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Current–voltage characteristics of Ag, Al, Ni–(*n*)CdTe junctions

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Abstract. **Schottky barriers of Ag, Al, Ni–(*n*)CdTe structures have been prepared and studied. The films were prepared by rf sputtering and doped with Cd metal. Diode ideality factor of these junctions are greater than unity and barrier height varies from 0·6–0·7 eV and are affected by room illumination. Photovoltaic effect of these junctions was very poor and fill factor below 0·4. Low doping concentration, high defect density, presence of an interfacial layer and presence of high series resistance are perceived to affect the *J–V* characteristic.**

Keywords. **Schottky barrier junction; series resistance; photovoltage.**

1. Introduction

Cadmium telluride, a group II–VI amphotaric intermetallic compound has been considered to be a promising candidate for opto-electronics and photovoltaic devices (Loferski 1956; Wysocki and Rapport 1960; Anthony *et al* 1985; Tommer 1988; Sebastian 1992). As it has a direct band gap and close to the visible region, it has a high absorption coefficient which is required for a good theoretical conversion efficiency (Gould and Bowler 1988). This has led to the investigation of CdTe hetero-junction and metal–CdTe Schottky barriers (Chu *et al* 1983).

Different techniques have been employed to prepare CdTe films and their junctions with metals. Das *et al* (1984) have reported studies of sputtered and In- and Cd-doped films with Au as the barrier metal. Isett and Raychaudhary (1984) have studied the deep levels in Au–(*n*)CdTe Schottky barrier. Sarmah and Rahman (1999) have studied sputtered CdTe film with Ag–(*n*)CdTe–In structure. Mandal *et al* (1986) have examined the surface modified CdTe photoelectrochemical (PEC) solar cell. Ponpon and Siffert (1977) have reported high efficient (*n*)CdTe Schottky barrier. From these studies it has been observed that there is a need for a systematic study on metal–CdTe junction with suitable barrier metal and proper doping material.

In the present paper, Schottky barriers of rf sputtered Cd-doped CdTe films have been reported. Counter electrodes of Ag, Al and Ni were used as barrier metals.

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2. Experimental

99·999% pure 5″ diameter disc type CdTe target procured from M/s Testbourne, UK was used to sputter on chemically clean glass substrates. The CdTe films were prepared in an Argon atmosphere at a pressure of $1{\cdot}5 \times 10^{-3}$ torr. The sputtering unit with 2 kW rf generator working at 13·56 MHz was procured from Hind High Vacuum Co. Pvt. Ltd., India. Rf power could be varied from 0 to 2 kW. The unit was designed to hold 3 water cooled targets. The doping of the films was done by simultaneously sputtering Cd metal from a few pellets fixed on the CdTe target. Rf power was kept at 180 W to get optimum resistivity of the film at 3·8 cm substrate–target distance (Sarmah and Rahman 1990). The ohmic contact was made by indium metal which was deposited by vacuum evaporation on glass substrates prior to CdTe sputter deposition. The counter electrodes (barrier metals) of Ag, Al or Ni were vacuum deposited onto rf sputtered CdTe film. Both disc as well as rectangular type electrodes were used for studying junction properties. For measurement of current–voltage (*J–V*) characteristics in dark and under illumination, the samples were kept in a specially designed vacuum chamber. The chamber was fitted with a glass window which could be kept closed or opened and could be evacuated up to 10^{-3} Torr. The junction was illuminated using white light from a tungsten filament projector lamp (500 W). The *J–V* curves were drawn with the help of *X–Y* recorder (Digital Electronics Ltd.). Details of experimental arrangement and measurement have been reported in our earlier paper (Sarmah and Rahman 1998).

3. Results and discussion

Current–voltage characteristics of these junctions show the rectifying nature of the device indicating the presence of a barrier. The lower electrode indium was tested for ohmic contact up to 8 V. Figure 1 shows the *J–V* characteristics of three typical junctions in dark and under room illumination. At low voltage (below 0·5 V) and at room temperature the junctions show more or less ohmic behaviour. At higher voltages the junctions show a space charge limited condition. While Ag–(*n*)CdTe almost follow a square law ($J \propto V^2$), Al–(*n*)CdTe and Ni–(*n*)CdTe shift towards Schottky barrier diode at higher forward and reverse bias.

The current density–voltage relation can be expressed by (Rhoderik 1978)

$$J = J_0 \exp(qV/nkT)\,\{1 - \exp(qV/kT)\}.$$

A plot of $\ln[J/(1 - e^{-qV/kT})]$ against V gives diode ideality factor (n) and saturation current density, J_0. Figure 2 shows such three plots for three typical junctions. Diode ideality factor (n) of these junctions are much larger than unity and saturation current density varies from 5×10^{-5} to 15×10^{-5} A/sq·cm. The barrier heights obtained are below 0·7 eV (with Ni electrode). The junctions are affected by illumination (figure 1). Though identical with *J–V* curves in dark, an enhancement of current with voltage has been observed due to generation of extra carriers. Saturation current density and diode ideality factor have been observed to increase upon illumination. Reverse current does not saturate and shows a bias dependence of barrier height. Table 1 shows the values of diode ideality factor, saturation current density, barrier height and series resistance of three typical samples obtained for *J–V* characteristics in dark as well as under room illumination.

There are various factors affecting *J–V* curves of these junctions. It has been observed that *J–V* curves are functions of doping concentration and electrode area. There can be many reasons to get diode ideality factor greater than unity (Henish 1984); presence of an interfacial layer, image force lowering of barrier height, recombination of electrons and holes in the depletion regions, tunneling effect are the main reasons. They are also responsible for reverse current not showing saturation. It is not ascertained which factors are dominating the process. However, the present structure can be best fitted with the formation of a Schottky barrier with a thin interfacial layer. Another important factor is the presence of a series resistance (discussed separately). The formation of a Schottky barrier has been confirmed from the temperature effect on the current–voltage characteristics for Ag–(*n*)CdTe junction (Sarmah and Rahman 1999). A plot of $\ln(J_0/T^2)$ vs T^{-1} showed a straight line and the Richardson constant evaluated is around 60. This value was used to calculate barrier height of these junctions. As the doping concentration is moderate, the current transport is assumed to be mainly dominated by the thermionic emission process (Sze 1983). Upon illumination of the junction, more

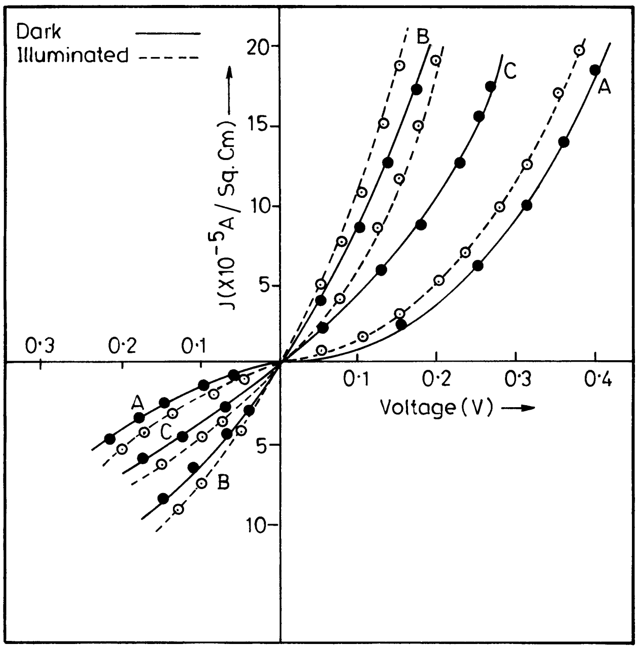

Figure 1. *J–V* characteristics of three typical junctions in dark and under room illumination (at 300°K). Samples A, B and C are Ag–(*n*)CdTe, Al–(*n*)CdTe and Ni–(*n*)CdTe, respectively (thickness, 9500 Å; doping concentration, $9{\cdot}3 \times 10^{14}$ cm^{-3}; electrode area, $3{\cdot}2 \times 10^{-2}$ sq·cm).

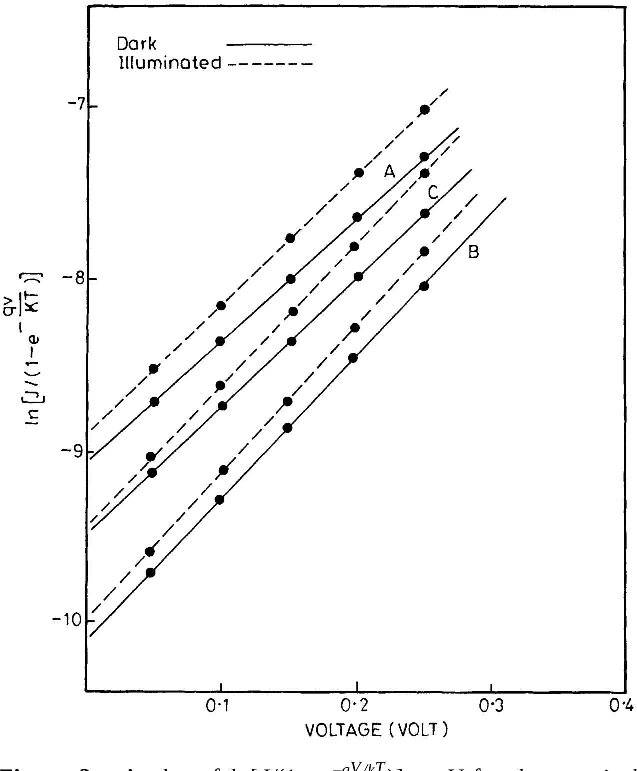

Figure 2. A plot of $\ln[J/(1 - e^{-qV/kT})]$ vs V for three typical junctions in dark and under room illumination (sample parameters are same as in figure 1).

Table 1. Values of some physical parameters for three typical junctions in dark and under room illumination (sample parameters are same as in figure 1).

	In dark				Under room illumination			
Junction	n	J_0 ($\times 10^{-5}$ A/sq·cm)	Barrier height (eV)	Series resistance (kΩ)	n	J_0 ($\times 10^{-5}$ A/sq·cm)	Barrier height (eV)	Series resistance (kΩ)
Ag	6	8	0·65	0·95	9	15·0	0·61	0·70
Al	7	4·5	0·61	2·10	8	8·5	0·55	1·80
Ni	5	12	0·70	0·50	6	16·5	0·65	0·35

carriers are generated and forward current increases. The *J–V* curves further shift from the 'non-ideal' position affecting the ideality factor. The similar increase of ideality factor in CdTe junction due to increase of forward current has been reported earlier (Das *et al* 1984).

3.1 *Effect of series resistance*

There has been a series resistance (R_S) associated with the neutral region of the semiconductor (between depletion layer and ohmic contact) (Rhoderik 1978). An estimate of series resistance from ln *I* vs *V* plot (not shown here) shows that these devices have very high series resistance not less than 500 ohms (junction with Ni electrode) and decreases upon illumination. At larger forward current, voltage drop across the series resistance causes the actual voltage drop across the barrier region to be less than the voltage applied to the terminals of the junction. Thus *J–V* curves deviate from the ideal condition and the current is proportional to $\exp[q(V–IRs/kT–1)]$. The series resistance of Al–(*n*)CdTe junction exceeds 2 kΩ (table 1).

3.2 *Photovoltaic effect*

The Schottky barrier junctions were studied for their photovoltaic performance under the light intensity of 100 mW/sq·cm. Light was allowed to fall on the junction in vacuum through water filter to reduce the heating effect. Figure 3 shows current–voltage curves of three typical junctions for photovoltaic effect. Low photovoltage has been observed in these junctions. Since the counter electrode was not made too thin to allow the whole light to penetrate through it, a minute fraction of it absorbed at the surface is not ruled out. Fill factor of these junctions varies from 0·35–0·38. The nature of the graphs indicate the presence of a series resistance in the device. Table 2 shows the open circuit voltage, short circuit current and fill factor of a few typical samples. There are various factors responsible for the reduction in the photovoltage (Sze 1983) such as high defect density, presence of an interfacial layer, low doping concentration and presence of series resistance. Low photovoltage in CdTe Schottky barriers has also been reported by Das *et al* (1984).

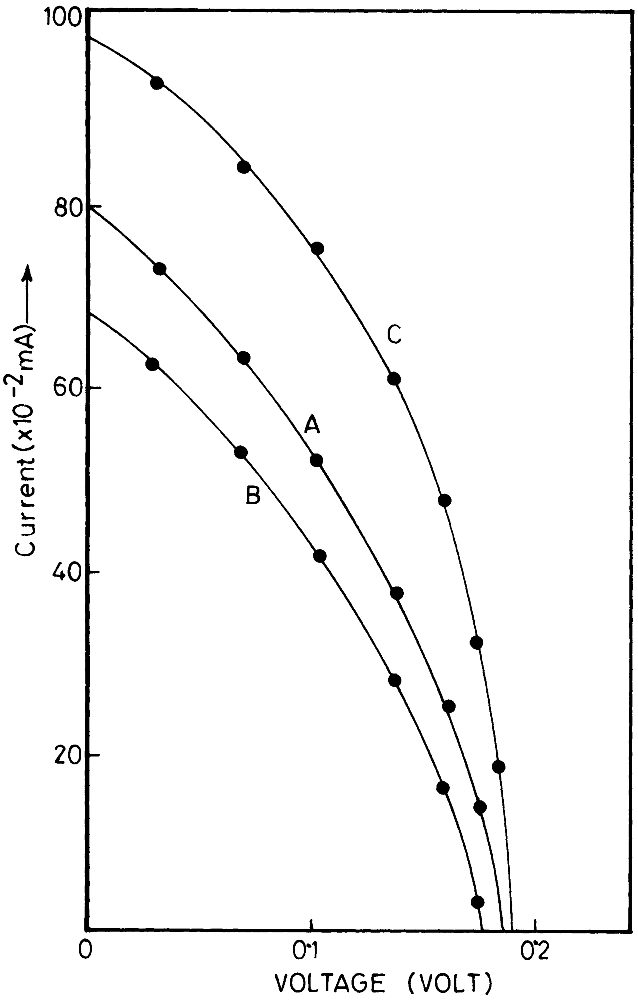

Figure 3. Solar cell plots for three typical junctions at 100 mW/sq·cm light intensity (sample parameters are same as in figure 1).

Table 2. Open circuit voltage, short circuit current, fill factor and efficiency of three typical junctions (sample parameters are same as in figure 1).

Counter electrode	Illumination (mW/sq·cm)	Short circuit current (mA)	Open circuit voltage (mV)	Fill factor	Efficiency (%)
Ag		0·80	188	0·350	1·61
Al	100	0·61	178	0·322	1·21
Ni		0·97	192	0·389	2·23

4. Conclusions

A study on Ag, Al, Ni–(*n*)CdTe junction shows that a barrier has been formed at these junctions and is affected by illumination. Doping concentration, series resistance, high defect density, presence of an interfacial layer are some factors affecting *J–V* curves to deviate from ideal. These are also responsible for low photovoltaic performance.

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