Radiation Physics and Chemistry 193 (2022) 109992

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

The effects of electron irradiation on the current-voltage and capacitance-voltage measurements of Sn/*p*-GaAs/Au diodes

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A R T I C L E I N F O

Keywords:
GaAS
Diode
Electron irradiation
Seri resistance
Barrier height
III-V semiconductor

A B S T R A C T

In this study 11 (eleven) Sn/*p*-GaAs/Au diodes were identically fabricated. Au and Sn metals were used in order to fabricate the ohmic and rectifier contacts, respectively. The effect of electron irradiation of high electron energy of 6, 12, 15 and 18 MeV and low electron fluence of 1×10^{12} electrons/cm^2 on the various parameters such as barrier height (BH), ideality factor (IF), series resistance (R_s), and rectification ratio (RR), acceptor concentration (N_a), diffusion potential (V_d) obtained from current-voltage (*I–V*) and capacitance-voltage (*C–V*) characteristics of Sn/*p*-GaAs/Au diodes was evaluated. The BH value of one (D2) of the unirradiated 11 Sn/p-GaAs/Au diodes was calculated as 0.82 eV, 0.86 eV and 0.94 eV from ln(I)–V characteristics according to the thermionic emission (TE) theory, modified Norde's functions, and *C–V* characteristics, respectively. The BH values calculated ln(*I*)–*V* and Norde's functions were found to be very close to each other. The values of RR, IF, and BH of D2 diode calculated from ln(*I*)–*V* according to TE theory were calculated as 1×10^6, 1.09 and 0.82 eV, 1×10^6, 1.06 and 0.81 eV, 1×10^6, 1.09 and 0.82 eV, 1×10^6, 1.12 and 0.83 eV, 1×10^6, 1.13 and 0.82 eV for before and after 6, 12, 15 and 18 MeV electron irradiation, respectively. The R_s value of unirradiated and 6, 12, 15 and 18 MeV electron irradiated D2 diode was calculated from Norde's function was calculated 29, 30, 30, 27, and 26 Ω, respectively. Since these parameters remain nearly unchanged after electron irradiation, it can be said that electron radiation has no significiant effect on ln (*I*)–*V* characteristics and the Sn/*p*-GaAs/Au diodes are insensitive to high-energy electron -irradiation.

1. Introduction

Semiconductor based devices communicate with each other through metal/semiconductor (M/S) contacts in electronic circuits (Coskun et al., 2006). Therefore, it is important to determine how the contact parameters change with high-energy electron radiation. In a radiation environment, when semiconductor devices are exposed to electrons, neutrons, proton, ions, ^{60}Co γ-ray, and alpha particle, defects and damages may occur in semiconductor devices (Karatas et al., 2005). High-energy particles penetrate the interface and low-energy particles cause severe lattice damage in the form of interstitials, vacancies and defect complexes at the near interface of the device (Dharmarasu et al., 1998). These defects and damages can cause the performance of the semiconductor device to decrease.

Gallium arsenide (GaAs)-based devices have some advantages over Si-based devices for high-speed and high-power applications due to the high electron mobility in GaAs, high carrier mobility, direct band gap of 1.42 eV which is nearly ideal for single junction solar cells, low power consumption, the higher breakdown field, chemical inertness, mechanical stability and the availability of semi-insulating GaAs substrates (Ye et al., 2003; Lu et al. 2006; Soylu et al., 2011).

GaAs, CdTe, InP, GaN, SiC semiconductor materials offer higher radiation tolerance against γ-rays, electrons, protons, and neutrons and can work in harsh environments over extended durations as compared to Si or Ge (Dixit and Sharma, 2020). Therefore GaAs is very desirable for space applications thanks to the high absorption coefficient of GaAs (Rao et al., 2010).

Many studies have been conducted to understand the effect of radiation on the electrical properties of metal/GaAs diodes (Karatas et al., 2005; Dharmarasu et al. 1998; Rao et al. 2010; Lowe et al., 1977; Ashok

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https://doi.org/10.1016/j.radphyschem.2022.109992
Received 13 July 2021; Received in revised form 20 December 2021; Accepted 22 January 2022
Available online 25 January 2022
0969-806X/

et al., 1978; Jayavel et al. 1999, 2003; Hullavarad et al. 1999). Protons and electrons irradiated GaAs solar cells showed a greater resistance to radiation than Si solar cells (Lowe et al., 1977). Ashok et al. (1978) reported that the GaAs metal/insulator/semiconductor (MIS) diodes are insensitive to γ-irradiation, while neutron irradiation changed current-voltage (*I–V*) characteristics significantly with little free carrier compensation. While ^{60}Co γ-ray irradiation caused an increase in the barrier height (BH) calculated from capacitance–voltage (*C–V*) measurements, BH obtained from ln (*I*)–*V* measurements remained approximately constant for the Au/*n*-GaAs diode (Karatas et al., 2005). The Au/*n*-GaAs diodes were irradiated with high energy of 70 MeV carbon ions with various ion fluences of 1×10^{11}, 1×10^{12} and 1×10^{13} ions/cm^2 and *I–V* and *C–V* characteristics of were analysed. The reverse leakage current increased with increasing ion fluence (Jayavel et al., 1999).

Jayavel et al. (2002) found that the BH of Ni/*n*-GaAs decreased, the ideality factor (IF) deviated from the ideal behavior, the reverse leakage current increased with increasing proton fluences. The effect of high energy nitrogen ion irradiated *n*-GaAs diode was investigated using deep level transient spectroscopy (Jayavel et al., 2003).

Dharmarasu et al. (1998) reported an increase in reverse bias current, a decrease in BH and an increase in the series resistance value (R_s) of Pd/*n*-GaAs diode with low energy proton irradiation fluence. The high reverse bias current for higher proton fluence is likely due to irradiation-induced defects that cause tunneling at the interface across the barrier (Dharmarasu et al., 1998). Only minor changes in GaAs solar cell parameters were observed up to an electron dose of 100 kGy, with good tolerance for electrons of 8 MeV energies (Rao et al., 2010).

In this study, Au has selected as ohmic contact metal and Sn selected to form Schottky contact. In the previous studies, Deniz et al. (2014) and Vandenbroucke et al. (1987) used Au metal to form ohmic contact. The detailed information on the *I–V* characteristics of metal/n-GaAs diodes has been documented in the literature (Ozavci et al., 2013; Yildirim et al., 2009; Korucu et al., 2013; Dharmarasu et al., 1998; Jayavel et al., 2002). But, very few reports are available about the Schottky diode properties of metal/*p*-GaAs (Soylu et al., 2011; Mazari et al., 2002; Myburg et al., 1998; Deniz et al., 2014; Vandenbroucke et al., 1987). To the best of authors knowledge, there is no experimental data available on the *I–V* measurements of Sn/*p*-GaAs/Au Schottky diode in literature. Also, there is no study on the effects of electron irradiation on the *I–V* and *C–V* characteristics of the Sn/*p*-GaAs/Au diodes. Therefore in this study, the aim is to fabricate Sn/*p*-GaAs/Au diodes with high BH and low IF and analyze the effects of irradiation with electron energies of 6, 12, 15, 18 MeV with a constant fluence of 10^{12} electrons/cm^2 on *I–V* and *C–V* characteristics. Hence, the data presented in this study is believed to contribute to the existing data on the radiation hardness of GaAs based devices.

2. Experimental procedure

First *p*-GaAs sample with a thickness of 375 μm was cleaned with trichloroethylene, acetone and methanol for 5 min, to remove surface impurity layer and improve the quality of device, respectively. Then it was rinsed with de-ionized water, etched in $5H_2SO_4+H_2O_2+H_2O$ solution for 60 min. Lastly, it was rinsed with deionized water and dried with high purity nitrogen (N_2). To form ohmic contact, gold (Au) metal was evaporated on the back of *p*-GaAs sample using the thermal evaporation method at 10^{-6} Torr and annealed at 450 °C for 3 min in a pure N_2 atmosphere in a quartz tubes. Then, to form the rectifier (Schottky) contact, tin (Sn) of 99.99% purity on the other surface of p-GaAs sample was evaporated with a metal shadow mask of 1.00 mm diameter at a pressure of 10^{-6} Torr. The thickness of the Sn film was 1000 Å. Thus the 11 Sn/*p*-GaAs/Au diodes (Schottky contacts) which was labeled as D1, D2, …and D11 were fabricated on the same *p*-GaAs semiconductor substrate by evaporation of Sn. Later, *I–V* measurements of all diodes were taken before the Sn/*p*-GaAs/Au was irradiated. Then, the diodes were exposed to 6 MeV electron irradiation at room temperature and *I–V* measurements of all diodes were taken. This process was repeated in electron irradiation with energies of 12, 15 and 18 MeV, respectively. The electron fluence for each electron irradiation is 10^{12} electrons/cm^{-2}. Also, during the electron irradiation process no bias voltage was applied to the Sn/*p*-GaAs/Au diodes. A Siemens–Primus linear electron accelerator which allowed to accelerate the electrons up to 21 MeV energy was used for electron irradiation. The *I–V* and *C–V* measurements were carried out using a Keithley 2400 Picoammeter/Voltage source and a HP 4192 A LF Impedance analyzer, in dark and at room temperature, respectively. The schematic diagram of Sn/*p*-GaAs/Au diode is illustrated in Fig. 1.

3. Results and discussion

Schottky diodes made from high mobility semiconductors possess the *I–V* characteristics given by the thermionic-emission (TE) theory, provided the forward bias is not too large. According to TE theory, *I–V* characteristics can be defined as (Rhoderick and Williams, 1988);

$$I = I_0\left[\exp\left(\frac{qV}{kT}\right) - 1\right] \tag{1}$$

In practice diodes never satisfy the ideal Eq. (1) exactly, but can be more closely described by the modified equation

$$I = I_0\exp\left(\frac{qV}{nkT}\right)\left[1 - \exp\left(-\frac{qV}{kT}\right)\right] \tag{2}$$

where IF (*n*) is approximately independent of *V* and is greater than unity. For values of *V* greater than $3kT/q$, Eq. (1) can be written

$$I = I_0\ \exp\left(\frac{qV}{nkT}\right) \tag{3}$$

where I_0 is the reverse saturation current and it is defined by,

$$I_0 = AA^{*}T^2\left(\exp\left(-\frac{q\Phi_b}{kT}\right)\right) \tag{4}$$

where *V is* the bias voltage, *A* is the diode area (0,00785 cm^2), A^* is the Richardson constant, *T* is temperature in Kelvin, *k* is Boltzmann constant ($8{,}625 \times 10^{-5}$ eV K^{-1}), *q* is electronic charge ($1{,}6 \times 10^{-19}$ C), Φ_b is the zero bias apparent BH, respectively.

From Eq. (3), the value of *n* is determined as follows:

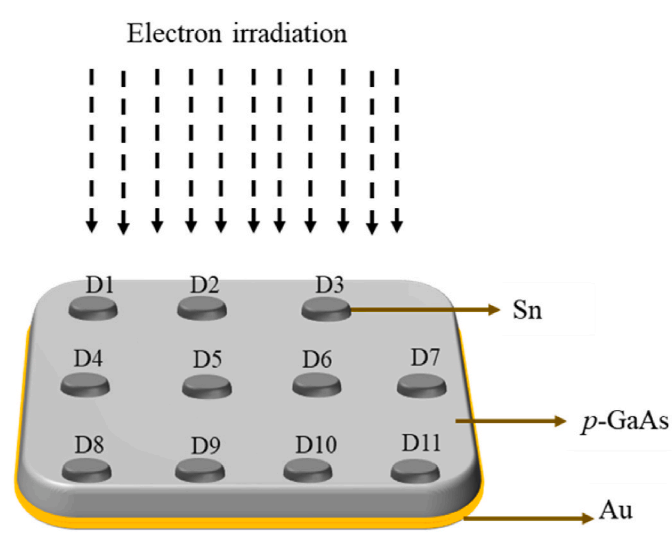

Fig. 1. Schematic diagram of Sn/*p*-GaAs/Au diodes.

$$n = \frac{q}{kT}\left(\frac{dV}{d(lnI)}\right) \quad (5)$$

The ln(*I*)–*V* characteristics of the unirradiated 11 Sn/*p*-GaAs/Au diodes are illustrated in Fig. 2. All diodes show a good rectifying properties with relatively low reverse bias current.

Fig. 3 shows ln (*I*)–*V* characteristics of the unirradiated and electron (energy of 6, 12, 15, and 18 MeV) irradiated Sn/*p*-GaAs/Au diodes with a relatively low-fluence of 10^{12} electrons/cm^2.

Coskun et al. (2006) investigated the effects of high-energy (6, 9, 12 MeV) and relatively low-dose (3×10^{12} electrons/cm^2) electron irradiation on the parameters of *n*-ZnO-based ohmic and Schottky contacts. The IF of the Au/*n*-ZnO diode increased and BH decreased with increasing electron energy. It was concluded that the atoms of the contact elements diffused into the semiconductor material and thus turning the rectifying character to the ohmic behavior with the influence of radiation–matter interaction (Coskun et al., 2006). Krishnan et al. (2008) investigated the effect electron irradiation of 8 MeV energy up to a dose of about 100 kGy (equivalent to a fluence of 3.02×10^{13} electrons/cm^2) on the *I–V* characteristics of Al/*p*-Si Schottky diodes. A decrease in the BH and an increase in the IF were observed up to a dose of about 25 kGy. It was reported that the degradation in the diode properties may be due to the introduction of radiation-induced interfacial defects via displacement damage. (Krishnan et al., 2008). Cinar et al. (2010) studied the effect of electron irradiation with various energies (6, 12 and 15 MeV) with a constant fluence of 10^{12} electrons/cm^2 on *I–V* of Au/Ni/6H–SiC and Au/Ni/4H–SiC Schottky diodes. They found that the electrical characteristics of Au/Ni/6H–SiC and Au/Ni/4H–SiC diodes are sensitive to electron irradiation. Aydogan and Turut (2011) investigated the effect of 12 MeV electron irradiation with fluency of 10^{12} electrons/cm^2 on *I–V* characteristics of Au/Carmine/*p*-Si/Al. The IF and R_s values increased and the reverse bias current and capacitance decreased with 12 MeV electron irradiation. This was attributed to decrease in net ionized dopant concentration with electron irradiation.

In the present study, as seen in Fig. 3, there is no significiant change in the ln (*I*)–*V* characteristics of the Sn/*p*-GaAs/Au diodes after electron irradiation. Using TE theory, the BH and IF values of Sn/*p*-GaAs/Au diodes were calculated from the y-axis intercept and slope of the linear region of the experimental forward bias ln(*I*)–*V* data for each electron irradiation, respectively.

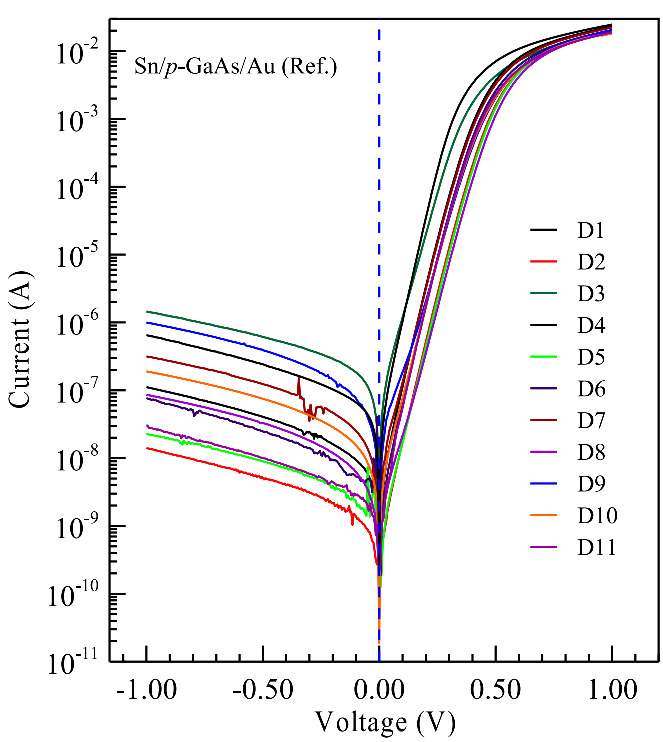

Fig. 2. The ln (*I*)–*V* characteristics of the unirradiated 11 Sn/*p*-GaAs/Au diodes (labeled as D1, D2, …and D11).

The IF and BH values of unirradiated and electron irradiated 11 Sn/*p*-GaAs/Au diodes are given in Tables 1 and 2, respectively. The IF and BH values of the Sn/*p*-GaAs/Au diodes varied from 1.07 to 1.35 and 0.70–0.82 eV before irradiation, 1.06 to 1.36 and 0.69–0.81 eV under 6 MeV irradiation, 1.09 to 1.39 and 0.69–0.82 eV under 12 MeV irradiation, 1.10 to 1.34 and 0.70–0.83 eV under 15 MeV irradiation, and 1.11 to 1.35 and 0.70–0.82 eV under 18 MeV irradiation, respectively. The calculated values of BH are the same for unirradiated some diodes. The average IF n and standard deviation values (σ) were determined to be 1.17 and 0.092 before irradiation, 1.18 and 0.097 under 6 MeV irradiation, 1.20 and 0.100 under 12 MeV irradiation, 1.20 and 0.082 under 15 MeV irradiation, 1.20 and 0.083 under 18 MeV irradiation, respectively. The average *BH* Φ and standard deviation values (σ) were determined to be 0.78 and 0.038 before irradiation, 0.78 and 0.044 under 6 MeV irradiation, 0.78 and 0.044 under 12 MeV irradiation, 0.79 and 0.042 under 15 MeV irradiation, 0.79 and 0.042 under 18 MeV irradiation, respectively. The Sn/*p*-GaAs/Au diodes have a BH and a low leakage current. Thus, it can be said that the IF and BH values almost remain constant after irradiation. The calculated values of IF ($n < 1.4$) reveal mostly thermionic emission to be the dominant transport mechanisms for all diodes.

The BH and IF values of various diodes fabricated using GaAs semiconductor in the literature were given in Table 3.

A quality diode should have a high BH, a low IF, a low leakage current, a low R_S, and a high rectification ratio (RR = $I_{forward}/I_{reverse}$). For an ideal Schottky diode, IF has a value of 1.0. The IF values have changed between 1.07 and 1.10 for 6 Sn/*p*-GaAs/Au diodes as seen in Table 3. These values are lower than the values of 1.41 and 1.14, which was found by Soylu et al. (2011) and Vandenbroucke et al. (1987), respectively. The mean value BH of 0.78 for the unirradiated Sn/*p*-GaAs/Au diodes is higher than BH values reported by Soylu et al. (2011), Mazari et al. (2002), Myburg et al. (1998), Deniz et al. (2014), Vandenbroucke et al. (1987) for some metal/*p*-GaAs diodes. The Sn/*p*-GaAs/Au diodes have RR between about 10^4 and 10^6 at ±1.0 V and a RR as high as 10^5 was achieved for the 6 Sn/p-GaAs/Au diodes (Table 4). The RR value for almost all diodes hasn't changed after electron irradiation at different energies.

The forward bias ln(*I*)–V characteristics of the Sn/*p*-GaAs/Au diodes deviate from linearity due to the effect of R_s at large applied voltages and thus high power dissipation occurs. R_s is influenced by the presence of the interface layer between the metal and the semiconductor, low quality of ohmic contact, organic impurities, interfacial states and bulk resistance of the semiconductor (Nicollian and Brews, 1982; Lapa et al. 2020).

Norde's (1979) function modified by Bohlin (1986) can be used to determine the Φ_b and R_s values of the Sn/p-GaAs/Au diodes. They are given as follows:

$$F(V) = \frac{V_0}{\gamma} - \frac{kT}{q} ln\left(\frac{I(V)}{AA^*T^2}\right) \quad (6)$$

Here, the value of γ ($\gamma = 2$) should be selected as a number greater than the value of n obtained from the ln (I) − V characteristics.

$$\Phi_b = F(V_{min}) + \left[\left(\frac{\gamma - n}{n}\right)\right]\left[\frac{V_{min}}{\gamma} - \frac{kT}{q}\right] \quad (7)$$

$$R_s = \frac{(\gamma - n)kT}{qI_{min}} \quad (8)$$

Fig. 4 shows the F(V)–V plots of the unirradiated Sn/*p*-GaAs/Au diodes. Fig. 5 shows the $F(V) - V$ plot of one (D2) of the unirradiated and electron irradiated 11 Sn/*p*-GaAs/Au diodes.

BH values determined from Eq. (7) and R_s values determined from

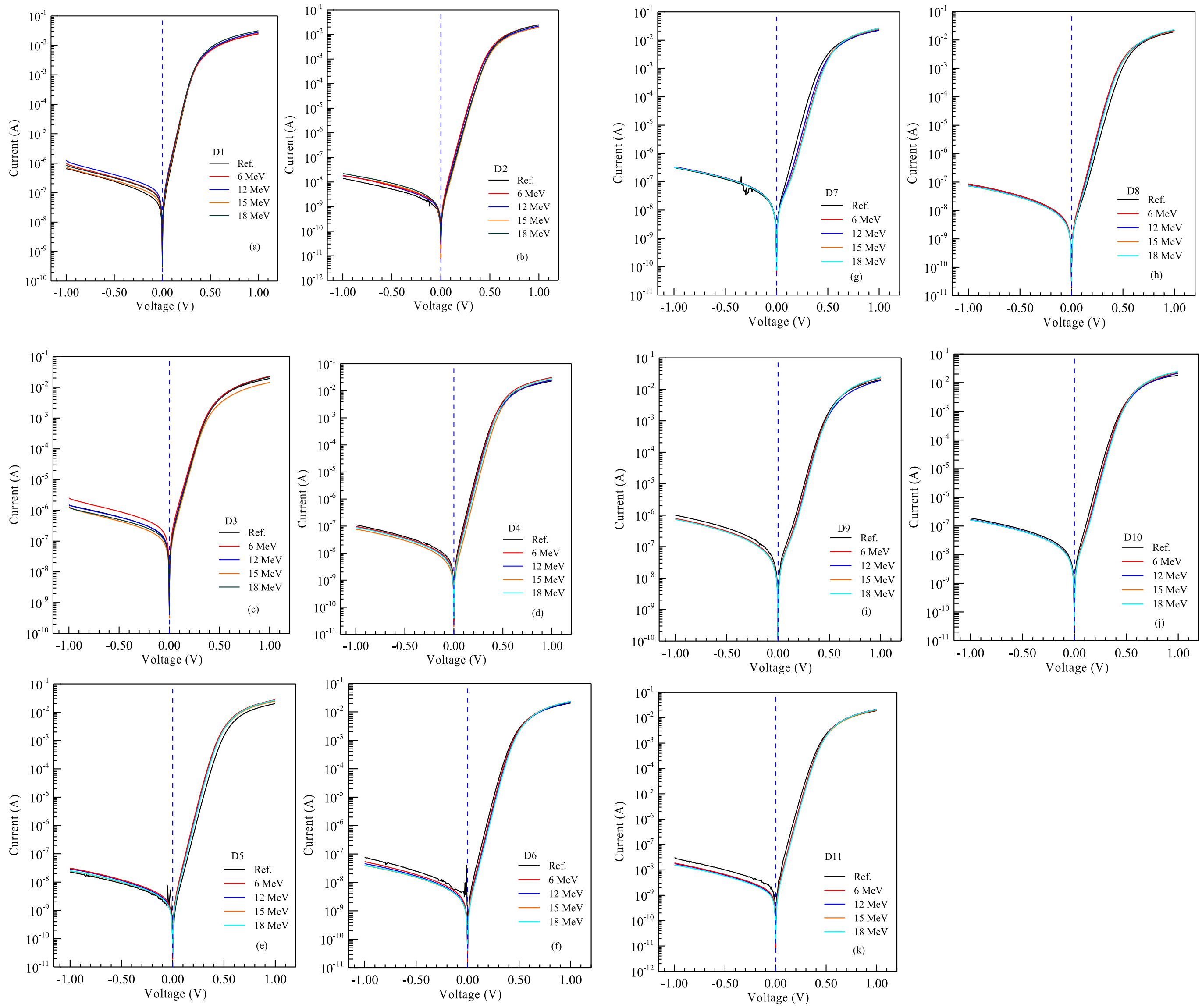

Fig. 3. (a)–(k). The ln (*I*)–*V* characteristics of unirradiated and electron irradiated 11 Sn/*p*-GaAs/Au diodes.

Table 1
The IF values calculated from ln(*I*)–*V* according to TE theory of Sn/*p*-GaAs/Au diodes before irradiation and under 6, 12, 15, and 18 MeV electron irradiation, respectively.

IF (*n*)					
Diode number	Before irradiation	6 MeV irradiation	12 MeV irradiation	15 MeV irradiation	18 MeV irradiation
D1	1.07	1.08	1.11	1.10	1.11
D2	1.09	1.06	1.09	1.12	1.13
D3	1.26	1.30	1.39	1.33	1.35
D4	1.10	1.12	1.16	1.17	1.16
D5	1.10	1.09	1.11	1.15	1.15
D6	1.10	1.12	1.15	1.16	1.16
D7	1.21	1.25	1.24	1.26	1.26
D8	1.23	1.22	1.20	1.20	1.19
D9	1.35	1.36	1.36	1.34	1.34
D10	1.22	1.22	1.23	1.22	1.22
D11	1.10	1.16	1.12	1.15	1.13
n	1.17	1.18	1.20	1.20	1.20
σ	0.092	0.097	0.100	0.082	0.083

Table 2
The BH values calculated from ln(*I*)–*V* according to TE theory of Sn/*p*-GaAs/Au diodes before irradiation and under 6, 12, 15, and 18 MeV electron irradiation, respectively.

Φ_b (eV)					
Diode number	Before irradiation	6 MeV irradiation	12 MeV irradiation	15 MeV irradiation	18 MeV irradiation
D1	0.72	0.71	0.70	0.71	0.71
D2	0.82	0.81	0.82	0.83	0.82
D3	0.70	0.69	0.69	0.70	0.70
D4	0.78	0.78	0.79	0.80	0.79
D5	0.82	0.80	0.81	0.81	0.81
D6	0.79	0.80	0.80	0.81	0.81
D7	0.77	0.80	0.79	0.79	0.80
D8	0.80	0.79	0.80	0.81	0.81
D9	0.76	0.77	0.77	0.78	0.78
D10	0.78	0.79	0.80	0.80	0.80
D11	0.80	0.80	0.81	0.81	0.82
Φ	0.78	0.78	0.78	0.79	0.79
σ	0.038	0.044	0.044	0.042	0.042

Table 3
Experimental IF and BH values reported for various metal/p-GaAs diodes in the literature.

Diode	IF	BH (eV)	Ref.
Sn/p-GaAs	1.17 (average value for eleven diodes)	0.78 eV (average value for eleven diodes)	Present work
Al/p-GaAs	1.41	0.68	Soylu et al. (2011)
Al/p-GaAs	–	0.67	Mazari et al. (2002)
Ru/p-GaAs	–	0.60	Myburg et al. (1998)
Ga/p-GaAs	–	0.83	Myburg et al. (1998)
Al/p-GaAs	–	0.67	Myburg et al. (1998)
Au/Pd/p-GaAs	–	0.68	Deniz et al. (2014)
Al/p-GaAs	1.14	0.59	Vandenbroucke et al. (1987)

Table 4
The RR values of Sn/p-GaAs/Au diodes the before and after 6, 12, 15, and 18 MeV electron irradiation.

	RR (at ±1 V)				
Diode number	Before irradiation	6 MeV irradiation	12 MeV irradiation	15 MeV irradiation	18 MeV irradiation
1	4×10^4	3×10^4	2×10^4	4×10^4	4×10^4
2	1×10^6	1×10^6	1×10^6	1×10^6	1×10^6
3	1×10^4	9×10^3	1×10^4	1×10^4	2×10^4
4	2×10^5	3×10^5	3×10^5	3×10^5	3×10^5
5	9×10^5	9×10^5	1×10^6	1×10^6	1×10^6
6	3×10^5	4×10^5	5×10^5	6×10^5	6×10^5
7	7×10^4	8×10^4	7×10^4	7×10^4	8×10^4
8	2×10^5	3×10^5	3×10^5	3×10^5	3×10^5
9	2×10^4	3×10^4	3×10^4	3×10^4	3×10^4
10	1×10^5	1×10^5	1×10^5	1×10^5	1×10^5
11	6×10^5	1×10^6	1×10^6	1×10^6	1×10^6

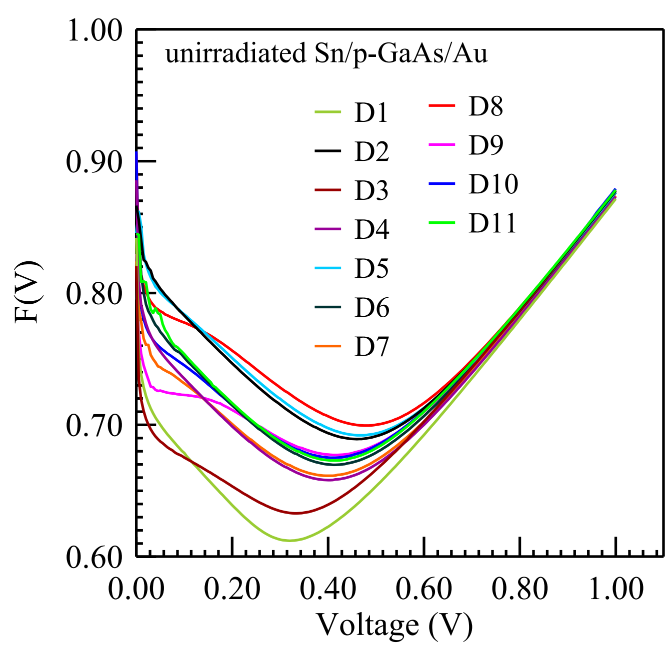

Fig. 4. The $F(V)$–V plots of the unirradiated 11 Sn/p-GaAs/Au diodes.

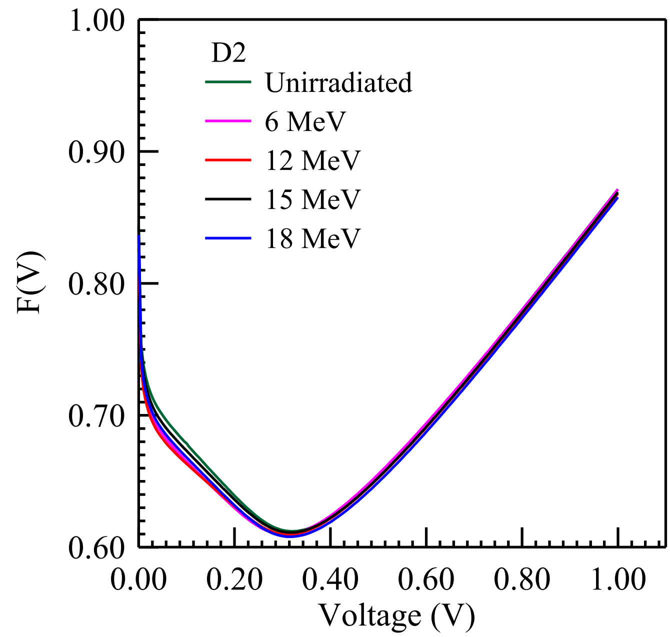

Fig. 5. $F(\mathrm{V}) - V$ plots of one (D2) of the unirradiated and electron irradiated Sn/p-GaAs/Au diodes.

Eq. (8) are presented in Tables 5 and 6, respectively. The value of R_s for all diodes is small. This shows a low resistivity ohmic contact between p-GaAs and Au. The BH and R_S values of eleven Sn/p-GaAs/Au diodes varied from 0.72 to 0.86 eV and 23–45 Ω before irradiation, 0.72–0.85 eV and 22–36 Ω under 6 MeV irradiation, 0.71–0.84 eV and 23–33 Ω under 12 MeV irradiation, 0.71–0.85 eV and 21–42 Ω under 15 MeV irradiation, 0.70–0.85 eV and 13–45 Ω under 18 MeV irradiation, respectively. The average *BH* and standard deviation values (σ) were determined to be 0.80 and 0.048 before irradiation, 0.79 and 0.045 under 6 MeV irradiation, 0.79 and 0.047 under 12 MeV irradiation, 0.80 and 0.044 under 15 MeV irradiation, 0.79 and 0.045 under 18 MeV irradiation, respectively. The average seri resistance R_s and standard deviation values (σ) were determined to be 33 and 6.5 Ω before irradiation, 29 and 5.0 Ω under 6 MeV irradiation, 29 and 3.4 Ω under 12 MeV irradiation, 28 and 6.2 Ω under 15 MeV irradiation, 25 and 8.4 Ω under 15 MeV irradiation, respectively. The BH values obtained from Norde's functions are in good agreement with the values obtained from the ln (I)–V.

Figs. 6 and 7 show the C–V and reverse bias $1/C^2$–V characteristics of one (D2) of the unirradiated and electron irradiated 11 Sn/p-GaAs/Au diodes at a frequency of 500 kHz. As seen in Fig. 6, a very slight decrease in the capacitance value was observed after electron irradiation between 6 and 18 MeV. Thus, it can be concluded that electron irradiation has not contributed significantly to the increase of deep level defects [7].

The values of acceptor concentration (N_a) and diffusion potential (V_d) were obtained from the slope and extrapolation of the linear part of the C^{-2}–V curves to the voltage axis for the before and after electron irradiation. The N_a, V_d and BH values of unirradiated and electron irradiatiated Sn/p-GaAs/Au (D2) are given in Table 7. There is a slight decrease in the N_a value due to the trapping effect of the irradiation induced defects. The value of V_d and BH remains almost unchanged after irradiation because there is no significiant change in the depletion region of the Sn/p-GaAs/Au diode.

4. Conclusion

In this study, the Sn/p-GaAs/Au diodes of high BH were fabricated. The effect of high-energy electron irradiation on I–V and C–V characteristics of the 11 Sn/p-GaAs/Au diodes was evaluated. It wasn't

Table 5
The BH values obtained calculated from modified Norde's functions for the unirradiated and electron irradiated 11 Sn/*p*-GaAs/Au diodes.

Φ_b (eV)					
Diode number	Before irradiation	6 MeV irradiation	12 MeV irradiation	15 MeV irradiation	18 MeV irradiation
1	0.73	0.72	0.71	0.72	0.70
2	0.86	0.85	0.84	0.85	0.85
3	0.72	0.70	0.70	0.71	0.74
4	0.80	0.80	0.80	0.81	0.79
5	0.86	0.83	0.83	0.82	0.82
6	0.82	0.82	0.82	0.82	0.84
7	0.77	0.81	0.79	0.79	0.82
8	0.83	0.80	0.81	0.82	0.78
9	0.76	0.77	0.78	0.78	0.81
10	0.79	0.80	0.81	0.81	0.75
11	0.82	0.81	0.83	0.83	0.78
Φ	0.80	0.79	0.79	0.80	0.79
σ	0.048	0.045	0.047	0.044	0.045

Table 6
The BH values obtained calculated from modified Norde's functions for the unirradiated and electron irradiated 11 Sn/*p*-GaAs/Au diodes.

R_s (Ω)					
Diode number	Before irradiation	6 MeV irradiation	12 MeV irradiation	15 MeV irradiation	18 MeV irradiation
1	23	28	24	21	16
2	29	30	30	27	26
3	30	33	29	42	45
4	28	22	26	22	21
5	33	28	23	24	24
6	36	31	26	22	30
7	31	19	29	23	19
8	28	32	33	31	24
9	35	30	33	30	27
10	42	25	30	31	13
11	45	36	31	31	25
R_S	33	29	29	28	25
σ	6.5	5.0	3.4	6.2	8.4

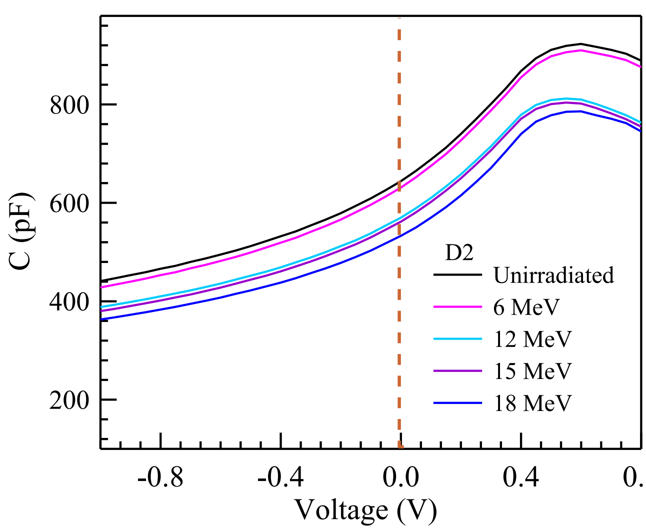

Fig. 6. The *C–V* characteristics of one (D2) of the unirradiated and electron irradiated 11 Sn/*p*-GaAs/Au diodes at a frequency of 500 kHz.

observed very significiant change in the *I–V* characteristics of Sn/*p*-GaAs/Au diodes under the electron irradiation. The capacitance value of electron irradiated diode slightly decreased. The BH, IF, and *Rs* values of Sn/p-GaAs/Au remained nearly constant and the diodes were insensitive to electron irradiation. These results confirm the Sn/p-GaAs/Au diodes could be used in space applications as the electron irradiation-resistant contacts.

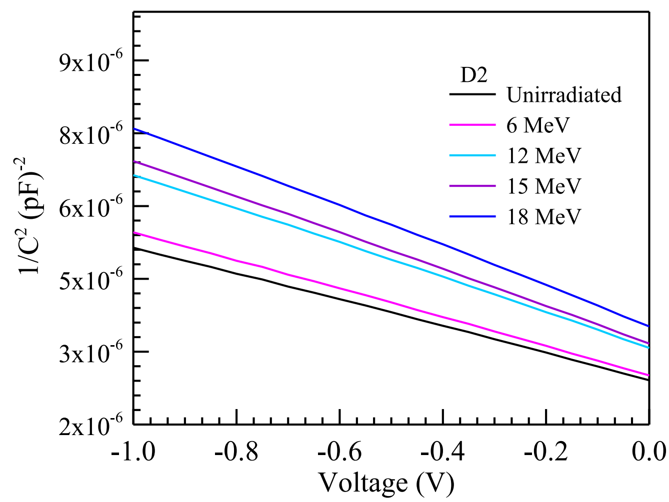

Fig. 7. The reverse bias 1/C^2–V characteristics of one (D2) of the unirradiated and electron irradiated 11 Sn/*p*-GaAs/Au diodes at a frequency of 500 kHz.

Table 7
The acceptor concentration (N_a), diffusion potential (V_d) and BH values of one (D2) of the unirradiated and electron irradiatiated 11 Sn/*p*-GaAs/Au calculated from C^{-2}–V characteristics.

	Acceptor concentration (N_a)	V_d (eV)	BH (eV)
Unirradiated	6.5×10^{16}	0.89	0.94
6 MeV	6.0×10^{16}	0.86	0.91
12 MeV	5.0×10^{16}	0.87	0.93
15 MeV	4.7×10^{16}	0.85	0.90
18 MeV	4.3×10^{16}	0.87	0.93

CRediT authorship contribution statement

Songül Duman: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Fikriye Şeyma Kaya:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Hülya Doğan:** Writing – original draft, Writing – review & editing. **Güven Turgut:** Investigation. **Yılmaz Şahin:** Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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