The effects of gamma irradiation on electrical characteristics of Zn/ZnO/n-Si/Au-Sb structure

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Abstract. In this research, we have investigated the electrical characteristics of Zn/ZnO/n-Si/Au-Sb structure before and after ^{60}Co gamma (γ)-ray source irradiation with the total dose range of 0-500 kGy at room temperature. Electrical measurements of this structure have been performed using current–voltage (I–V) and capacitance-voltage (C–V) techniques. Experimental results show that the values of the ideality factor obtained from I–V measurements increased and the values of the barrier height obtained from reverse-bias C–V measurements decreased after gamma-irradiation. The results show that the main effect of the radiation is the generation of laterally inhomogeneous defects near the semiconductor surface.

INTRODUCTION

In many cases, the Schottky barrier height on chemically prepared semiconductor surfaces indicates the presence of interfacial layer whose thickness is dependent on exposure time of the semiconductor surface in the chemically cleaned substrates [1]. Recently, several groups have investigated the effect of radiation on the electrical characteristics of diodes. In many of these studies, exposure to energetic radiation has been employed as a tool to controllably introduce point defects and gain insight into the nature of intrinsic defects, such as vacancies and interstitials, and their effect on optical and transport properties [2].

In space applications, nuclear investigations, extraction uranium ores and semiconductor devices for their treatment have to work under strong radiation conditions involving high energy particles. An important point for such applications is that the semiconductor material with high radiation resistivity ensures that the devices operate safely during long periods of time. A high-energy electron irradiation effect is reported for ZnO, GaN and SiC [4].

Applications of ZnO-based devices are mainly dependent on the type and concentration of point defects (primarily zinc and oxygen vacancies and Zn interface). This problem is mostly related to the interaction of ZnO with high energetic particles.

In this study diode characteristics, before and after irradiation, were investigated using C–V and I–V measurements. According to the results, we can say that the interfacial layer reduces the effect of radiation. It is hoped that the broad bandgap ZnO, can withstand radiation more than compound semiconductors such as GaAs. But the end results ZnO is greater resistance to electrons, protons and heavier ions radiation more than GaN [3]. This result can also be dependent on the rate of defect losses in ZnO partially [3]. But the different fluxes encountered in space may lead to differences in the formation of defects and in the rate of annealing. The reverse bias leakage current, the barrier height, and the diode ideality factor show only a small change when the total change is ≤ 10%. These results are consistent with the defects formation in ZnO by the irradiation of the active region of the rectification.

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EXPERIMENTAL

In this study we used n type Si wafer pieces of (100) orientation and one side polished. At first, the wafer was chemically cleaned [5]. After the cleaning process, the wafer is immediately inserted in to the vacuum room. Extensive alloys such as Au–Sb are used for n-Si ohmic contact. We have used Au–Sb alloy for ohmic contacts are made by evaporating on the non-polished side of the n-Si wafer pieces when vacuum was decreased by 10^{-6} Torr and then by thermal annealing at 300°C for 3 min inflowing nitrogen in a quartz tube furnace. The ZnO thin film was then grown on the sample by using RF magnetron sputtering system. After these processes we used DC sputtering system and Zn target, to form the Zn contacts. In this system Zn, was then deposited through a mask in dots of the shape of approximately 1mm diameter. In this way, the Zn/ZnO/n–Si/Au-Sb structure was obtained. The I–V and C–V characteristics of the diode were measured using a Keithley 487 Pico-amperometer/voltage source and HP model 4192 ALF impedance analyzer under dark conditions. And then, this sample was subjected to γ-radiation, and then I-V and C-V measurements were taken again.

RESULTS AND DISCUSSION

Figure 1 shows the forward and reverse bias I–V characteristics of the diode before and after γ-irradiation. It is seen that after γ-radiation in the diode, leakage current has been increased. Therefore, the height of the Schottky barrier is reduced.

According to thermionic emission theory, forward bias current of a Schottky diode depending on the applied potential that calculated by current equation [5]. The values of ideality factor and barrier height are obtained from the corresponding equations [5].

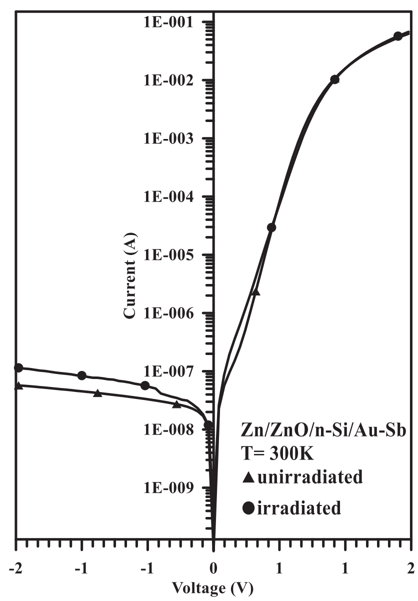

FIGURE 1. The I–V characteristics of the Zn/ZnO/n-Si/Au-Sb structure before and after irradiation.

The values of the ideality factors before and after irradiation are calculated as 2.15 and 2.45, respectively. The values of barrier height for before and after irradiation are calculated as 0.774 and 0.742 eV, respectively. The values of the ideality factor have increased after irradiation. There was a decrease in the barrier height value. Due to γ-radiation, the defects can be created in the crystal lattice and this causes an increase in the ideality factor. Increasing in the ideality factor also indicates that for the diode, the current transport mechanism cannot be a thermionic emission type and it may be a tunnelling type transport [6].

Figures. 2 (a) and (b) is for C–V characteristics of this diode before and after irradiation at various frequencies. These figures show that the values of the capacitance decrease with the irradiation and increasing frequency [3].

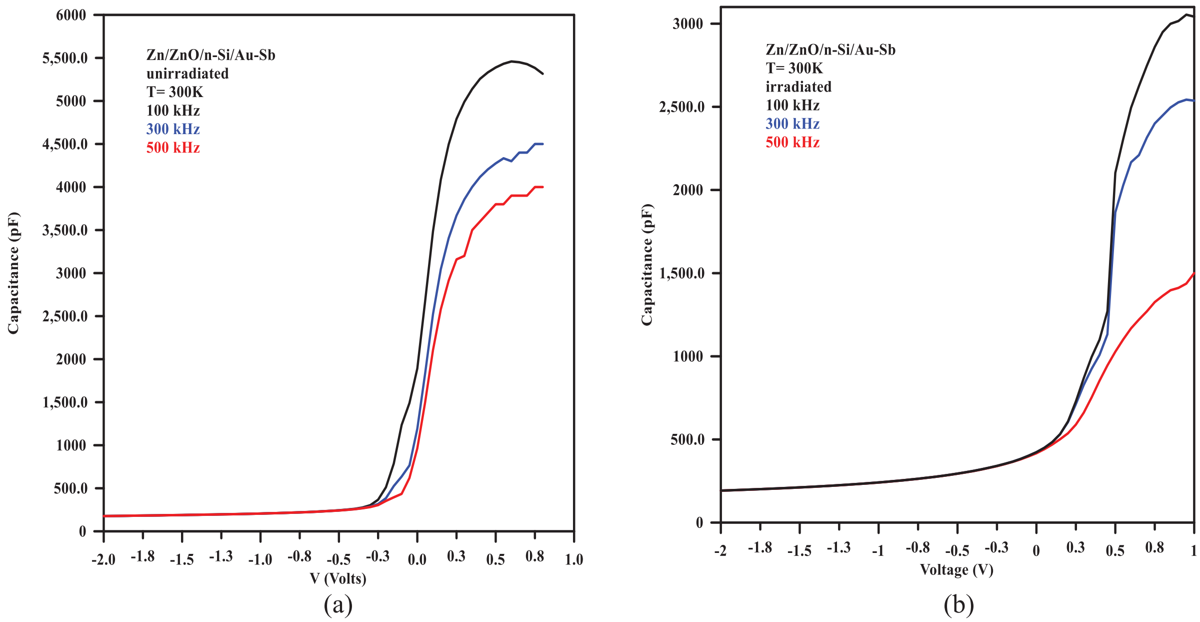

FIGURE 2. The forward and reverse bias C–V characteristics of the Zn/ZnO/n-Si/Au-Sb structure a) before and b) after γ-radiation at various frequencies

Figure. 3 (a) and (b) shows up the reverse bias C^{-2}–V characteristics of these diodes before irradiated, at various frequencies. It seems that the C^{-2}–V are almost linear. This can be explained by the absence of the excess capacitance [7].

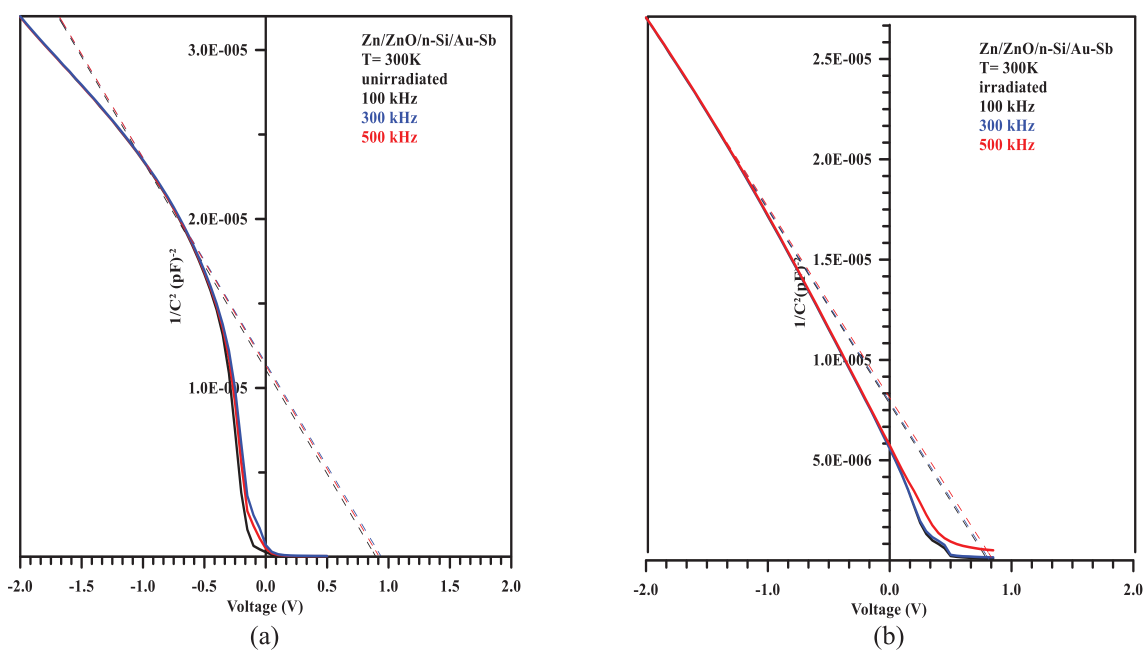

FIGURE 3. The forward and reverse bias C–V characteristics of the Zn/ZnO/n-Si/Au-Sb structure a) before and b) after γ-radiation at various frequencies

According to thermionic emission theory and with the help of the graphs given above, the parameters related to the structure are calculated and given by table1.

TABLE 1. The characteristic parameters of the Zn/ZnO/n-Si/Au-Sb structure obtained from I-V and C-V characteristics before and after γ-radiation.

Radiation situation	I–V			C^{-2}–V				
	n	I_0 (A)	Φ_b (eV)	f(kHz)	V_d (eV)	N_d (cm^{-3})	E_f (eV)	Φ_b (eV)
Unirradiated	2.15	$8.24x10^{-9}$	0.774	100	0.901	$15.79x10^{15}$	0.1937	1.095
				300	0.943	$15.92x10^{15}$	0.1935	1.136
				500	0.950	$16.05x10^{15}$	0.1933	1.143
Irradiated	2.45	$2.76x10^{-8}$	0.742	100	0.807	$20.06x10^{15}$	0.1875	0.994
				300	0.821	$20.17x10^{15}$	0.1874	1.008
				500	0.852	$20.40x10^{15}$	0.1871	1.039

CONCLUSIONS

It was found that the electrical characteristics of the Zn/ZnO/n-Si/Au-Sb structure are sensitive to γ-radiation and the values of the ideality factor increases and barrier height decreases after γ-radiation. The degradation in properties of this structure may be due to the radiation-induced interfacial defects and lattice defects via displacement damage [5]. Leakage current of the diode has been increased after γ-radiation. This increase in leakage current with dose may be due to the generation of carriers in the depletion region as a result of the radiation induced lattice defects as reverse current is proportional to the concentration of minority carriers near the junction [8]. The increase in reverse bias current with γ-radiation may be due to the presence of radiation induced crystal lattice defects which act as trapping or recombination centers shortening the life time of the minority carriers [9]. The ideality factor calculated from the non-irradiated forward characteristics were 2.15. The ideality factor of the schottky diodes was larger than unity. Generation–recombination, tunneling, interface impurities and interfacial oxide layer are the possible factors for the higher value of ideality factor [10]. Because of ZnO interface, the change of the ideality factor and in barrier height is less. And this is due to the fact that ZnO is radiation resistant. Irradiation might have introduced defects at the Zn/ZnO/n-Si/Au-Sb interface leading to the reduction in Schottky barrier height.

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