

# Characterization of Thin Film Al/p-CdTe Schottky Diode

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## Abstract

A study has been made on the behavior of Al/p-CdTe thin film junction grown by thermal evaporation method. I-V characteristics show that the Al makes Schottky contact with p-CdTe. The variation of junction capacitance with frequency and voltage has been studied to evaluate the barrier height. The activation energy and band gap have been estimated by studying variation of resistivity with temperature. Using all these data, band diagram of Al/p-CdTe has been proposed.

**Key Words:** Al, p-CdTe, Schottky, C-V, band diagram.

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## 1. Introduction

In recent years, II-VI compound semiconducting thin films have drawn much attention for their potential application in optoelectronics. Among these, CdTe is unique, since it can be prepared with both p- and n-type conductivities. It has been successfully used in solar cells, infrared detectors etc. It has the advantage of a nearly ideal band gap for solar photo conversion and a short absorption length when compared to grain sizes typically encountered, which reduces the recombination at grain boundary [1]. The Schottky junction is one of the fundamental structures in electronics and finds application in electronic devices like low-voltage, high-current rectifiers. Metal/CdTe interfaces play an important role in opto-electronic devices and have been studied by different research groups [2–9]. Pattabi et al [2] have studied Au/CdTe interface and effect of irradiation on the electrical properties of the junction. They have found that thermionic emission-diffusion is the dominant conduction mechanism under forward bias. Also they have observed the changes in device parameters at the irradiation dose of 70kGy and above. Naby [10] has studied the radio frequency-sputtered Al/CdTe Schottky junction and observed thermionic emission dominated conduction. In the present study junction behavior of evaporated Al/CdTe has been investigated.

## 2. Experimental

CdTe thin films were prepared by thermal evaporation of a stoichiometric powder of the compound (99.99% pure, from Aldrich Chemical Co.) in a residual pressure of  $10^{-5}$  torr. Cleaned glass substrates were

used as substrate and molybdenum was used as boat source. Glass substrates were first cleaned with soap liquid. Then they were dipped in a weak solution of chromic acid for 24 hours. After that they were washed with distilled water and dipped in beaker containing acetone and dried. The films were grown by maintaining the substrate at room temperature (RT) and also at 180 °C (ET). The thickness of the films was of the order of 400 to 500 nm. The thickness was measured by multiple beam interference method. Structural study was done using Rigaku Miniflex X-Ray diffractometer (30 kV, Cu K $\alpha$ ). Chemical composition of the film was analyzed by energy dispersive analysis of x-rays. Al film was also grown by thermal evaporation method. Hot probe technique was adopted to find the type of conductivity. The variation of resistivity of CdTe with temperature was studied and hence activation energy was calculated. A Cr/Al thermocouple was used to monitor temperature.

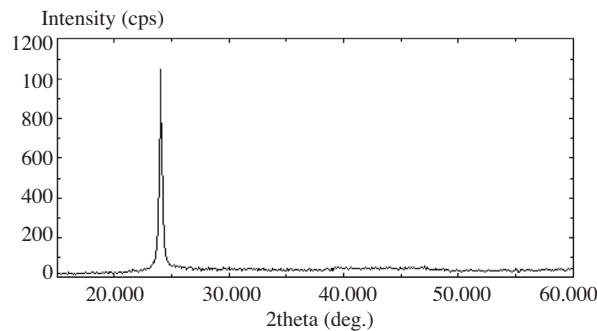
A Keithley model 2400 source meter was used for I-V characterization and a Keithley 3322 LCZ meter was used for capacitance and resistance measurement. All the measurements were done under dark condition and in air ambient.

### 3. Results and Discussion

X-Ray diffractogram of the CdTe thin film grown at room temperature is shown in Figure 1. It reveals that film is in cubic structure and a strong preferred <111> orientation of micro crystallites. The grain size of the crystallites (G) has been estimated using the following relation [11]:

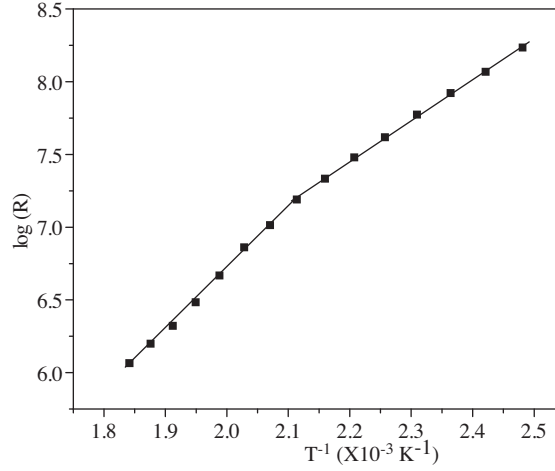
$$G = \frac{k\lambda}{\beta\cos\theta} \quad (1)$$

where  $k$  is shape factor ( $\approx 1$ ),  $\lambda$  is the wavelength of X-Ray used,  $\theta$  is the Bragg's angle and  $\beta$  is the FWHM of the peak. The grain size was of the order of 8 to 9 nm.



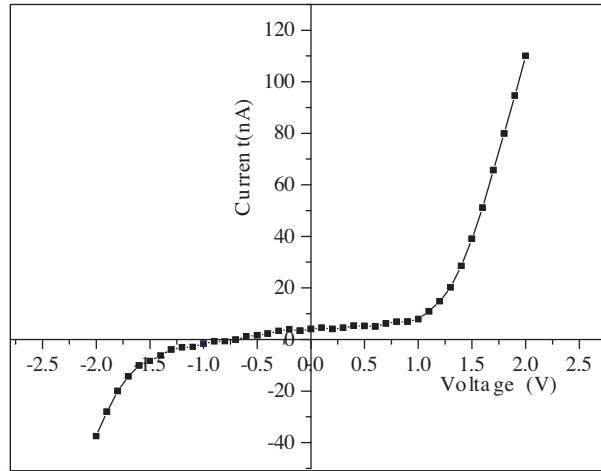
**Figure 1.** XRD of CdTe thin film deposited at room temperature.

All the films deposited at room temperature have been found to be p-type. From EDAX, it has been observed that film deposited at room temperature is Te rich (Cd/Te  $\approx 0.83$ ) whereas the film deposited at 180 °C is nearly stoichiometric (Cd/Te  $\approx 0.93$ ). This might be because of decomposition of the compound and preferential evaporation of lower vapor pressure constituent of the compound [12, 13]. The band gap energy computed from the study of variation of electrical resistivity with temperature yielded a value of 1.56 eV for these films in the intrinsic region (Figure 2). The thermal activation energy of extrinsic region was found to be 0.65 eV.



**Figure 2.** Variation of resistivity of CdTe with temperature.

To get ohmic contact between a metal and p-semiconductor, the work function of metal  $\Phi_m$  must be greater than that of semiconductor  $\Phi_s$  [14]. Thermally evaporated Al film on CdTe thin film has been found to produce non-ohmic contact. I-V characteristic of the Schottky junction is shown in the Figure 3. At low voltage, the current varies exponentially with voltage (Figure 4) suggesting conduction by thermionic emission [5]. The current through the Schottky diode at lower voltage under a forward bias  $V$  is given by the relation



**Figure 3.** I-V Characteristic of Al/p-CdTe Schottky barrier.

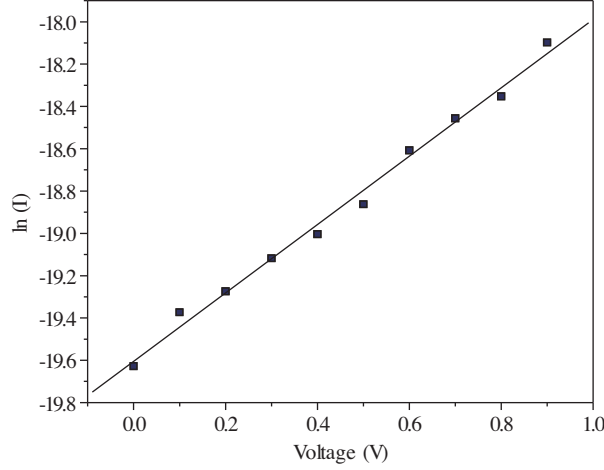
$$I = I_s \left[ \exp \left( \frac{qV}{nkT} \right) - 1 \right], \tag{2}$$

where  $I_s$  is the reverse saturation current,  $k$  is Boltzmann constant,  $q$  is the electronic charge and  $n$  is the ideality factor [2]. The ideality factor obtained in the present case is 1.27. Pattabi et al [2] have reported higher ideality factor for Au/CdTe Schottky diode. An ideality factor greater than unity is generally attributed to the presence of a bias dependent Schottky barrier height. Interfacial oxide layer may also be the possible cause for a higher ideality factor [2]. At voltage above 1.2 V, a non-ohmic relation  $I \propto V^2$  fits the curve (Figure 5). This suggests that, in this region, current is controlled by space charge limited conduction (SCLC) and allows us to use space charge limited (SCL) theory for I-V analysis [5]. In the SCLC

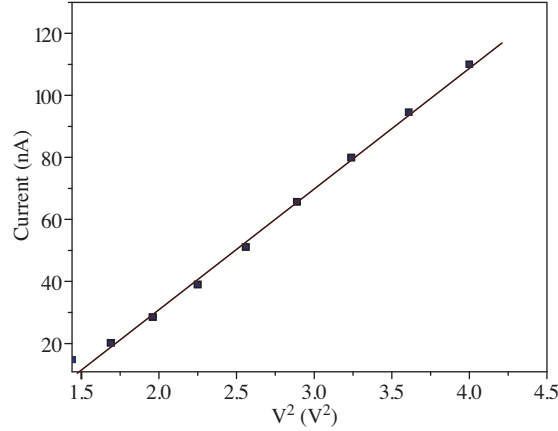
region, the current can be related to the voltage via the relation [6]

$$I = \frac{\varepsilon_r N_C}{8L^3 N_t} A \mu \varepsilon V^2 \exp(-E_t/kT), \quad (3)$$

where  $\varepsilon_r$  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 film thickness,  $A$  is the device area,  $\mu$  is the mobility and  $\varepsilon$  is the permittivity.



**Figure 4.**  $\ln I$  vs.  $V$  at lower voltages.



**Figure 5.**  $I$  vs  $V^2$  at higher voltages.

The junction capacitance shows a rapid decrease with frequency. The resistance shows almost similar variation with frequency (Figure 6). The depletion region of the Schottky barrier behaves in some respects like a parallel-plate capacitor. There is a parallel conductance due to the reverse current of the diode, so the equivalent circuit consists of a capacitor in parallel with a resistor. The insulating interfacial layer, as occurs when there is an oxide film on the surface of semiconductor, alters the capacitance. The capacitance of the interfacial layer comes in series with the capacitance of depletion region.

The Schottky relation relating capacitance with the applied reverse bias may be written as

$$C = \left( \frac{q\varepsilon_s N_d}{2} \right)^{1/2} \left( V_{do} + V - \frac{kT}{q} \right)^{-1/2}, \quad (4)$$

where  $V_{do}$  is the diffusion voltage at zero bias [15]. The linearity in the plot of  $C^{-2}$  as a function of  $V$  indicates the uniform doping of depleted region and abrupt junction (Figure 7). The barrier height obtained

in present case is 0.44eV. Slight increase in capacitance has been found for the film deposited at 180 °C, which is nearly stoichiometric. But no considerable variation has been observed in barrier height. Abdel Nabay studied Al/p-CdTe junction and reported the barrier height of 0.63 eV [10]. Darwish has reported barrier height of 0.63 eV for Al/p-CdTe thin film junction [5]. One possible cause for the deviation from expected value in their study is non-stoichiometry on the surface. Only for stoichiometric surfaces, the barrier height depends on the work function of the metal, whereas this is not so for non-stoichiometric surfaces [16]. Also the thin oxide layer formed between metal and semiconductor on exposure to atmosphere has been reported to influence the barrier height [15]. This layer may be considered to be an insulator, even though it may be so thin that it does not possess the band structure which is the characteristic of thick oxide. Because of the potential drop in the oxide layer, the zero bias barrier height will be lower than it would be in an ideal diode, provided there is no charge contained in the layer. Also when a bias is applied, part of the bias voltage is dropped across the insulating layer so that the barrier height  $\phi_b$  is a function of the bias voltage. In the present case, the barrier height is independent of the applied bias voltage indicating the passive role of the interfacial layer.

The proposed band diagram of Al/p-CdTe is shown in Figure 8.

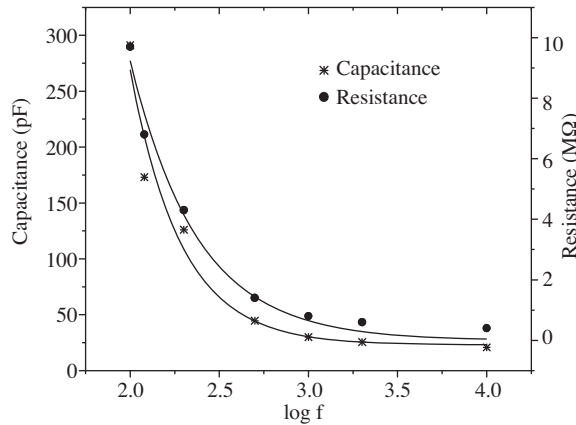


Figure 6. Variation of capacitance and resistance with frequency.

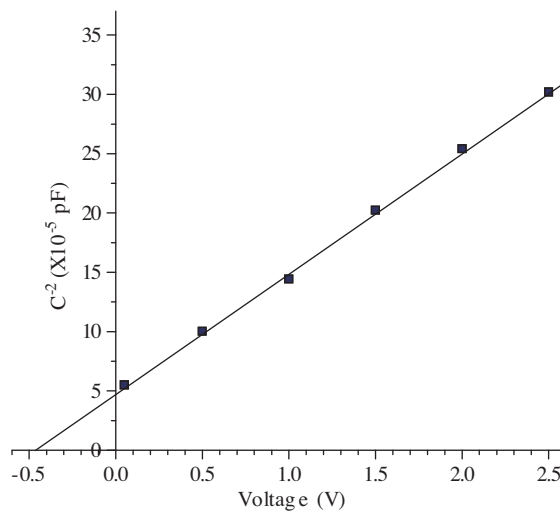
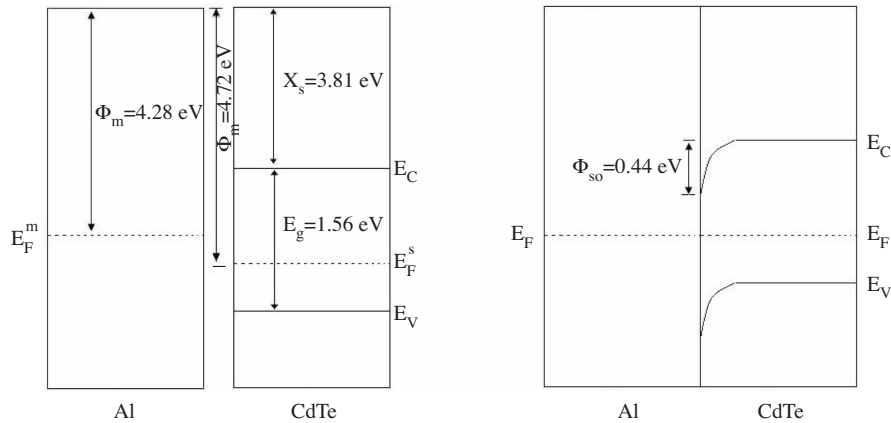


Figure 7. Plot of  $C^{-2} - V$  of Al/p-CdTe Schottky barrier.



**Figure 8.** Proposed band diagram of Al/p-CdTe junction.

## 4. Conclusions

Room temperature deposited cadmium telluride films are cubic in structure with strong preferred  $\langle 111 \rangle$  orientation of micro-crystallites. Al makes Schottky contact with p-CdTe with a barrier height of 0.44 eV. At lower bias voltages, current conduction is by thermionic emission where as at higher voltages, current is controlled by SCLC. The junction capacitance and resistance of the Schottky junction decrease almost exponentially with frequency. Based on the results, band diagram for Al/p-CdTe is proposed.

## References

- [1] J. Britt and C. Ferekides, *Applied Physics Letter*, **62**, (1993), 22.
- [2] M. Pattabi, S. Krishnan, Gansh and X. Mathew, *Solar Energy*, **81**, (2007), 111.
- [3] L. A. Kosyachenko, X. Mathew, V. V. Motushchuk and V. M. Sklyarchu, *Solar Energy*, **80**, (2006), 148.
- [4] H. Sitter, H. Heinrich, K. Iischka and A. Iopezotero, *Journal of Applied Physics*, **53**, (1983), 4948.
- [5] S. Darwish, *Physics B*, **349**, (2004), 296.
- [6] X. Mathew, *Semiconductor Science and Technology*, **18**, (2003), 1.
- [7] M. Yosuf, D. Sands and C. G. Scott, *Solid State Electronics*, **44**, (2000), 923.
- [8] X. Yi and J. J. Liou, *Solid State Electronics*, **38**, (1995), 1151.
- [9] H. Demtsus and J. R. Sites, *Thin Solid Films*, **510**, (2006), 320.
- [10] M. Abdel Naby, *Renewable Energy*, **6**, (1995), 567.
- [11] S. Lalitha, R. Sathyamoorthy, S. Senthilarasu, A. Subbarayan and K. Natarajan, *Solar Energy Materials and Solar Cells*, **82**, (2004), 187.
- [12] K. N. Shreekanthan, V. B. Kasturi and G. K. Shivakumar, *Indian Journal of Engineering and Materials Science*, **10**, (2003), 433.
- [13] R. W. Berry, P. M. Hall and M. T. Harris, *Thin Film Technology* (Van Nostrand Reinhold Company, 1968)
- [14] D. Nagchoudhuri, *Semiconductor Devices* (Tata McGraw-Hill Publishers, 1989)
- [15] E. H. Rhoderick and R. H. Williams, *Metal-Semiconductor Contacts* (Oxford Science Publications, 1988)
- [16] K. M. Al-Shibani, *Physics B*, **322**, (2002), 390.