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FABRICATION AND *I-V* CHARACTERISTICS OF *p-Si/n-ZnO:Er* HETEROJUNCTIONS

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ABSTRACT

In this work, Er doped ZnO films and silicon substrates were used as n-type and p-type semiconductors, respectively. In order to obtained *p-Si/n-ZnO:Er* heterojunction structures, top (aluminum; Al) and bottom (gold; Au) metal contacts were deposited using a evaporator and sputter, respectively. The electrical characterization of these heterojunctions were investigated by current–voltage (*I–V*) characteristics at room temperature and in dark. It was observed that *Au/p-Si/n-ZnO:Er/Al* heterojunction structures have rectifying properties. The diode parameters such as barrier height, series resistance and ideality factor were investigated by using *I–V* measurement data. These parameters were determined by using different methods.

Keywords: ZnO, Heterojunctions, Diode parameters

1. INTRODUCTION

Nowadays, deposition and applications of nanostructured zinc oxide (ZnO) semiconductors such as nanofiber, nanograins and nanorods have been extensively reported because of their good optical and electronic properties [1-3]. Due to these properties, ZnO is a significant material and having high potential for using at various technological and industrial fields such as solar cells, varistors, gas sensors, transistors, transparent conductive oxides, and supercapacitors. [4-9]. Electrical, optical and structural properties can be modified with deposition parameters or dopant elements [10-13]. In recent years, zinc oxide (ZnO) films doped with Rare Earth (RE) elements have been taken attention due to their superior optical and electrical properties. RE dopant elements used to prepare wide band gap semiconductors proceeds to be of attention especially for display applications involving ultraviolet (UV), visible, and infrared (IR) light emission [14-16]. On the one hand materials production for high-tech are very important, on the other hand their' productions using low-cost method are more important. Therefore, solution methods are preferred to systems requiring vacuum. Sol gel method, which is one of the solution methods, is preferred as it is a simple method because it can be applied to large surfaces, it allows multi-layer film production.

Iwan et. al [17] deposited undoped and 1, 4 and 8 wt% Er doped ZnO films onto p-Si substrates by spray pyrolysis method. They characterized X-ray photoelectron spectroscopy (XPS) spectra, AFM images and PL spectra of the deposited films. The *p-Si/n-ZnO* and *p-Si/n-ZnO:Er* heterostructure were fabricated, and performed the *I-V* and EL measurements of these structures. They reported that these heterojunctions showed good rectification characteristics and radiated to clear green emission.

In this study, the *p-Si/n-ZnO* heterojunctions were fabricated using Er dopant at different level (0.2, 0.4, 0.6, 0.8 and 1.0 %) nanostructured ZnO films. The codes of fabricated diodes are given in Table 1. The electrical characterization of the fabricated diodes was investigated by *I-V* measurements under dark conditions. The diode parameters (*n* ideality factor, ϕ_B barrier height and R_s serial resistance) were calculated by using different methods. In the available literature, a report about *p-n* heterojunction with deposited ZnO:Er films by the same technique has not been reported. Therefore, it is expected to contribute to the literature of this study.

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2. EXPERIMENTAL METHODS

The procedure for preparing the Er doped (0.2, 0.4, 0.6, 0.8 and 1.0 %) nanostructured ZnO films were described in our previous studies [18]. Aluminum (Al) and gold (Au) metals were evaporated as top and bottom metal contacts for fabrication of *p-Si/n-ZnO:Er* (DZEr) heterojunctions. VAKSIS PVD Handy-MT/101T model metal evaporation and OLED system was used for evaporating top contacts. Top aluminum (purity of 99.99%) contacts were evaporated by thermal evaporation using shadow-mask (circule radius 0.25mm) onto the nanostructured ZnO films. For the bottom contact, Au metal was evaporated using the EMS550X coating with a 90 nm thickness on the matte surface of *p-Si* substrates. Figure 1. shows a schematic diagram representing fabricated *p-n* heterojunctions. The *I-V* measurements of the fabricated p-n heterojunctions in the dark were carried out using a semiconductor characterization measurement system (KEITHLEY 4200 SCS).

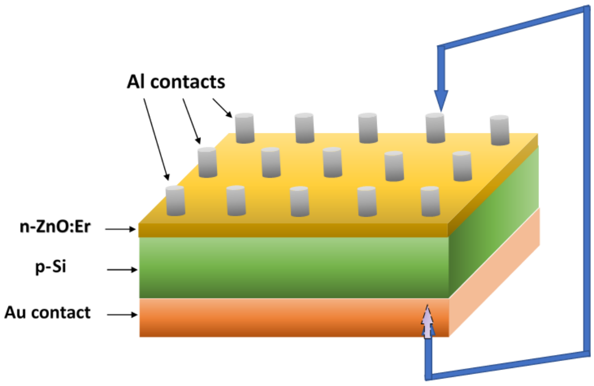

Figure 1. Schematic diagram of *p-Si/n-ZnO: Er* (DZEr) heterojunction diode

2. RESULTS AND DISCUSSION

3.1. *I-V* characteristics of fabricated p-n heterojunctions

The *I-V* plots of fabricated DZEr diodes are given in Figure 2. It is evident from these plots that the fabricated junctions show rectifying behavior. There are some important parameters (such as n, ϕ_B and R_s) that must be determined in order to explain the electrical properties of a diode and to determine its proximity to the ideal. Using these measurement results, diode parameters were calculated with different methods. In order to calculate these parameters, there must be a relation between current and voltage. The relation between current and voltage is obtained by considering the thermionic emission (TE) theory. Considering the TE theory, the equation of the current passing through a diode is written as follows [19]:

$$I = I_o\left[\left(\exp(\frac{qV}{nkT}\right)-1\right] \qquad (1)$$

where I_o, q, V, k and T are reverse saturation current, electronic charge, applied voltage, Boltzmann constant and temperature (in Kelvin), respectively. The I_o is given by the following expression:

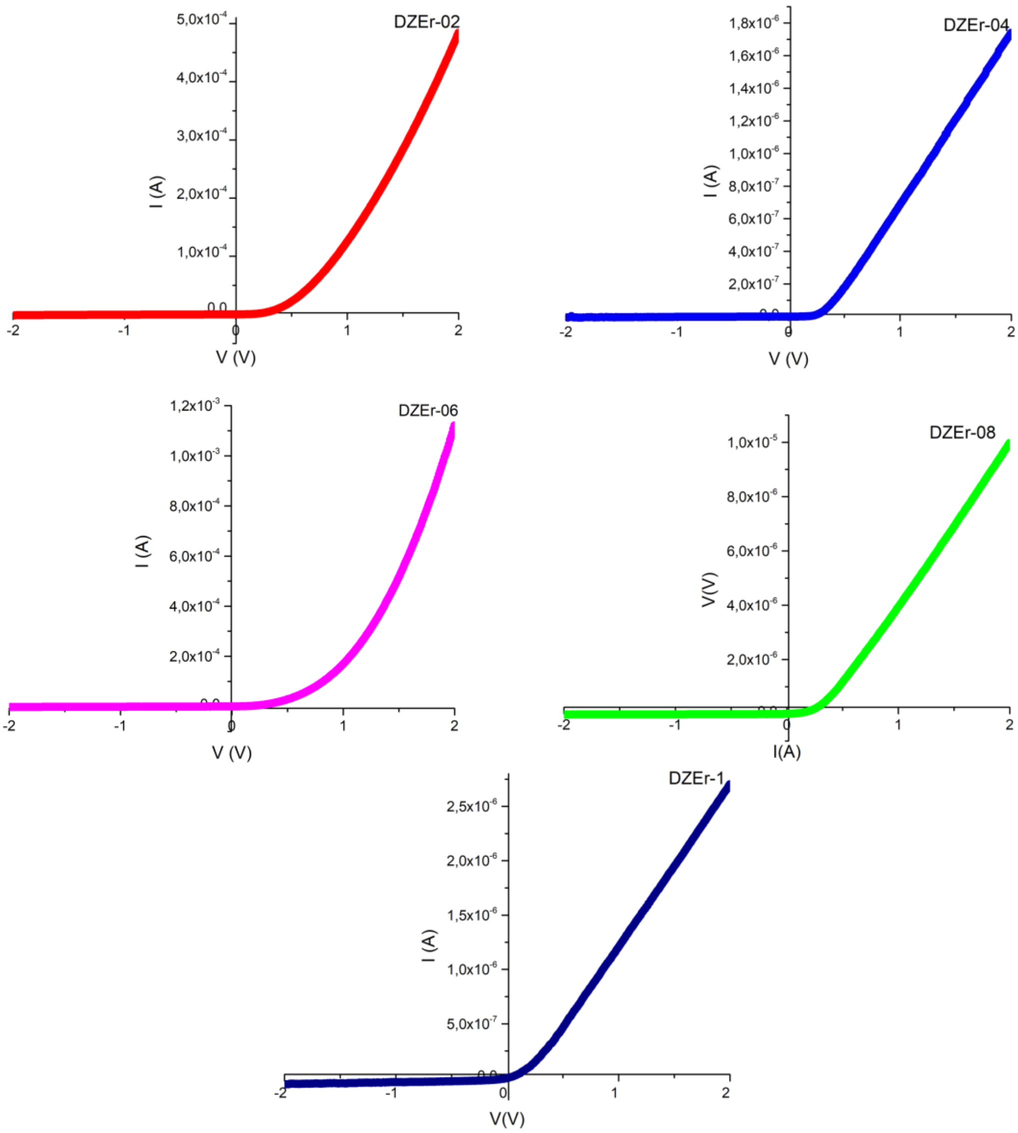

Figure 2. *I-V* characteristics of DZEr heterojunction diodes

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

where A and A^* are rectifying contact area and effective Richardson constant, respectively. For an ideal diode, TE theory is considered to be effective. n value of a heterojunction can be determined by TE theory. The *logI-V* plots of fabricated *DZEr* diodes are given in Figure 3. The n values are calculated by Eq. (1) using slope of the linear part of the forward bias part of the semi-logarithmic graphs given in Fig. 3. The ϕ_B values are calculated by Eq. (2) using calculated by extrapolating the linear region of the forward semi-logarithmic *I-V* plots at zero voltage. The n and ϕ_B values for the fabricated diodes were calculated, and given in Table 1.

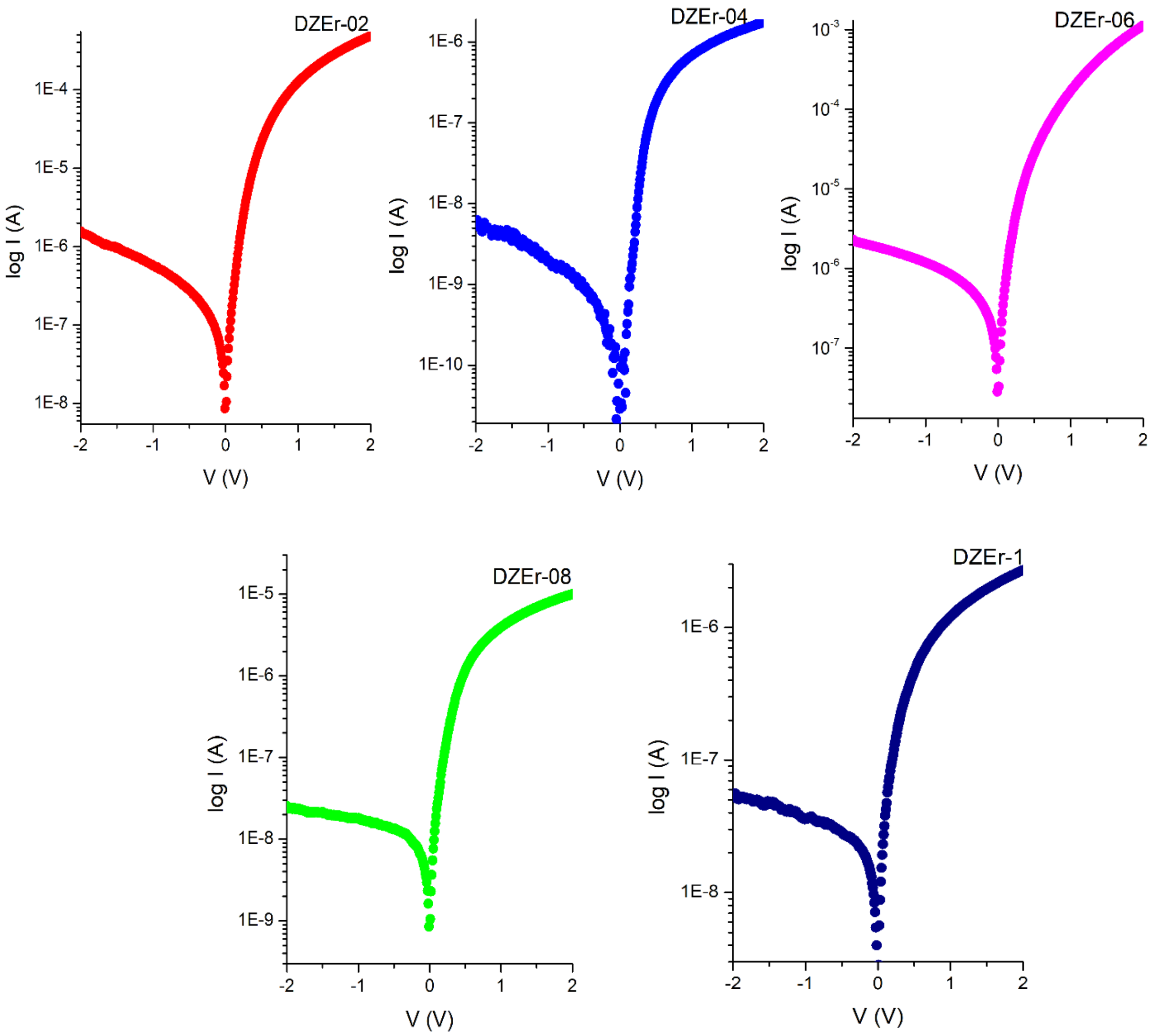

Figure 3. log*I*-*V* characteristics of DZEr heterojunction diodes

Table 1. Diode parameters of the fabricated DZEr heterojunctions

ZnO Film	**Diode Code**	***Method***			
		TE		***Norde***	
		n	**$Ø_b$ (eV)**	**$Ø_b$ (eV)**	**R_s (kΩ)**
0.2% Er doped	DZEr-02	2.17	0.69	0.72	9.06
0.4% Er doped	DZEr-04	2.24	0.66	0.68	8.98
0.6% Er doped	DZEr-06	2.36	0.66	0.68	8.56
0.8% Er doped	DZEr-08	2.28	0.75	0.76	258.29
1.0% Er doped	DZEr-1	2.19	0.66	0.68	2.75

Another method was developed by Norde to determine the ϕ_B and R_s for contacts. The Norde function is [20]

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

where γ is an integer (greater than n value) and $I(V)$ is the current obtained from I–V measurements. Using the data in Norde plot (Figure 4), the ϕ_B and R_s for each diode were calculated and given in Table 1. It can be seen from Table 1 that the ϕ_B values calculated by using traditional TE theory and those by using Norde method are in good agree with both each other and literature [15, 21, 22].

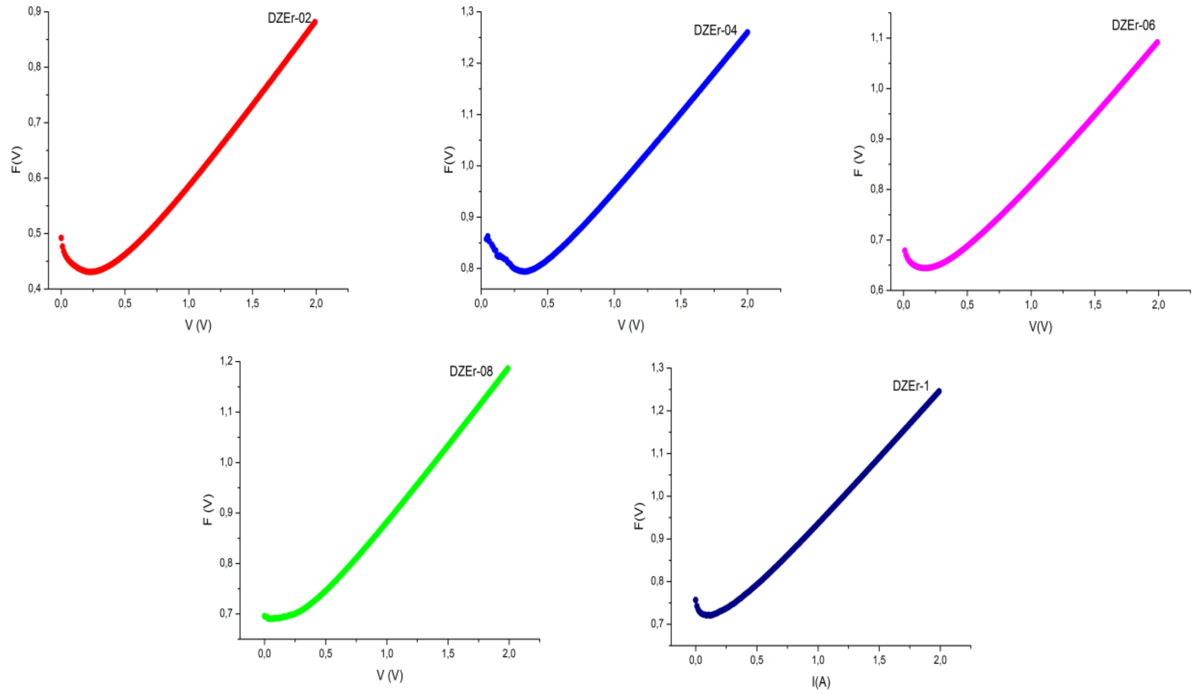

Figure 4. F(V)-V plots of DZEr heterojunction diodes

As the amounts of Er increase, n values for *DZEr* diodes have increased first, then decreased. In the literature, this trend has also been reported for *p*-*n* heterojunction fabricated using ZnO films with other dopants [23, 24]. The calculated n values are greater than 1. It can be explained by the presence of the interface layer between the metal and the semiconductor. In addition, the presence of R_s also affects the n value. The R_s values calculated using the Norde method are all in kΩ. In the literature, it was reported the similar results for the *p*-*n* heterojunction diodes fabricated using doped ZnO films. [22, 24, 25]

4. CONCLUSIONS

For device application, the *DZEr* heterojunction structures were fabricated. The electrical properties of these heterojunction structures were investigated by *I-V* measurements. It was determined that these structures showed a good diode-like rectifying property in the dark. The diode parameters were determined by using different methods such as TE method and Norde methods.

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