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

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ABSTRACT

The present paper reports the fabrication and detailed electrical characterization of p-ZnTe/n-CdTe heterojunction diodes prepared by vacuum deposition method. The possible conduction mechanisms of the heterojunction diode were determined by analyzing the *I–V* characteristics. The *C–V* characteristics of the heterojunction diodes were studied to determine the barrier height, carrier concentration and thickness of the depletion region in the heterojunction. A theoretical band diagram of the heterojunction was drawn based on Anderson's model.

1. Introduction

The II–VI semiconductor compounds, such as cadmium telluride (CdTe), cadmium sulphide (CdS), zinc telluride (ZnTe), and zinc selenide (ZnSe) have become the subject matter of extensive research in the last few decades, thanks to their direct and wide energy bandgaps and other electrical and optical properties which makes them attractive candidates for the fabrication of optoelectronic devices. A great deal of success has been achieved in the fabrication of devices such as solar cells [1], LEDs [2–6], photodetectors from these materials. However the difficulties in doping and making ohmic contacts have been the major impediments in their commercial utilization. Materials such as ZnTe, and CdS exhibit self compensation and have strong preference to either p- or n-type conductivities [7]. Problems like these and many other reasons have forced researchers to search for different possibilities such as using the heterostructures of two different compound semiconductors.

Heterostructures involving two different members of II–VI compounds have thus gained considerable attention of late. Many of the heterostructures have now become integral part of optoelectronic devices. The best example is the CdTe–CdS heterostructure which is now widely used in CdTe based solar cells [1]. The heterostructure of ZnSe and ZnTe has been employed to make ohmic contacts in some ZnSe based devices [8] while ZnTe–CdTe heterostructure has reportedly enhanced the efficiency of CdTe based solar cells by providing a low resistance back contact [9]. In the present paper, we report the fabrication and characterization of p-ZnTe/n-CdTe which is a less studied heterojunction. Several useful information about the heterojunction, determined by detailed *I–V* and *C–V* analysis, has been presented.

2. Experimental details

The CdTe and ZnTe films required for the heterojunction were obtained by vacuum evaporation method, inside a 12 inch vacuum chamber (HINDHIVAC 12A4D). High purity (99.99%) CdTe powder and ZnTe ingots (Aldrich) were used as source materials and molybdenum boats were used to evaporate these source materials, by resistive heating. The depositions were carried out in a residual pressure of about 10^{-5} torr, at a rate of about 30 nm/min. Initially, separate films of CdTe and ZnTe were deposited on glass substrates at different substrate temperatures. The structure, composition and electrical properties of these films were studied as a function of substrate temperature and optimum substrate temperature for preparing the films required for the heterojunctions were finalized. To fabricate the heterojunction, first a back contact of silver was made on a well cleaned glass substrate and CdTe film was deposited on top of this contact at a temperature of about 533 K. The ZnTe film was deposited on top of CdTe film at room temperature and finally the second silver contact was made on top of the ZnTe layer. The schematic diagram of the heterojunction is shown in Fig. 1. The overall size of the device was about 2 cm^{-2} and the area

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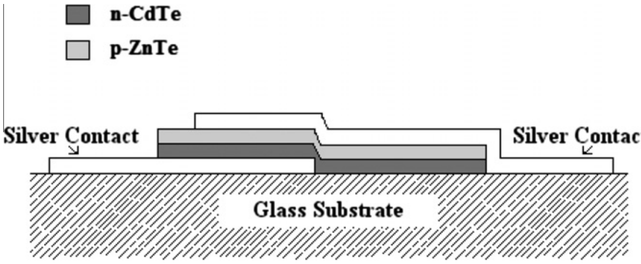

Fig. 1. Schematic diagram of the heterojunction.

of the junction region was about 0.2 cm^{-2}. X-ray diffraction (XRD) patterns of the films were obtained by a Rigaku Miniflex XRD unit. Keithley Multimeter (2002) and Source Meter (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 vacuum deposited ZnTe thin films, predominantly display p-type conductivity. The films deposited at room temperature were found to be rich in tellurium whereas the films deposited at higher substrate temperatures were nearly stoichiometric. However all the films were p-type regardless of their composition. On the other hand, vacuum deposited CdTe thin films were found to display either p- or n-type conductivity depending on their composition. The films deposited at room temperature were rich in tellurium and displayed p-type conductivity while films deposited above 513 K were n-type due to the excess of cadmium. The detailed study of composition and electrical properties of vacuum deposited ZnTe and CdTe thin films have been reported in our previous publications [10,11]. In order to obtain n-type CdTe films substrate temperature was maintained at 533 K during the deposition. The XRD patterns of ZnTe and CdTe films are shown in Fig. 2. Both the films show cubic structure with a strong (1 1 1) texture.

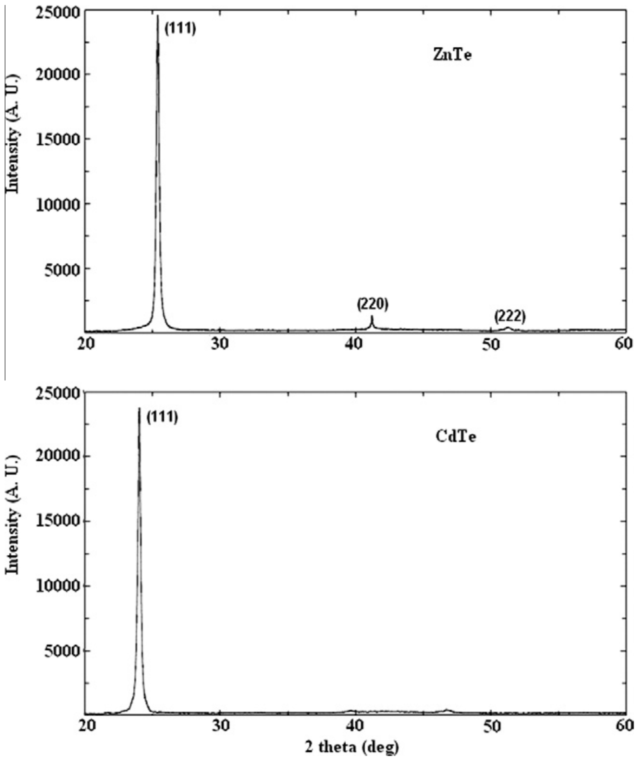

Fig. 2. The XRD patterns of p-ZnTe (deposited at 300 K) and n-CdTe (deposited at 533 K) films.

Fig. 3 shows the I–V curves of p-ZnTe/n-CdTe heterojunction at different ambient temperatures. The heterojunction shows the rectifying behavior similar to a typical p–n junction diode. Fig. 4 shows I–V curve of the heterojunction in logarithmic scale. The rectification factor of the diode was found to be about 16.5. The conduction mechanism in a heterojunction diode usually follows the model proposed by Sze and Crowell [12]. According to this model, the conduction occurs mainly due to thermionic emission and the forward current varies with the voltage according to the equation,

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

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) with V, for low forward bias voltages (Fig. 5) was found to be linear, suggesting that the thermionic emission is the dominant conduction mechanism at low voltages. The diode ideality factor 'n' was found to be about 2.79.

In the case of thermionic emission, saturation current I_s is given by [13],

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

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-CdTe heterojunction as shown in Fig. 6. This observation further indicates that the conduction mechanism operating in the heterojunction is thermionic emission. The barrier height $\varphi_{b,}$ calculated from the slope of the graph, was found to be 0.81 eV.

The variation of ln(I) with V was not perfectly linear (Fig. 7) at higher voltages, 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. 8), was found to make a better 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 [14],

$$I = \left(\frac{AV^2 N_C \mu \varepsilon_0 \varepsilon_r}{8L^3 N_t}\right) \exp\left(\frac{-E_t}{kT}\right) \tag{3}$$

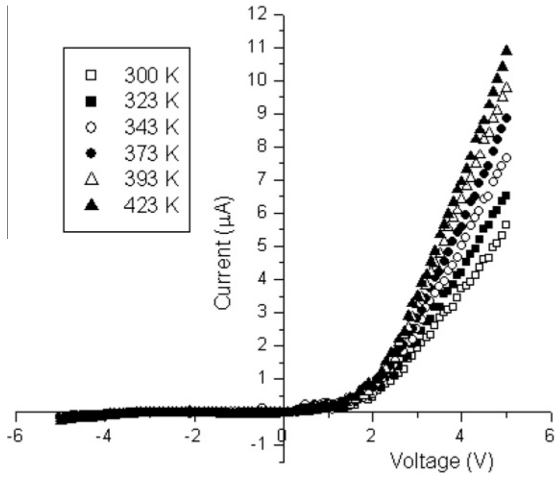

Fig. 3. The I–V curves of p-ZnTe/n-CdTe heterojunction diodes at different ambient temperatures.

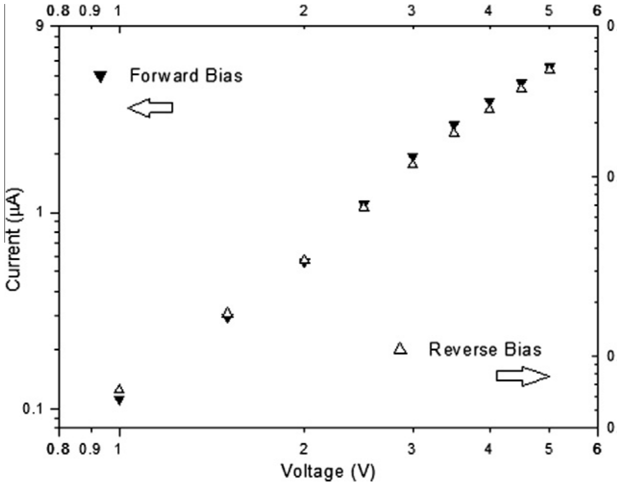

Fig. 4. The *I–V* characteristics of the heterojunction in logarithmic scale.

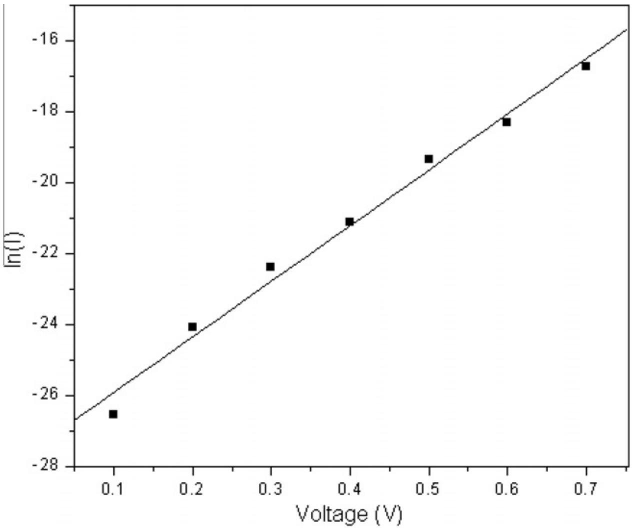

Fig. 5. The variation of ln(*I*) with voltage for p-ZnTe/n-CdTe heterojunction diode at lower voltages.

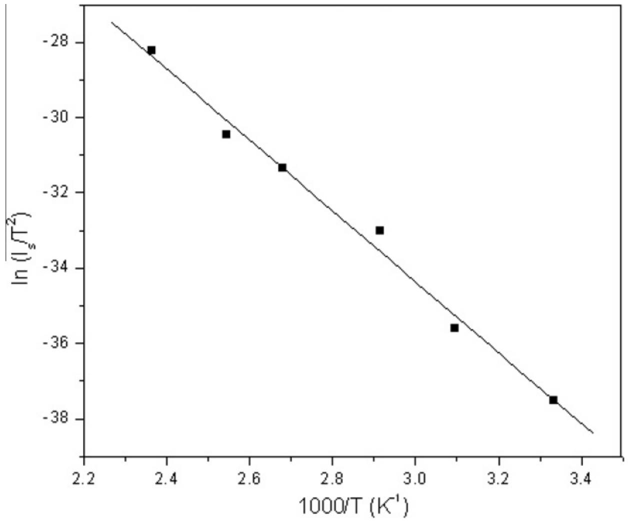

Fig. 6. The variation of $\ln(I_s/T^2)$ vs. $1/T$.

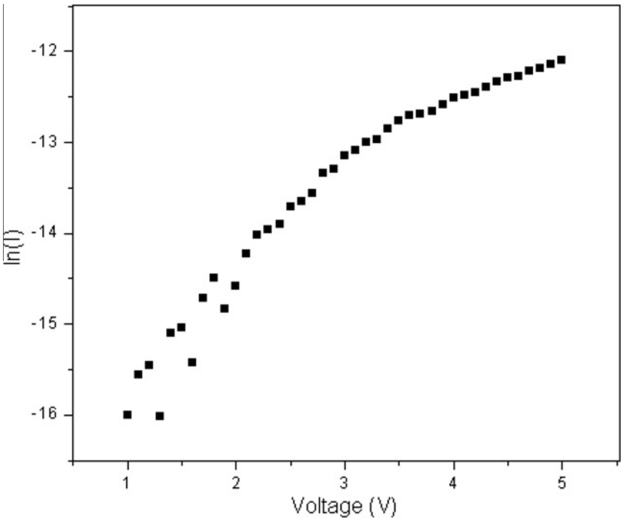

Fig. 7. The variation of ln(*I*) with voltage.

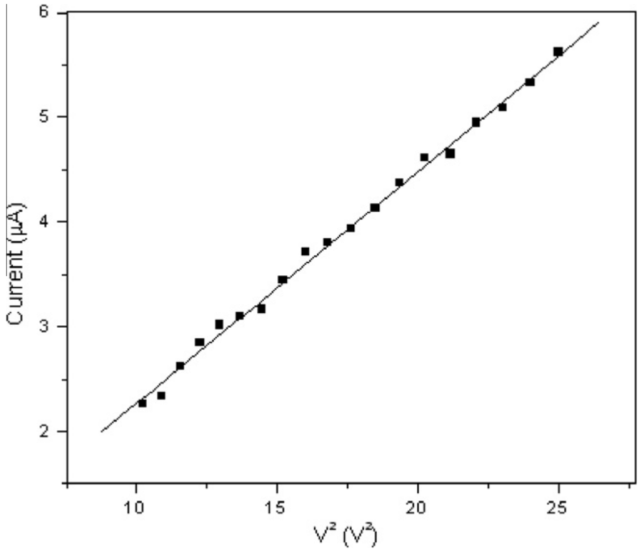

Fig. 8. The variation of current with V^2.

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.

Fig. 9 shows the variation of C^{-2} with reverse bias voltage forp-ZnTe/n-CdTe heterojunction diode, 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 [15],

$$C^{-2} = 2\left[\frac{\left(V - V_b + \frac{kT}{q}\right)}{qC_0C_rNA^2}\right] \tag{4}$$

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,

$$\frac{dC^{-2}}{dV} = \frac{2}{qC_0C_rA^2} \tag{5}$$

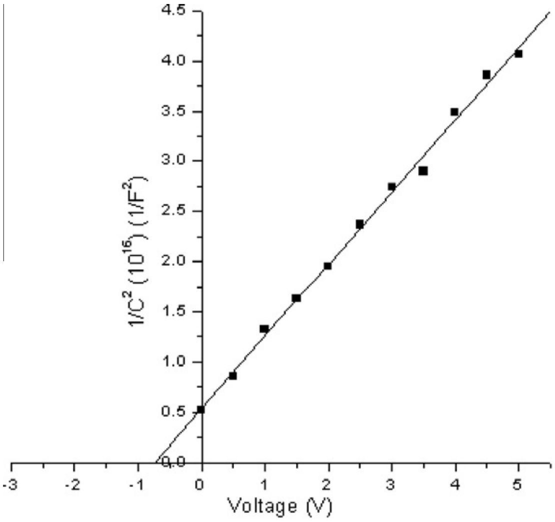

Fig. 9. The variation of $C^{-2}$with voltage (at 300 kHz).

and the value was found to be about $1.21 \times 10^{18}\ \mathrm{m}^{-3}$. The thickness d_s of the depletion region is given by the equation,

$$d_s = \frac{\varepsilon_0 \varepsilon_r A}{C_0} \tag{6}$$

where C_0 is the capacitance at zero bias. In the present case the observed value of d_s was about 106 nm.

A theoretical energy band diagram for p-ZnTe/n-CdTe heterojunction constructed on the basis of Anderson's model is shown in Fig. 10. The band diagram shows a staggered, type-II heterostructure. The bandgap and activation energies of n-CdTe and p-ZnTe were determined by studying the variation of resistance with ambient temperature. The theoretical values of discontinuities in conduction (ΔE_c) and valence band (ΔE_v) were found to be 0.28 eV and 0.45 eV respectively. The theoretical barrier height was found to be 0.65 eV which is smaller than the value obtained from *I–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-CdTe 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 2.79. 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 band diagram of p-ZnTe/n-CdTe heterojunction, drawn based on Anderson's model, showed a type-II heterostructure.

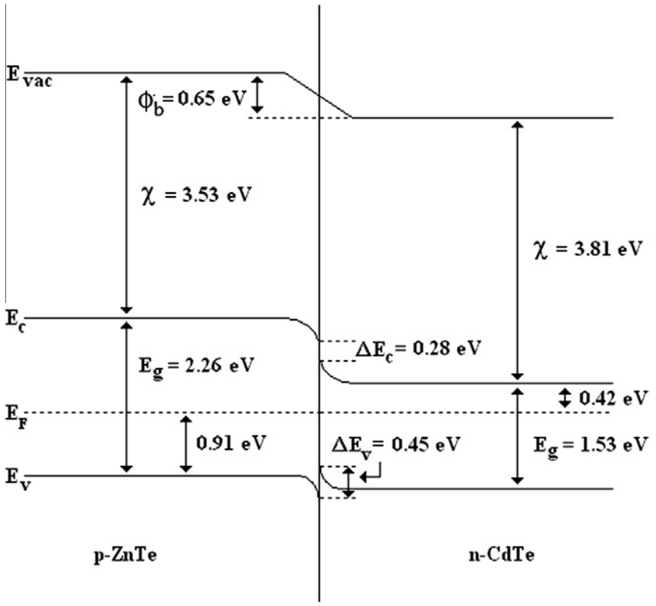

Fig. 10. The band diagram of p-ZnTe/n-CdTe heterojunction diode.

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