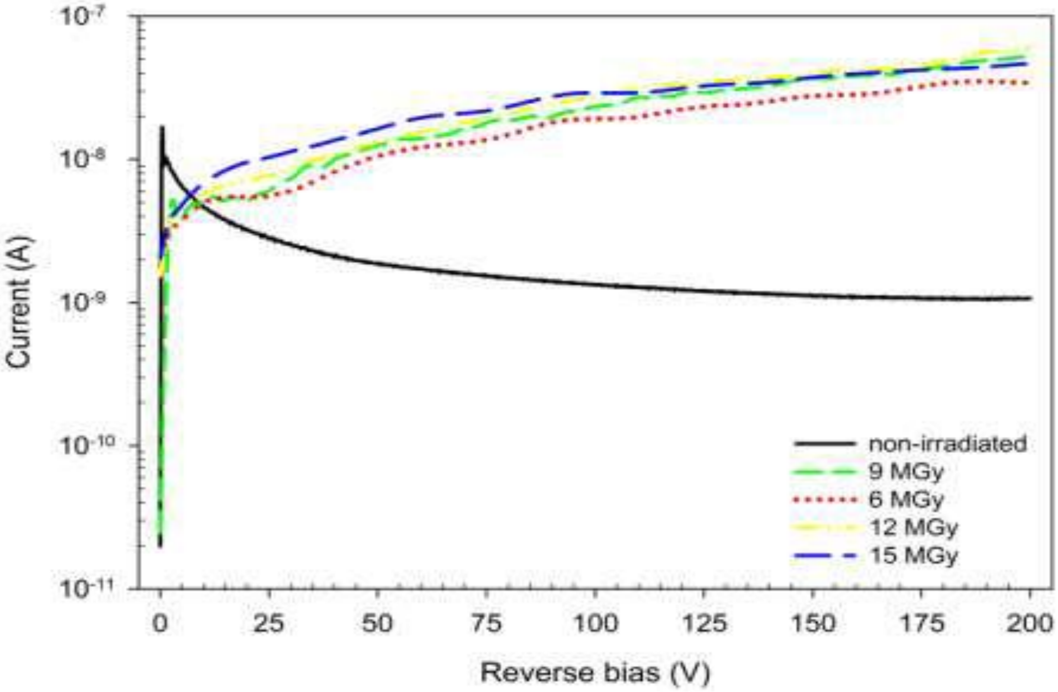
where *C* is a constant that depends on the relationship between dopant density and resistivity and on the diode geometry, *ND* is the dopant density [5].

3. RESULTS AND DISCUSSION

Fig. 2(a) shows the forward bias (FB) current-voltage (I-V) characteristics of pre and post irradiated 4H-SiC Schottky diodes. The results indicated that semilogarithmic FB of I-V curves decrease and shift towards higher voltages as the radiation dose increased. Current-voltage curves also exhibit a linear behaviour at low injection regions. In case of irradiation with 6, 9 and 12 MGy, semilogarithmic FB of I-V curves increase up to 0.5 V then start to saturate. However, irradiation with 15 MGy, FB of I-V curve starts to saturate at 0.4 V. It's also noted that the behaviour of I-V curves is dominated by the series resistance R_s at high voltages. Fig. 2(b) shows the reverse bias of I-V measurements indicated that the increasing of RB current as well as irradiation dose increased. The decrease of forward bias current for high fluence is related to the increased of the resistance, while the decrease of the barrier height is mainly responsible for the increasing of the reverse bias current.



(a)



(b)

Fig. 2 (a) Semilogarithmic forward bias I-V and (b) Semilogarithmic reverse bias I-V curves of pre and post irradiation

Table 1 Electrical parameters of 4H-SiC Schottky diodes extracted from I-V characteristics

Radiation dose (Gy)	Ideality factor N	Barrier height, ϕ_b (eV)	Saturation current, I_s (A)	Series resistance, Rs (Ω)
Non irradiated	1.04	1.20	$4.22x10^{-15}$	1.3
6M	1.05	1.24	$8.51x10^{-16}$	11.0K
9M	1.05	1.24	$8.51x10^{-16}$	33.2K
12M	1.09	1.22	$2.09x10^{-15}$	109K
15M	1.10	1.23	$1.40x10^{-15}$	15M

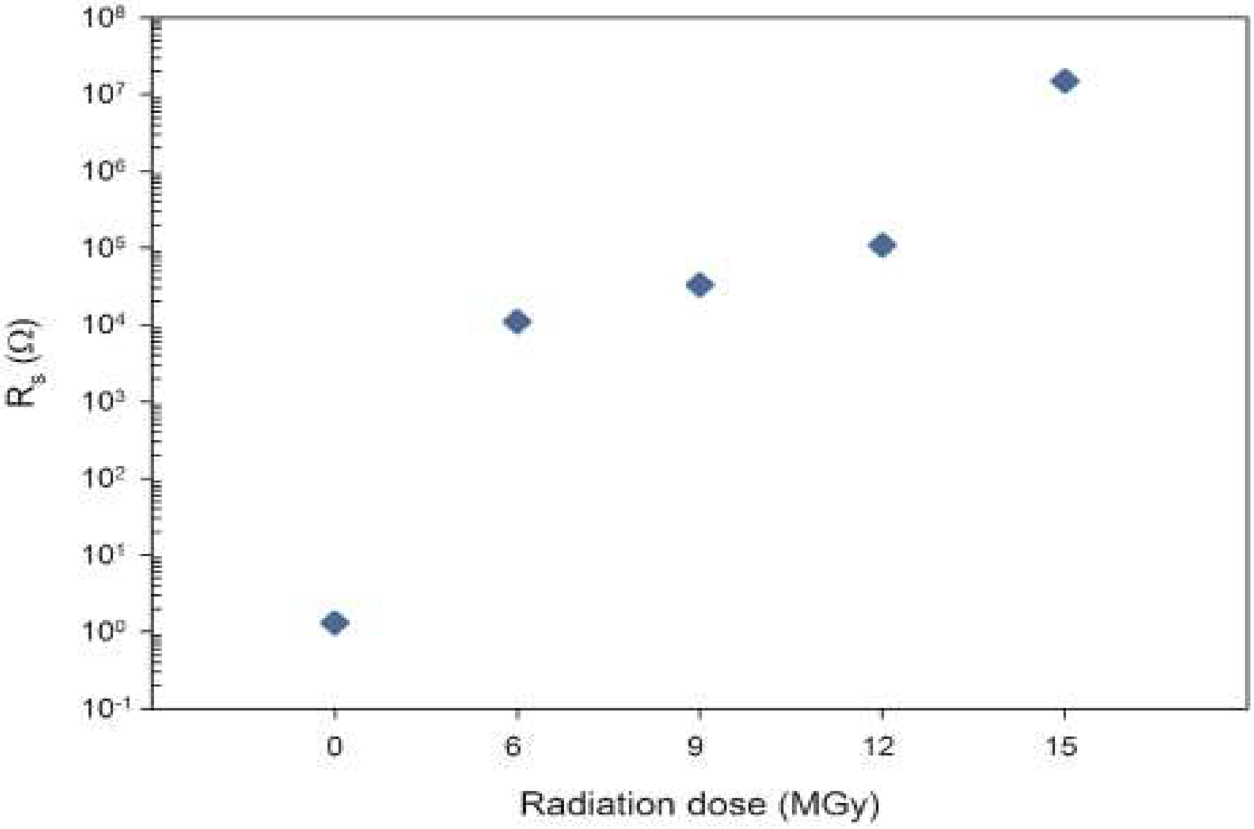


Fig. 3 Relation between series resistance *Rs* and radiation dose

The drastic increase of the leakage current is most likely because of new defect levels that act as efficient carrier traps and recombination centers. Benkovska et al. [6] observed that after irradiation of 9 MeV, series resistance and leakage current of 4H-SiC Schottky diodes increased as a result of deep energy levels originated in the structure. Generally, the results show that the barrier height was decreased while the ideality factor was increased. On the other hand, Benkovska et al. [6] reported that the leakage current of 4H-SiC Schottky diode decreased after irradiation with 6 MeV and significant decrease in barrier height because of irradiation induced traps at the interface. The decrease of leakage current can be explained as a result of dopant deactivation caused by radiation. Therefore, radiation induced defects in 4H-SiC promote interaction electrically with dopand, leading to its deactivation and finally reduce of free-carrier concentration. In turn, it contributes to the decrease of the leakage current in reverse bias [5]. The increasing of series resistance is also related to the free carrier deactivation. Radiation induced displacement damage gives rise to carrier removal which decreases the effective dopant density based on the formula,

$$ND = ND0 - A\Phi \qquad (2)$$

where $ND0$ is the dopant density before irradiation,Φ is the radiation fluence, and A is the rate of carrier removal [5]. It also indicated that the decreasing of effective dopant density leads to the increase of the series resistance. Cınar et al. [2] studied the effect of the electron irradiation on the series resistance of Au/Ni/6H-SiC and Au/Ni/4H-SiC Schottky contacts reported that an increase in series resistance was due to the reduction of the mobility and the free carrier concentration. Dachev et al. [7] was also reported that the decreasing of the electrical characteristics for both diodes is because of the concentration carrier reduction due to the trapping effect of the irradiation induced defects.

4. SUMMARY

4H-SiC diodes were irradiated with high dose electron radiation and electrical characteristics was successfully analysed. The results clearly indicated that the forward bias current significant degraded due to an increase in the series resistance R_s. The results also observed that reverse bias leakage current increased due to the density of generation-recombination (G-R) centres increased associated with the electron-induce displacement damage. However, the degradation of barrier height (Φ_b) was not significant, both saturation current (I_s) and ideality factor (n) were also not noticeable degraded.

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