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Studies on vacuum deposited p-ZnTe/n-ZnSe heterojunction diodes

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ABSTRACT

p-ZnTe/n-ZnSe heterojunction diodes were prepared by vacuum deposition and a detailed electrical characterization of the heterojunction was performed. The *I–V* and *C–V* characteristics of the heterojunction diodes were studied to determine the conduction mechanism, barrier height, space charge density and thickness of the depletion region in the heterojunction. The bandgap and activation energies of n-ZnSe and p-ZnTe were also determined and a theoretical band diagram of p-ZnTe/n-ZnSe heterojunction was drawn based on Anderson's model.

1. Introduction

Zinc Telluride (ZnTe) is a II–VI semiconductor compound which has many attractive potential applications in the field of optoelectronics. ZnTe has a direct bandgap of 2.26 eV [1,2] which falls in the pure green region of the electromagnetic spectra. The direct bandgap of ZnTe makes it a highly suitable material for the fabrication of optoelectronic devices such as green light emitting diodes [3–6], photo-detectors, THz emitters and detectors [3,7]. Since there is only a small valence band offset of 0.1 eV between ZnTe and CdTe, ZnTe can be used as a back contact material to obtain higher efficiency in CdTe based solar cells [8].

Heterostructures involving ZnTe have attracted considerable attention of late. The main focus is on the study of the electrical properties of such heterostructures. Studies are being done on p-ZnTe/n-ZnSe heterostructure with the intention of utilizing them in optoelectronic devices. This kind of heterostructure is known to have high valence band offset which is useful for forming ohmic contacts [9]. Although there are reports on the fabrication of p-ZnTe/n-ZnSe heterostructures, in most of them higher end techniques like epitaxy have been utilized to obtain the heterostructure [10,11]. The present work concentrates on the fabrication of p-ZnTe/n-ZnSe heterostructure by simple and cost effective vacuum evaporation technique and on their detailed electrical characterization.

2. Experimental details

ZnSe and ZnTe films were deposited on well cleaned glass substrates by vacuum evaporation method, inside a 12 in. vacuum chamber (HINDHIVAC 12A4D). 99.99% pure ZnSe and ZnTe ingots (Aldrich) were used as source materials and molybdenum boats were used to evaporate these source materials, by resistive heating. Silver contacts were made, by vacuum evaporation, on both sides of the heterojunction. The depositions were carried out in a residual pressure of about 10^{-5} Torr, at a rate of about 30 nm/min. X-ray diffraction (XRD) patterns of the films were obtained by a Rigaku Miniflex XRD unit. The compositions of the films were determined by JEOL (JSM 5800) energy dispersive analysis (EDS) unit. Keithley Multimeter (2002) and SourceMeter (2400) were used for current and voltage measurements and Wayne Kerr precision component analyser was used for measuring the capacitance.

3. Results and discussion

The electrical properties of vacuum deposited thin films depend heavily on the composition of the films which in turn depends on the deposition parameters. In our previous study [12] it was found that the substrate temperature, maintained at the time of deposition, can vary the composition of the ZnTe films to a large extent. The ZnTe films deposited at the room temperature were rich in Tellurium and those deposited at 553 K were nearly stoichiometric. However all the films were found to be p-type. The variation of composition of the vacuum deposited ZnSe thin films as a function of substrate temperature is given in Table 1.

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Table 1
The Zn:Se ratio for ZnSe films deposited at different substrate temperatures.

Substrate temperature (K)	Zn:Se
300	0.89
373	0.95
423	1.00
473	1.07
523	1.13

The films deposited at room temperature were rich in Selenium and stoichiometric films were obtained at about 423 K. Good n-type conductivity was observed in ZnSe films deposited at 473 K. Hence all ZnSe films, used for the heterojunction, were prepared at a substrate temperature of about 473 K. The XRD patterns of ZnTe and ZnSe films are shown in Fig. 1. Both the films show cubic structure with a strong (1 1 1) texture.

Fig. 2 shows the *I*–*V* curves of p-ZnTe/n-ZnSe heterojunction at different ambient temperatures. The heterojunction shows the rectifying behavior similar to a typical p–n junction diode. The conduction mechanism in a heterojunction diode usually follows the model proposed by Sze and Crowell [13]. According to this model, the conduction occurs mainly due to thermionic emission and carrier diffusion and the forward current varies with the voltage according to the equation,

$$I = I_s \exp\left(\frac{qV}{nkT}\right)\left\{1 - \exp\left(\frac{-qV}{kT}\right)\right\} \tag{1}$$

where I_s is the reverse saturation current, k is Boltzmann's constant, n is the diode ideality factor, T is the temperature and q is the elementary charge. In the present case, the variation of $\ln(I/(1 - \exp(-qV/kT)))$ with V, for low forward bias voltages, (Fig. 3) was found to be linear, suggesting that the thermionic emission and carrier diffusion are the dominant conduction mechanisms at low voltages. The diode ideality factor '*n*' was found to be about 2.84.

In the case of thermionic emission, saturation current I_s is given by [14],

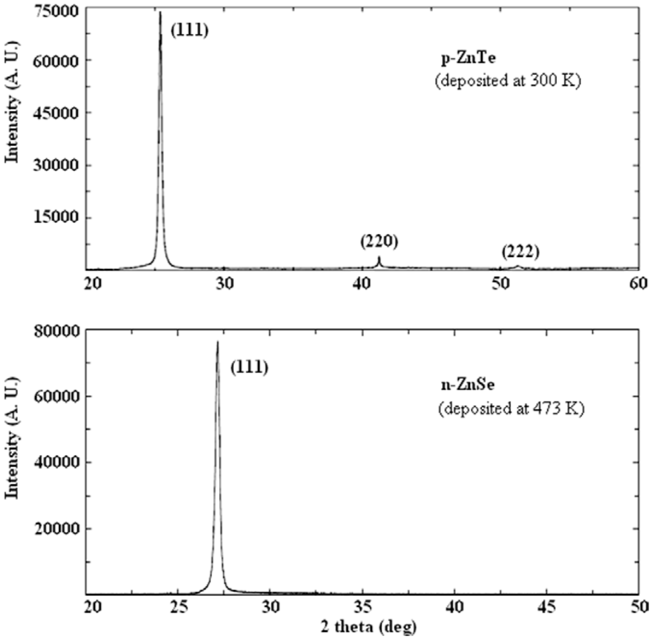

Fig. 1. The XRD patterns of **p-**ZnTe (deposited at 300 K) and **n-**ZnSe (deposited at 473 K) films.

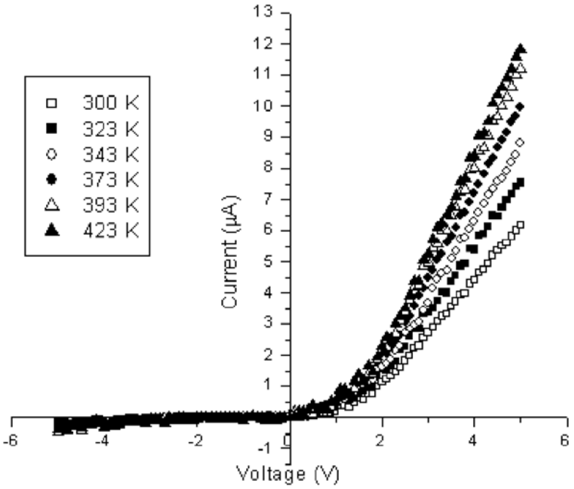

Fig. 2. The *I*–*V* curves of **p-**ZnTe/**n-**ZnSe heterojunction diodes at different ambient temperatures.

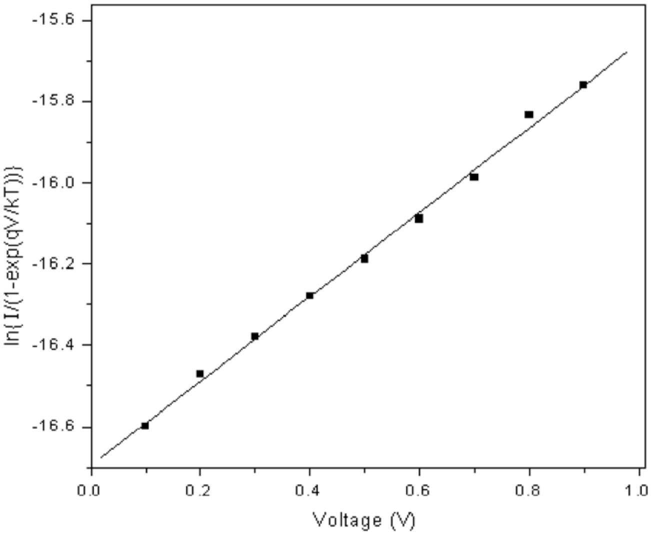

Fig. 3. The variation of $\ln\{I/[1 - \exp(-eV/kT)]\}$ with voltage for **p-**ZnTe/**n-**ZnSe heterojunction diode.

$$I_s = AA^*T^2 \exp\left(\frac{-\phi_b}{kT}\right) \tag{2}$$

where A is the device area, A^* is the Richardson's constant and ϕ_b is the barrier height. The variation of $\ln(I_s/T^2)$ with $1/T$ was found to be linear for p-ZnTe/n-ZnSe heterojunction as shown in Fig. 4. This observation further indicates that the conduction mechanism operating in the heterojunction is thermionic emission. The barrier height ϕ_b, calculated from the slope of the graph, was found to be 0.73 eV.

For higher forward bias voltages, Eq. (1) can be approximated as,

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

In such a case, the graph of ln(I) vs. V must be linear. However the graph of ln(I) vs. V drawn for p-ZnTe/n-ZnSe heterojunction was not perfectly linear (Fig. 5) indicating the possibility of a different type of conduction mechanism at higher voltages. A plot of I vs. V^2, drawn for higher bias voltages (Fig. 6), was found to make a bet-

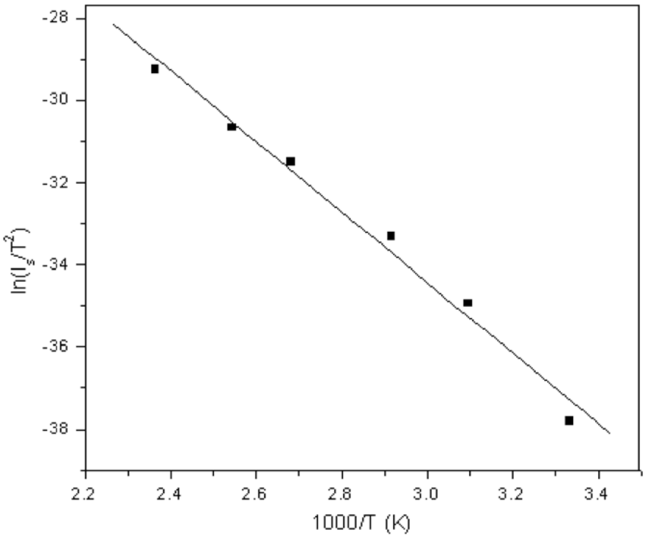

Fig. 4. The variation of $\ln(I_s/T^2)$ vs. $1/T$.

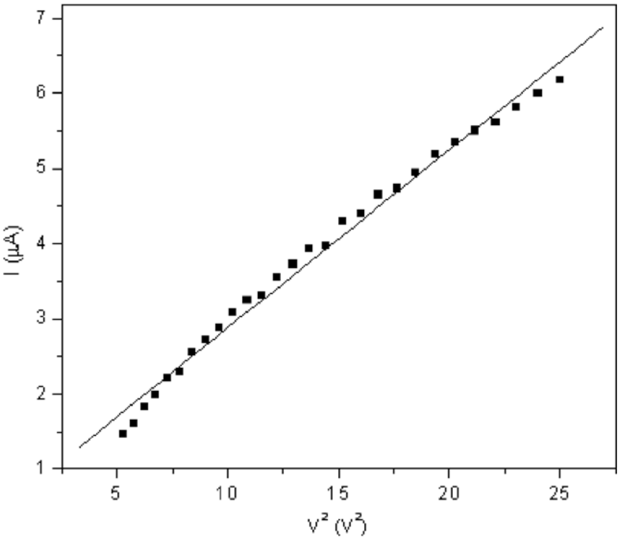

Fig. 6. The variation of current with V^2.

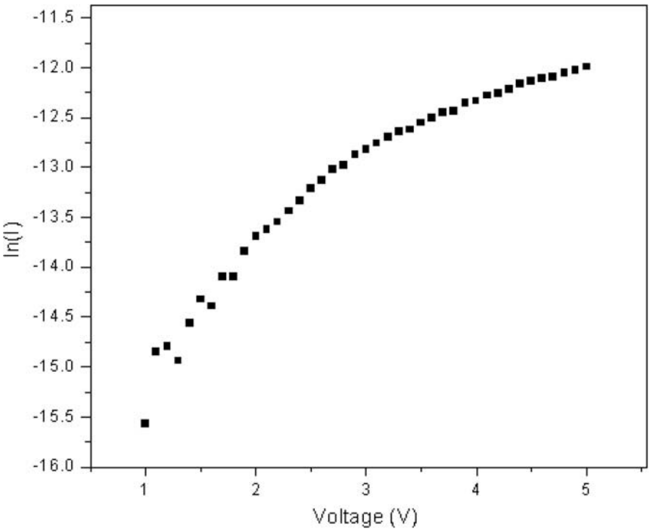

Fig. 5. The variation of ln(*I*) with voltage.

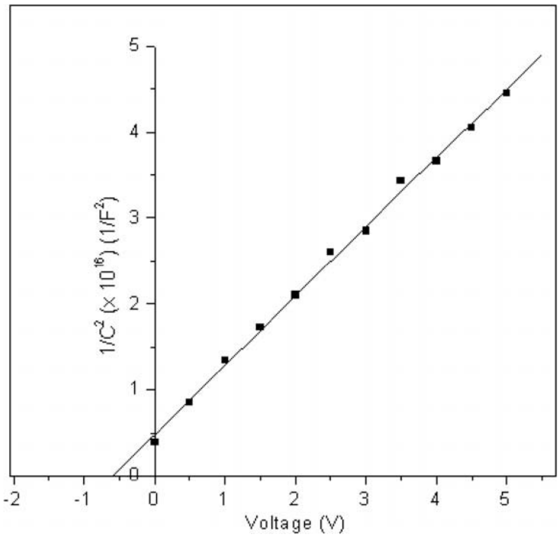

Fig. 7. The variation of C^{-2} with voltage (at 300 kHz).

ter linear fit. This suggests that the conduction mechanism at this region must be space charge limited conduction (SCLC). The forward current in SCLC is given by the equation [15],

$$I = \left(\frac{AV_2 N_C \mu \varepsilon_0 \varepsilon_r}{8L^3 N_t}\right) \exp\left(\frac{-E_t}{kT}\right) \tag{4}$$

where ε_r is the relative permittivity, N_C is the effective density of states, N_t is the concentration of traps with activation energy E_t, L is the thickness of the film, μ is the hole mobility and ε_r is the relative permittivity of the film.

The Fig. 7 shows the variation of C^{-2} with voltage for p-ZnTe/n-ZnSe heterojunction diode, with reverse bias, recorded at a frequency of 300 kHz. It can be seen that C^{-2} varies linearly with voltage V. This allows us to use the Schottky relation [16],

$$C^2 = 2\left[\frac{(V - V_b + \frac{kT}{q})}{q\varepsilon_0\varepsilon_r N A^2}\right] \tag{5}$$

where V is the applied voltage, V_b is the diffusion potential, N is the space charge density and A is the effective area of the diode. The linear nature of the graph indicates that the carrier concentration is uniform and the junction is an abrupt junction. The value of N was determined from the slope of the graph using the equation,

$$\frac{dC^{-2}}{dV} = \frac{2}{q\varepsilon_0\varepsilon_r N A^2} \tag{6}$$

and the value was found to be about $1.06 \times 10^{18}\ \mathrm{m}^{-3}$. The thickness d_s of the depletion region is given by the equation,

$$d_s = \frac{\varepsilon_0 \varepsilon_r A}{C_0} \tag{7}$$

where C_0 is the capacitance at zero bias. In the present case the observed value of d_s was about 92 nm.

A theoretical energy band diagram for p-ZnTe/n-ZnSe heterojunction constructed on the basis of Anderson's model is shown in Fig. 8. The band diagram shows a staggered, type-II heterostructure. The bandgap and activation energies of n-ZnSe and p-ZnTe were determined by studying the variation of resistance with ambient temperature. The discontinuities in conduction (ΔE_c) and valence band (ΔE_v) were found to be 0.56 eV and 1 eV respec-

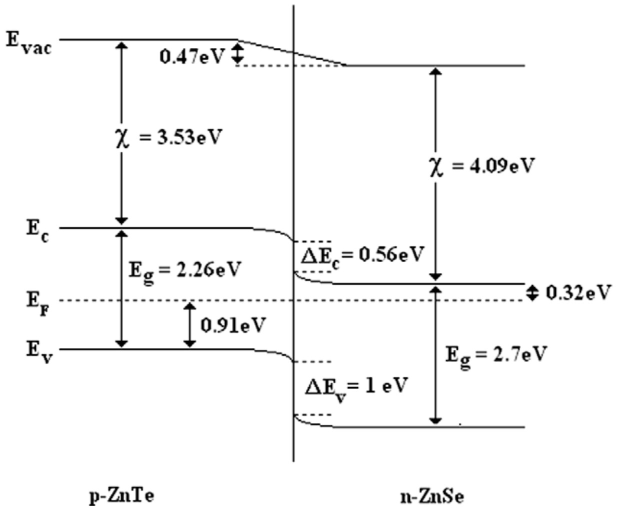

Fig. 8. The band diagram of **p-**ZnTe/**n-**ZnSe heterojunction diode.

tively. The theoretical bandgap was found to be 0.47 eV which is smaller than the value obtained from *C–V* measurements. This difference in the values is due to the fact that Anderson's rule applies to idealized heterojunctions and ignores the effect of quantum size effect, defect states and other perturbations which may arise due to lattice mismatches.

4. Conclusion

p-ZnTe/n-ZnSe heterojunction diodes were prepared by vacuum deposition. The electrical conduction in the diodes was found to take place by thermionic emission at low voltages and by space charge limited conduction at high voltages. The ideality factor of the diodes, determined from the *I–V* curves, was found to be 2.84. The variation of junction capacitance with reverse bias voltage was studied and the barrier height, space charge density and thickness of the depletion region were determined by plotting the C^{-2} vs. *V* graph. The bandgap and activation energies of n-ZnSe and p-ZnTe were determined by studying the variation of resistance with ambient temperature and a band diagram of p-ZnTe/n-ZnSe heterojunction was drawn. The heterostructure was found to have a large valence band offset, which is very useful in the formation of ohmic contacts.

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