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ELECTRICAL PROPERTIES OF CADMIUM TELLURIDE SCREEN-PRINTED FILMS FOR PHOTOVOLTAIC APPLICATIONS

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The II-VI semiconductors are of great importance due to their applications in optoelectronics, solar cells, integrated optics and electro-optic devices. Cadmium telluride is a suitable material for the fabrication of photovoltaic devices. We have prepared Cadmium telluride films in air atmosphere by Screen -printing method and studied their applications in photovoltaic devices. The energy band gap of these films were found to be 1.48 eV by reflection spectra in wavelength range 800-1000nm.The X-ray analysis of these films confirms the polycrystalline nature of prepared films having wurtzite (hexagonal) structure .The Schottky junction of Cadmium telluride using aluminium was made and the barrier height and ideality factor of it were determined by using current –voltage characteristics. The DC conductivity and activation energy of films were also measured in vacuum by two-probe technique. Screen-printing followed by sintering is a very simple and viable technique compared to other costly methods. It is less time consuming, less pollutant and ensures maximum material utility and offers a suitable method for preparing films on large area substrates.

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1. Introduction

Thin films promise high utility in solar cells out of which Cadmium chalcogenides have received intensive attention as their band gap lies close to the range of maximum theoretically attainable energy conversion efficiency [1]. They can also be used in hetrojunctions, IR detectors, switching devices and optoelectronics. The importance of high quality polycrystalline films of CdTe finds application in high efficiency solar cells [2-4].

Recently, there has been a rapid development in the field of II-VI semiconductors for their use in photovoltaic devices. Cadmium Telluride belonging to the II-VI group is widely used material for CdS/CdTe hetrojunction photovoltaic devices. It is due to the fact that CdTe have intermediate energy band gap, reasonable conversion efficiency, stability and low cost [5-7]. The increasing interest in solar absorption has created a demand for the characterization of absorbing semi conducting film materials in the visible range for their application in photovoltaic devices. The band gap Eg is the most important parameter in semiconductor Physics. Cadmium Chalcogenide materials have band gaps $1.4 \leq Eg \leq 2.4$ eV and reasonable overlap with the solar spectrum. CdTe is a promising base material for solar cells owing to its nearly optimum energy band gap and high absorption coefficient.

Several techniques have been used to produce CdTe thin films such as Electro deposition [8], Vacuum evaporation [9, 10], Close space sublimation method [11], Brush plating [12], Pulsed laser deposition [13], Chemical deposition method [14], and hot wall epitaxy [15]. The technique of Screen-printing followed by sintering offers interesting possibilities for preparing CdTe thin films [16-19].

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Our intention is to use this material for fabrication of photovoltaic devices & to study the electrical properties of CdTe films. Screen-printing followed by sintering is one of the best techniques for the preparation of polycrystalline films with ease, at low costs & large area applications. It is extremely simple and viable as compared to other cost intensive methods [16-19]. Study has been undertaken to investigate the photoactive properties of CdTe Screen-printed sintered films. It is easy to incorporate Screen-printing technique in the industrial production line.

2. Experimental details

In present investigation, CdTe films were prepared by Screen- printing followed by sintering process [16-19]. A commercially available CdTe powder with 99.99% purity was used as the starting material. Slurry consisting of CdTe powder, 10% wt. Of $CdCl_2$ and an appropriate amount of ethylene glycol were thoroughly mixed. $CdCl_2$ was used as an adhesive and ethylene glycol as a binder. The paste thus prepared was screen printed on ultra clean glass substrates, which had been cleaned by embry powder and acetone and finally washed with distilled water. The sample thus prepared was dried at 120°C for 4 hour in open air. The reason of drying the sample at lower temperature was to avoid the cracks in the samples. The removal of organic materials took place at about 400°C. So sintering temperature cannot be less than 400°C. Cadmium chloride is hygroscopic and its melting point is 568°C. However the evaporation of cadmium chloride starts above 400°C. So to get a stable sintered film, cadmium chloride and organic material should not remain in the sample. We optimized the sintering temperature and sintering time by performing the experimental process for different values of these two parameters and concluded that samples should be sintered at 500°C for 10 min in a temperature controlled furnace.

3. Techniques of characterization

The optical reflectance versus wave length traces of all the films were recorded in 800 – 1000 nm wavelength range using a double beam spectrophotometer (Hitachi U – 3400). The XRD traces were recorded using Philips X – ray diffractometer using $CuK_\propto$ radiation. The Schottky junction of CdTe metal was fabricated and barrier height and ideality factor were determined by using current voltage characteristics. For I-V measurements voltage was applied by Keithley programmable voltage source and current was measured by Keithley programmable electrometer. The DC conductivity of the films was measured in vacuum using two-probe technique.

4. Results and discussion

Optical and structural properties:

The optical and structural properties of prepared CdTe Sintered films have been reported elsewhere in detail [16]. The energy band gap of CdTe sintered films was found 1.48 eV by reflection spectra in wavelength range 800-1000nm using Tauc relation [16]. The XRD studies reveal that the prepared films were polycrystalline in nature having a wurtzite (hexagonal) structure [16].

Electrical transport properties:

The Electrical Transport properties of the materials are of great importance in determining whether the material is congruent with our necessities or not. The electrical properties are dependent on various film and growth parameters such as film composition, thickness, and substrate temperature and deposition rate. For Photovoltaic application important characterization include electrical conductivity and the interface behavior of the semiconductor with various metals.

4.1. Current-voltage characteristics

Schottky devised a model for the metal – semiconductor contacts known as the Schottky barrier (or Schottky effect). There is variety of applications using metal semiconductor contacts including diode, transistor, FET etc. When a metal is brought into immediate contact with a semiconductor, the conduction and valence bands of the semiconductor are brought into a definite energy relationship with the fermi level in the metal [20]. The current -voltage measurements of semi conducting thin films with metal contacts reflect the diode characteristics. The current - voltage measurements are seen to closely follow the diode equation of Schottky barrier diode. The measurement of Schottky barrier height by current-voltage (I –V) characteristics is done as follows: We can predict the ideal forward and reverse current-voltage characteristics of a Schottky barrier diode by the following equation [20 – 21].

$$J = J_S (e^{eV/nkt} - 1) \tag{1}$$

$$J_S = A^{**} T^2 \exp(-e\phi_B / kt) \tag{2}$$

Where, J is the current density (I/A), I is current flowing, A is area of contact (10^{-4} cm^2), J_s the saturation current density and n is the ideality factor. A^{**} is the effective Richardson constant, T the absolute – room temperature (300 K), ϕ_B the Schottky barrier height, k the Boltzman constant $(8.62 \times 10^{-5} eV/k)$. We plot a graph between forward current density J_F versus the applied voltage V_F for various metal Semiconductor contact. The extra polated values of current density to zero voltage give the saturation current density J_S. The barrier height can be obtained from the following equation

$$\phi_B = \left(\frac{kT}{e}\right) L_n (A^{**} T^2 / J_S) \tag{3}$$

The ideality factor of the junction is given by

$$n = \left(\frac{e}{kT}\right) \left[\partial V / \partial(\ln J)\right] \tag{4}$$

To fabricate Al/CdTe junctions, aluminium layer was thermally evaporated over the films of CdTe, which was already deposited on the conducting glass. The size of aluminium layer was smaller than that of films. The sample was mounted in a specially designed sample holder where a vacuum of $\sim 10^{-3}$ torr was maintained throughout the experiment. For measurements, two electrical contacts, one from aluminium and other from conducting glass, were taken. The voltage was applied by Keithley programmable voltage source across the sample and the resulting current was measured by a Keithley programmable electrometer. Measurements were made at room temperature.

Fig. (1) Shows the current – voltage characteristic of CdTe film with Aluminium contact. This shows good diode characteristics.

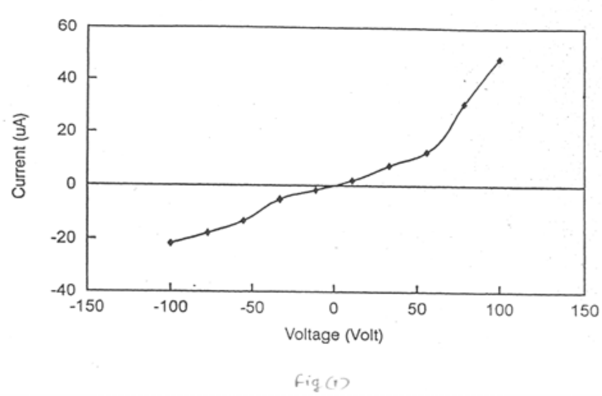

Fig. 1. Current-voltage characteristics of CdTe sintered film with Al contact.

The current – voltage characteristics show an appreciable increase in the forward bias conditions and a small reverse saturation under reverse bias conditions. The forward current – voltage characteristics are linear in the low field region indicating Schottky behaviour. At higher fields current – voltage characteristics becomes non-linear. The non–linearity of current – voltage characteristics over the wide voltage range is associated with the grain boundary effects within the sintered films as the polycrystalline films are generally characterized by the presence of moderately large grains, which are often comparable with the mean free path of the large carriers. As the applied voltage increases to certain value, the density of interface trap states at the grain boundary region decreases i.e. the traps in the semiconductor starts filling [22-23]. This phenomenon is commonly observed in materials having conducting grain in non - conducting matrix. We have calculated the Schottky barrier height using equation (3). Fig. (2) is the plot of LnJ_F versus V_F for CdTe film. We have also calculated the ideality factor of this junction using equation (4) and taking the value of LnJS and $[\partial(\ln J)/\partial V]$ from fig. (2).

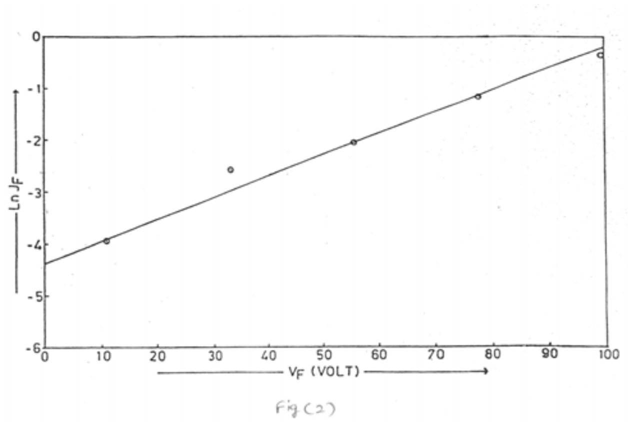

Fig. 2. A plot between LnJ_F versus V_F (Volt) for the calculation of barrier height..

The barrier height (ϕ_B) of Al / CdTe Schottky Junction was found to be 0.53V. The ideality factor (n) of Al/ CdTe Schottky Junction was found to be 1.19. The Cadmium Telluride whose films were formed was predominantly p – type as determined by the Hot Probe method. Hence these films are of p – type CdTe.

4.2 Electrical conductivity

The DC conductivity of a semiconductor at a temp T is given by $\sigma_{DC} = \sigma_0 \exp\left(-\frac{\Delta E}{kT}\right)$ where σ_0 is pre-exponential factor, ΔE the activation energy for the generation process and *k* is Boltzman's constant. We may write

$$\ln\sigma_{DC} = \ln\sigma_0 - \left(\frac{\Delta E}{kT}\right)$$

or

$$\ln\sigma_{DC} = -\left(\frac{\Delta E}{1000k}\right)\left(\frac{1000}{T}\right) + \ln\sigma_0$$

When we plot a graph between $\ln\sigma_{DC}$ and $\frac{1000}{T}$, a straight line obtained having sloped $\left(\frac{\Delta E}{1000k}\right)$ and intercept $\ln\sigma_0$. Thus, the activation energy can be calculated by using the slope of the straight line. The *DC* electrical conductivity of the samples were measured in dark, in the range of temperature 300-400k. The temperature dependence of the dark conductivity is shown in Fig. (3).

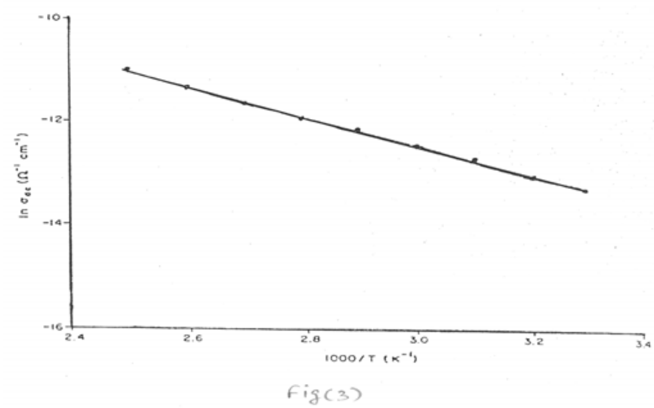

Fig.3. Temperature dependence of DC conductivity of CdTe sintered film.

The conductivity of CdTe samples increase with the increase in temperature. The plot of $\ln \sigma_{DC}$ against $\frac{1000}{T}$ for CdTe films is a straight line indicating that conduction in CdTe film is through thermally activated process. Obviously, the straight line nature of this plot suggests that grain boundary limited conduction is the dominant conduction mechanism. We would like to state that the grain boundaries are consequence of imperfections associated with the poly crystalline films. Seto [24] explains the high temperature conduction mechanism in semi conductors. In present investigation, the dark conductivity and activation energy of CdTe films comes out to be $3.72 \times 10^{-6} \Omega^{-1} cm^{-1}$ and 0.21eV, respectively. Activation energy for CdTe thin films prepared by different methods are reported by several workers [25-29], which is ~ 0.2 eV, which may be due to presence of a shallow impurity level at 0.2eV above the valence band.

5. Conclusions

Thus the optical and electrical studies are very much helpful in characterizing the material (CdTe) for its applications in photovoltaic devices. The band gap and parameters like barrier height and ideality factors are important for photovoltaic device fabrication. The band gap of CdTe Screen - printed sintered films comes out to be 1.48 eV. The Schottky barrier height and ideality factor for Al/CdTe Schottky junction was found to be 0.53V and 1.19 respectively. It has been observed that Dark DC conductivity and activation energy of CdTe comes out to be $3.72 \times 10^{-6}\ \Omega^{-1}\ cm^{-1}$ and 0.21 eV respectively. The conduction in CdTe film is through thermally activated process. The requisite of CdTe photovoltaic device are: optimum band gap, high quantum efficiency for electron hole pair generation, large barrier height, appropriate ideality factor, fairly high DC conductivity and activation energy and large absorption coefficient over a wide range of incident radiation. The Screen-printing (sintering) is the cheapest method for the preparation of CdTe photovoltaic films. Last but not the least cost effectiveness of such devices is another important advantage.

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