Current voltage conduction studies of lead phthalocyanine thin film

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The thin film of Lead Phthalocyanine (PbPc) on glass was prepared by Vacuum deposition method. Deposition of PbPc on pre-cleaned glass substrates under the pressure of 10^{-6} Torr was achieved by slowly varying the current. The rate of evaporation was properly controlled and maintained constant during all the evaporations. The thicknesses of the films were 150 nm, 300 nm and 450 nm on glass and 150 nm on KCl substrate. Current voltage conduction properties of Lead Phthalocyanine thin films have been studied. At the higher temperatures, the slope of I –V curves indicates that the thermally generated carrier density exceeds that of the injected charges. In the case, it is observed that the slope of log (J) vs log (V) curves is about unity for 300 K. The region is considered as ohmic. The plots of In (J/T^2) versus 1000/ T at different voltages tend to be straight lines at higher temperatures. The straight line behaviour occurs at above 320 K. However the domination of the thermionic emission behaviour is observed at higher temperatures

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1. Introduction

Metal phthalocyanines (MPc's) have received increasing attention over the last decade due to their potential applications in gas sensing devices [1]. They are organic semiconductors exhibiting high chemical and thermal stability. Semiconducting behaviour of phthalocyanine thin films is p-type at all temperature [2]. Dielectrics are basically insulator materials having a special property of storing and dissipating electrical energy when subjected to electromagnetic fields. Some semiconductors have also similar properties. Studies of these materials particularly in ac fields provide an insight of the electrical nature of the molecular or atomic species which constitute the dielectric materials [3]. An important aspect for the study of the dielectric properties of materials is to understand certain physical properties of the system, like the presence of impurities, voids, structural defects, various polarization and relaxation mechanics etc. [4].

The electrical and gas sensing properties of phthalocyanines are critically dependent on a range of material parameters, including film morphology, which in turn is determined by the preparation parameters such as deposition rate, substrate temperature and post deposition annealing[2, 5, 6]. Conduction measurements yield information which can be used to determine whether the intrinsic conduction process within the film itself can be described by the hopping model or band theory, under particular operating conditions [7]. Pc's absorb the light in different spectral region in between 500-720nm. Photovoltaic devices made from organic pigments have reached power conversion efficiency of a few percent [8,9] that is much lower than those of their inorganic combinations.

In the present work, we have characterized lead phthalocyanine (PbPc) in the form of a Schottky barrier device and investigated the charge generation mechanism. We have studied the temperature dependent of I-V characteristics of PbPc thin film sandwiched between Al and A1 electrodes i.e A1/PbPc/Al, with the aim to understand the charge generation mechanism.

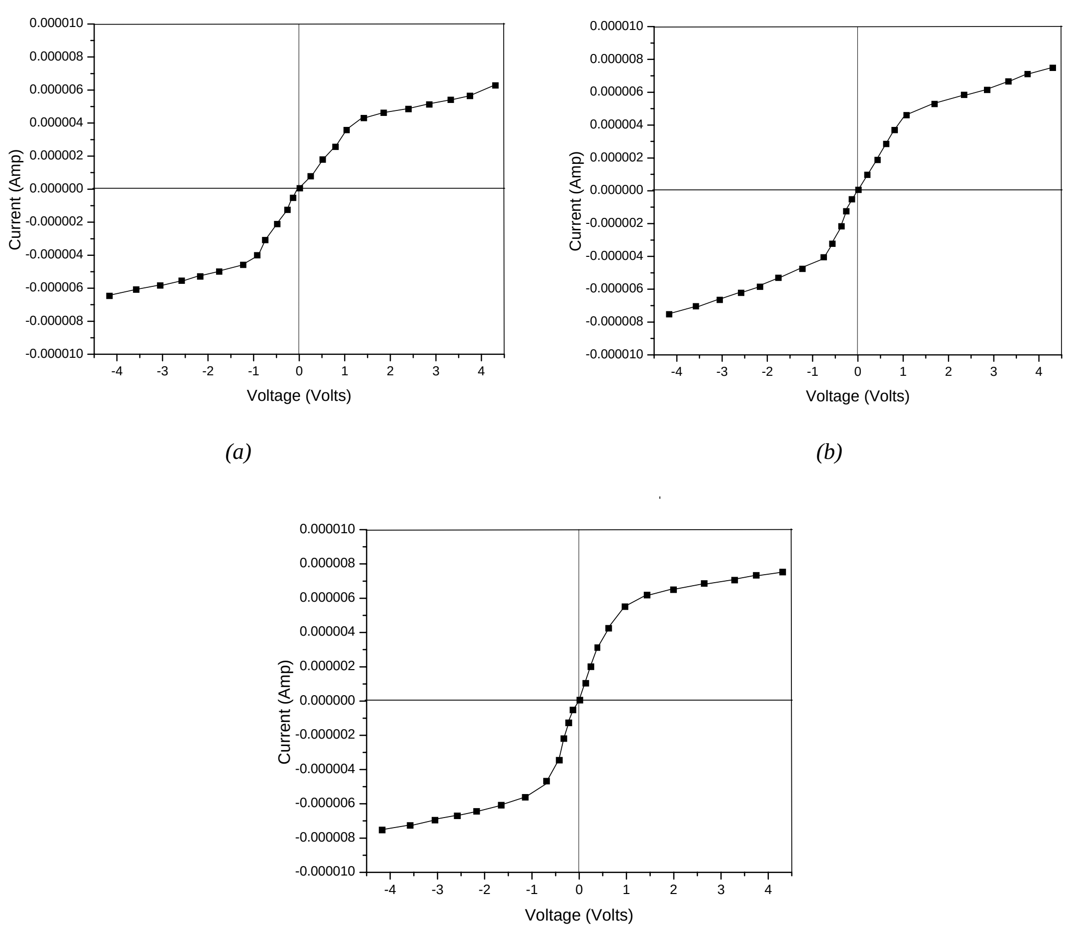
2. Experiment

The thin films of PbPc were deposited on cleaned Al coated glass substrates and KCl substrate by vaccum deposition technique. The current voltage studies on PbPc films were carried by forming Metal-Semiconductor-Metal (MSM) structures. The rate of evaporation was properly controlled and maintained constant during all the evaporations. Rotary drive was employed to maintain uniformity in film thickness. The film thicknesses were controlled to be 150 nm, 300 nm and 450nm by Quartz crystal monitor. The top electrode contact was made by evaporation of aluminum (A1) through an appropriate mask at a vacuum of 10^{-5} Torr. The resulting area of the device was about $1 cm^2$. Electrical measurements were performed using a subsidiary vacuum system and maintained at a pressure of 1.3×10^{-3} Pa. For the current voltage (I-V) measurement, Keithley electrometer with built in power supply was used.

3. Results and discussion

3.1. Effect of thickness

The current-voltage characteristic for a sandwich device of Al/PbPc/Al structure of thickness 150 nm, 300 nm and 450 nm on glass substrates are shown in Fig. 1. The applied voltage was changed from - 4.5 V to 4.5 V. In both forward and reverse bias region, the current is directly proportional to the applied voltage. The spectrum reveals that the current increases with increase the voltage. The current increase rapidly up to saturation point then increases slowly. From the figure 1 the current increases with increase the thickness of the film. As the thickness is increased, the number of injected carriers increases so that space charge accumulates limiting the current. The current density voltage characteristics of Au/PbPc/Au structure have identified an ohmic region followed by space charge limited conductivity [10].



(c)

Fig. 1. The current –voltage characteristics of PbPc Thin film on glass substrate for thickness
(a) 150 nm (b) 300 nm (c) 450 nm

3.2. Effect of substrate

The current-voltage characteristic for a sandwich device of Al/PbPc/Al structure of thickness 150 nm on glass substrates is shown in Fig. 2. The applied voltage was changed from - 4.5 V to 4.5 V. In both forward and reverse bias region, the current is directly proportional to the applied voltage.

The spectrum reveals that the current increases with increase the voltage. The current increase rapidly up to saturation point then increases slowly. It is observed from the above figures that current vary independently with substrate.

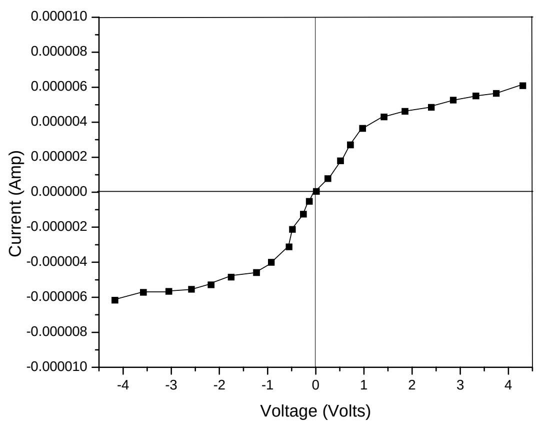


Fig. 2. The current –voltage characteristics of PbPc Thin film on KCl substrate for thickness 150 nm.

3.3. Effect of temperature

The current–voltage characteristics of Al/PbPc/A1 device recorded at different temperatures ranging from 250 to 350 K is shown in Fig. 3. As PbPc is a P type organic semiconductor, from schottky barrier and nearly ohmic contact with PbPc, respectively and thus gives rise to asymmetrical nature of J-V characteristics i.e, rectification effect. It is observed from the above figures that the current increases with increase the temperature.

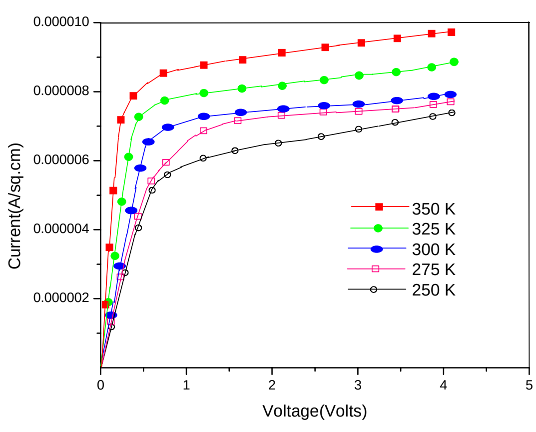


Fig. 3. The current –voltage characteristics of PbPc Thin film of thickness 450 nm at different temperatures

Fig. 4 show typical forward bias current –voltage characteristics of Al/PbPc/A1 device in log–log plot at different temperatures. This situation corresponds hole injection in the HOMO of PbPc through electrode into PbPc. It was observed in J-V characteristics of the device at low temperatures below 300 K. At low voltage, the slope of the Log (V) plots are approximately equal to unity, while at higher voltages above well defined transit voltage, the slope are approximately in between 2.0 and 2.5. These plots are typical of ohmic conduction at low voltage. It is well known that metal phthalocyanines (MPc's) are P type organic semiconductors; the condition is via holes only [11].

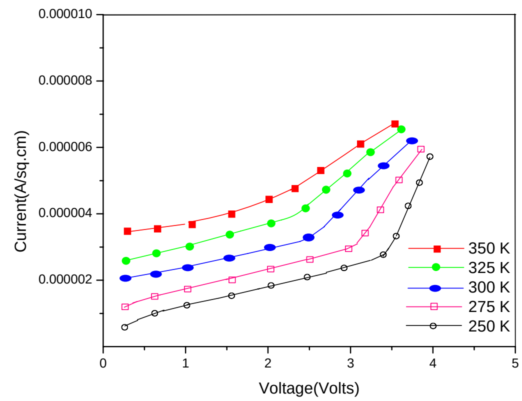


Fig. 4. The current –voltage characteristics of PbPc Thin film on glass substrate for thickness 450 nm in log-log scale

The A1 contact with organic semiconductor form relatively high barrier at low temperatures and therefore thermally generated carriers are few and the injected charge density is small so that the overall behaviour becomes ohmic. As the voltage is increased, the number of injected carriers increases so that space charge accumulates limiting the current. The numbers of thermally generated carriers increases with temperature, therefore the current increases with temperature. The super linear behaviuor seen in the Fig. 4 suggests that the injected charge carrier overcomes the transport capabilities of PbPc, hence giving rise to the accumulation of positive charge near the A1 hole injecting electrode and the bulk properties of the organic layer control the J-V characteristics. In the case, it is observed that the slope of log(J) vs log (V) curves is about unity for 300 K. The region is considered as ohmic. Above the ohmic region, the J – V characteristics may be fitted to the Richarson – schottky (RS) emission model. At higher fields, the metal work function for the thermionic emission is reduced, thus lowering the schottky barrier height.

As seen from Fig. 5, the plots of In (J/T^2) versus 1000/ T at different voltages tend to be straight lines at higher temperatures. The straight line behaviour occurs at above 320 K. However the domination of the thermionic emission behaviour is observed at higher temperatures indicates that a higher hole injection barrier exits at Al/ PbPc interface, since more thermal energy is required to overcome the potential barrier height.

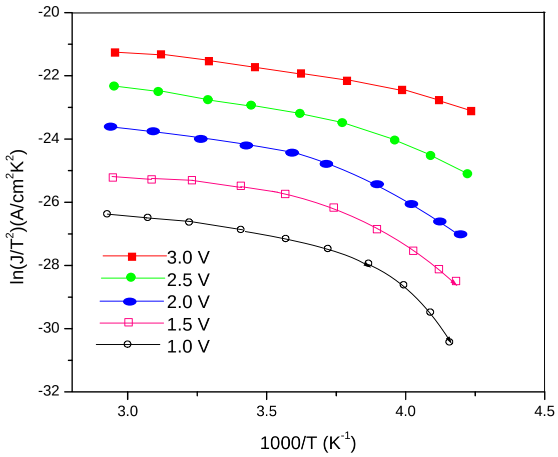


Fig. 5. The current –voltage characteristics of PbPc Thin film on glass substrate for thickness 450 nm of In(J/T^2) vs 1000/T

4. Conclusions

The current-voltage characteristic the applied voltage was changed from -4.5 V to 4.5 V in both forward and reverse bias region, the current is directly proportional to the applied voltage. The current increases with increase the thickness of the film. As the thickness is increased, the number of injected carriers increases so that space charge accumulates limiting the current. It is observed that current vary independently with substrate and current increases with increase the temperature. At low voltage, the slope of the Log (V) plots is approximately equal to unity. As the voltage is increased, the number of injected carriers increases so that space charge accumulates limiting the current. The numbers of thermally generated carriers increases with temperature, therefore the current increases with temperature. In the case, it is observed that the slope of log(J) vs log (V) curves is about unity for 300 K. The region is considered as ohmic. Above the ohmic region, the J – V characteristics may be fitted to the Richarson – schottky (RS) emission model. The straight line behaviour occurs at above 320 K. The thermionic emission behaviour is observed at higher temperatures indicates that a higher hole injection barrier exits at Al/ PbPc interface, since more thermal energy is required to overcome the potential barrier height.

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