



## Characterization of Zinc-phthalocyanine–CdS composite thin films for photovoltaic applications

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### A B S T R A C T

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The optical properties of ZnPc–CdS composite thin films have been measured. The composite layers were prepared by vacuum evaporation. The electrical conduction mechanism prevailing in these junctions was of Poole–Frenkel type and the activation energy was found to have a linear dependence with applied field. The maximum photoconductivity occurred at an energy gap around 1.5 to 1.7 eV. The photosensitivity is found to increase with increase in applied voltage.

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### 1. Introduction

Recently organic/inorganic composites have attracted much attention because of their potential application as new photoelectric materials that combine the desired properties of both the organic and inorganic components. It organic/inorganic composites are used in information storage [1], as gas sensors [2], thin film field effect transistors [3], solar cell and electro photographic systems [4]. Many studies have been made on organic/inorganic composites and chemical methods have been often used to prepare the organic/inorganic composites. Tracey et al. [5] prepared Copper Phthalocyanine (CuPc)/TiO<sub>2</sub> films by the sol–gel method, Roulades et al. [6] prepared  $\alpha$ -SiO<sub>x</sub>C<sub>y</sub>H<sub>z</sub> films by plasma enhanced chemical vapour deposition. However than physical method to prepare multilayer films 13 relatively simple offer easy control and can of thickness produce homogeneous films.

During the last couple of decades, much effort has been put into the development of solar cells based on small organic molecules and conjugated polymers [7–19]. Considerable activity has been spurred by their lightweight, potentially low-cost, tuneability of the electronic band-gap by chemical synthesis, and the simple fabrication of large-area flexible, thin film devices. However, the power conversion efficiency of organic photovoltaic devices is still much lower than that of inorganic photovoltaic devices. This is mainly attributed to the low photo generation efficiency of charge carriers and high electrical resistivity of organic materials caused by the low

density and mobility of charge carriers. Operation processes of an organic photovoltaic device on the molecular level consist of three consecutive fundamental steps: (1) absorption of light, (2) creation of separate charges at the donor–acceptor interface, and (3) selective transport of charges through the bulk of the device to the appropriate collecting electrodes. A prerequisite for high efficiency conversion of photons into electrical current is that the holes and electrons do not recombine before being swept out of the device to the external circuit. In order to reduce recombination, the electrons and holes are preferentially transported in different materials or phases. For example, in the case of donor–acceptor devices, an acceptor material with good electron conductivity and a donor material with good hole conductivity is ideal. Therefore, a metastable photoinduced charge-separated state and high charge carrier mobilities are important factors.

The ever-widening search for new thin film materials to meet the pressing demand has led to the selection of organic materials. The organic materials possess unique electronic properties, which render them essential in device fabrication and application. They also exhibit high dielectric field strength and low dissipation factor. Organic dyes used in molecular organic solar cells are suitable for light absorbers producing thin film solar cells below 1  $\mu$ m thickness. Easy production techniques, cheap material flexibility and low temperature processing are further possible advantages of most organic semiconductors.

In the present work, Cadmium Sulphide (CdS) has been chosen for the formation of a heterojunction with ZincPhthalocyanine (ZnPc). ZnPc, a p-type organic semiconductor material, is a suitable candidate for making solar cells. It possesses high absorption in the visible region, high thermal stability and optimum optical band

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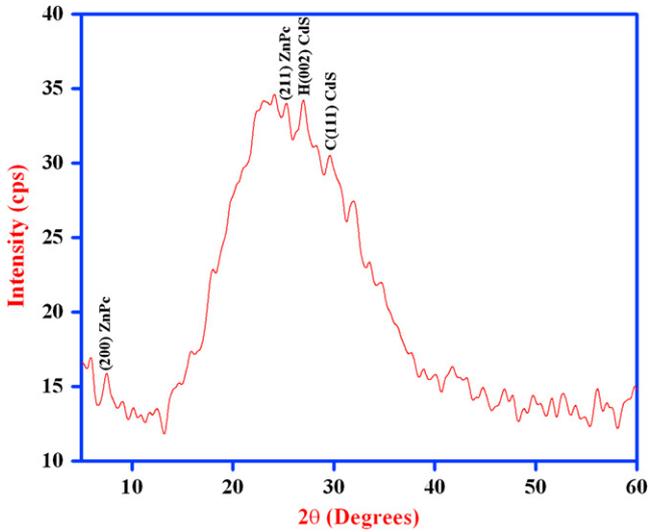


Fig. 1. XRD spectrum of ZnPc/CdS heterojunction of thickness 900 nm.

gap. ZnPc acts as an active layer in thin film solar cells. Among different techniques of deposition, ZnPc is formed by vacuum evaporation, which is a simple and clean technique. There is a lack of knowledge and understanding of basic issues behind the Organic/Inorganic junction performance and stability. Moreover it is necessary to study the organic/inorganic composite solar cell and its efficiency limiting parameters. Hence this paper deals with the characterizations of ZnPc/CdS junctions and the fabrication and characterization of ITO/ZnPc–CdS/Ag heterojunction thin film solar cells. The solar cell parameters (open circuit voltage, short circuit current, fill factor and efficiency) have been evaluated and the results are discussed in detail.

**2. Measurements**

In the present study ZnPc solar cells with the structure ITO/ZnPc–CdS/Ag have been fabricated. Polycrystalline p-type ZnPc films have been deposited onto the ITO substrates by thermal evaporation. A CdS window layer n-type has been formed on the ZnPc films by thermal evaporation, which results in the formation of a p-ZnPc/n-CdS heterojunction. The light intensity has been measured using an intensity meter. I-V characteristics of the device were studied in a rotary pumped vacuum system by employing DC

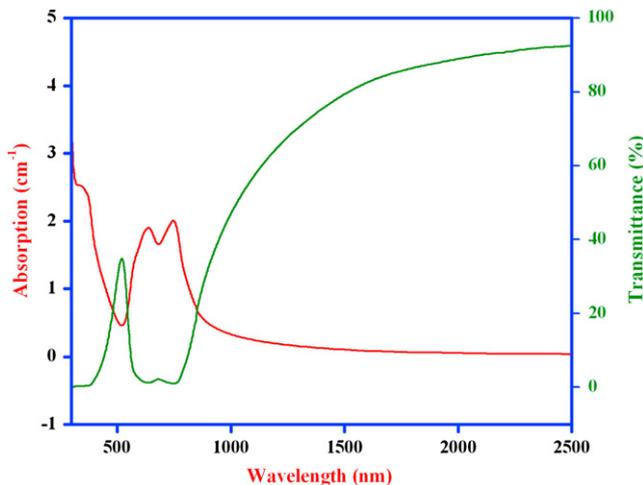


Fig. 2. Absorption and Transmission spectrum of ZnPc/CdS composite thin film.

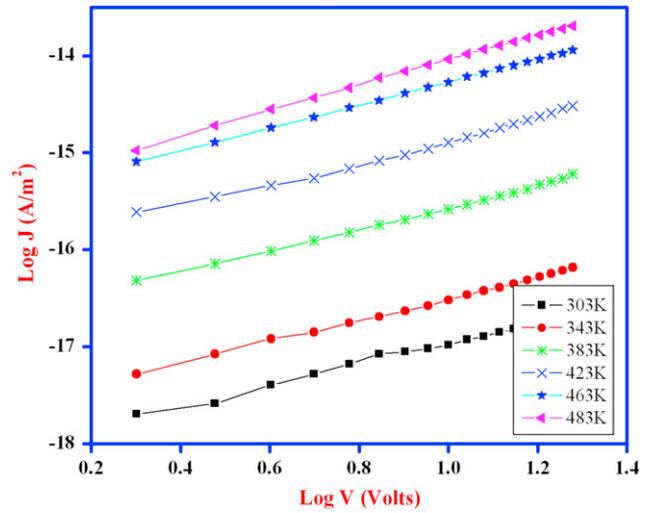


Fig. 3. Current – Voltage characteristics for Al/ZnPc–CdS/Al device at various temperatures.

regulated power supply in series with Digital Pico ammeter (DPM – 111) and digital voltmeter.

**3. Results and discussion**

*3.1. Structural studies*

The structure of the films was analyzed by an X-ray diffractometer (using  $\text{CuK}\alpha$  radiation with  $\lambda = 1.5418 \text{ \AA}$ ). Fig. 1 shows the X-ray diffraction spectra for ZnPc/CdS film and the important diffraction peaks at  $2\theta \approx 7.04^\circ, 23.7^\circ, 26.5^\circ$  and  $28.2^\circ$  were seen indicating preferred orientations of (200) ZnPc, (211) ZnPc, Hexagonal (002) and Cubic (111) CdS, respectively. The presence of a diffraction peak at  $2\theta \approx 28.2^\circ$ , corresponding, respectively, to the hexagonal (101) and as well as cubic (111) CdS is an indication that these two phases are present in the samples.

*3.2. Optical properties*

The optical properties of the ZnPc/CdS composite can be basically understood as the sum of the properties of each component,

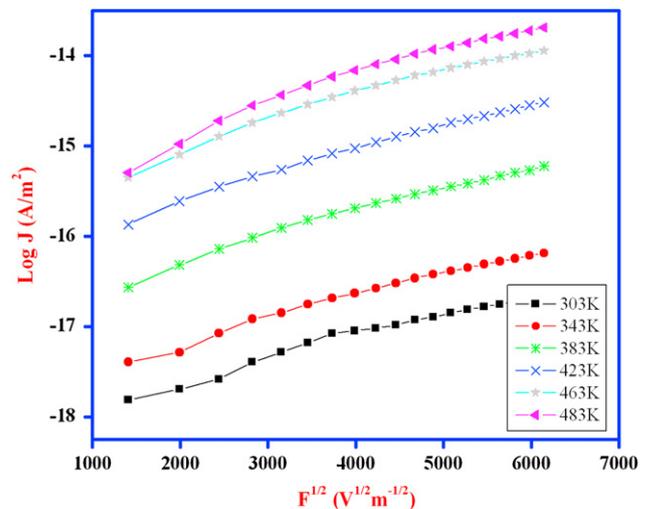


Fig. 4. Variation of Log Current density with square root of applied field for Al/ZnPc–CdS/Al device at various temperatures.

**Table 1**  
Experimental and theoretical  $\beta$  for different temperature of the Al/ZnPc–CdS/Al device.

Temperature (K)	$\beta$ Experimental (mV) <sup>1/2</sup> × 10 <sup>−4</sup>	$\beta$ Theoretical (mV) <sup>1/2</sup> × 10 <sup>−4</sup>	
		Schottky (mV) <sup>1/2</sup> × 10 <sup>−4</sup>	Poole–Frenkel (mV) <sup>1/2</sup> × 10 <sup>−4</sup>
303	1.589		
343	1.326		
383	0.996	0.854	1.462
423	1.384		
463	1.442		
483	1.514		

as shown in Fig. 2. The absorption spectra of composite films with a relatively long wavelength are similar to that of  $\alpha$ - crystalline ZnPc due to the transparency of CdS ( $E_g = 2.5$  eV) in the visible region, so that the same Q band peak at 628 nm of  $\alpha$ - crystalline ZnPc is also observed in the composites. Since the 628 nm peak is ascribed to exciton coupling due to the close interaction of Pc molecules, while the peak at 740 nm is due to the close interaction of Pc molecules [20], this indicates the amount of interaction between neighbouring ZnPc molecules.

3.3. Current-voltage (I-V) analysis

Information about the conduction mechanism was obtained in a ZnPc/CdS junction from J-V characteristics at different temperatures. Log J vs log V characteristics for the ZnPc/CdS junction at different temperatures are represented in Fig. 3. It is seen that the curve exhibits a linear fit for all the films studied, indicating that thermally- generated carriers, which in turn implied the Ohmic type of conduction in these films, control the current.

Fig. 4 represents the variation of log current with the square roof of applied field. It is observed that, in the high field region, the junctions exhibit linear current field characteristics for both devices for all the temperatures. This behaviour indicates that the conduction mechanism may be of either Schottky or Poole–Frenkel type. The theoretical values of  $\beta_{PF}$ -Poole–Frenkel and  $\beta_{RS}$  R.Schottky were calculated and given in Table 1. From the evaluated values it has been found that the experimental value of  $\beta$  coincides with the theoretical value for a Poole–Frenkel conduction mechanism. Therefore the conduction mechanism may be of the Poole–Frenkel type [21].

The activation energy has been determined using the relation  $I = I_0 \exp(-\Delta E/kT)$ . The activation energy has been calculated and is given in Table 2. It is clear from the table that the activation energy decreases with increasing applied voltage.

3.4. Photoconduction

The voltage dependence of photocurrent measured in the dark and with two different illuminations of the ZnPc/CdS junctions is shown in Fig. 5. It is observed that the dark current seems to be insignificant for samples of different thickness studied. The photocurrent increases with increase in illumination intensity as well as with applied voltage. The decrease in photocurrent may be

**Table 2**  
Activation Energy as a function of applied voltage for the Al/ZnPc–CdS/Al device.

Voltage (V)	Activation Energy (eV)	
	Al/ZnPc–CdS/Al	Zero Activation Energy (eV) Al/ZnPc–CdS/Al
2	1.256	
6	0.889	1.512
8	0.543	

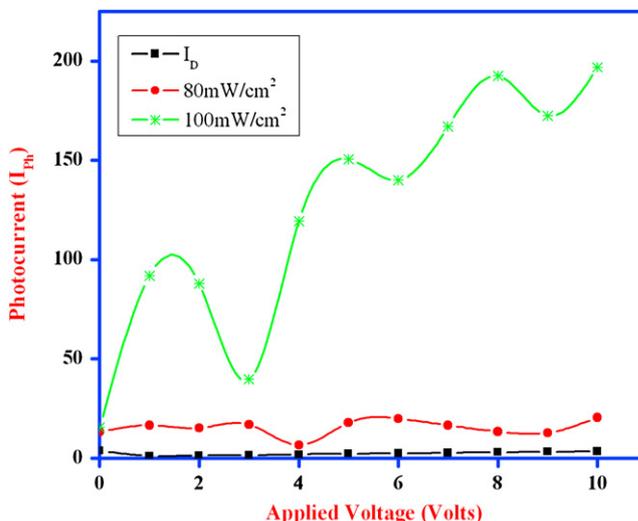


Fig. 5. variation of photocurrent with applied voltage at different illuminations for (ZnPc–CdS junction).

due to the surface texture of TiO<sub>2</sub> and CdS films in the junction with ZnPc. The observed linear dependence of photocurrent with voltage indicates that the junction is free from traps Further the junction requires post-deposition treatment to enhance the photocurrent response.

The photoconduction in the heterojunction has been studied as a function of wavelength in the range 400–700 nm. In the photoconductive spectrum (Fig. 6) the maximum of photoconductivity measured at 2volt bias condition is centred at 440 nm, which corresponds to 2.82 eV photon energy. It is interesting to note that the maximum of photoconductivity shifts towards higher wavelengths for higher applied voltages. A similar trend was observed for films coated at higher thickness studied in the present work. The maximum photoconductivity was centred around the 1.5–1.7 eV energy gap for all the films studied, which is suitable for solar cell applications. The variation of photosensitivity with applied voltage for junctions is represented in Fig. 7. The photosensitivity was found to increase with increase in applied voltage.

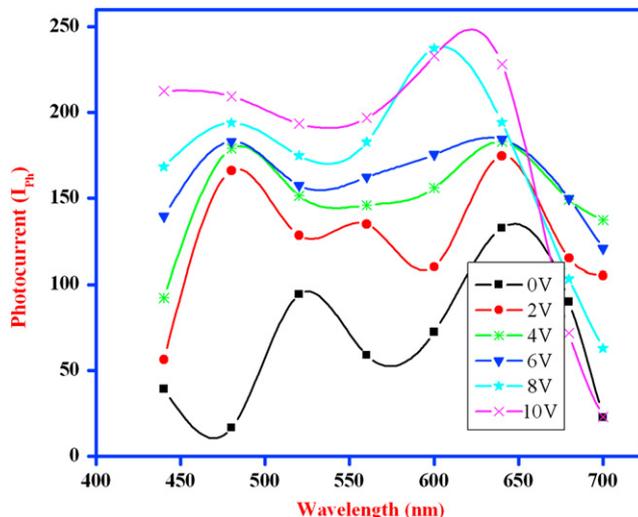


Fig. 6. variation of photocurrent with wavelength at different applied voltages for ZnPc–CdS junction.

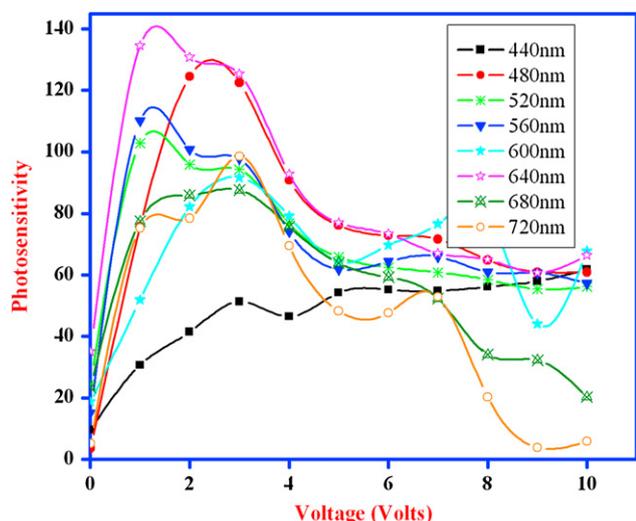


Fig. 7. Variation of photosensitivity with applied voltages for different wavelength ZnPc–CdS junction.

#### 4. Conclusion

The ZnPc/CdS are films polycrystalline in form. The electrical conduction mechanism prevailing in these junctions is of Poole–Frenkel type. The activation energy was found to have a linear dependence with the applied field. The maximum photoconductivity is centred around the 1.5–1.7 eV energy gap. Photosensitivity is found to increase with increase in applied voltage.

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