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Electrical and photosensing performance of heterojunction device based on organic thin film structure

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ABSTRACT

In this work, the heterojunction thin films of aluminum phthalocyanine chloride on *N*,*N*′-dioctyl-3,4,9,10-perylenedicarboximide device was fabricated by using thermal evaporation technique under high vacuum ($\sim 10^{-4}$ Pa). The morphology of the device was characterized by scanning electron microscopy (SEM). The dark current density–voltage (*J*–*V*), capacitance–frequency (*C*–*f*) and conductance measurements at different temperatures in the range 300–425 K were performed to determine the electrical properties of the device. The exponent of the light intensity dependence for the short-circuit photocurrent (J_{sc}) of the device indicates the presence of continuous distribution of traps. The device showed improvement in the open circuit voltage as compared to other organic compounds. The photosensitivity of the device was calculated and found to be 3.1 at ±1 V under illumination intensity of 100 mW/cm^2. This suggested that the device shows a photodiode characteristic. The interface state density of the device was determined using the conductance technique and was found to be low which suggested that the interface states at this density range are not effective on the device characteristics which supports the efficient properties for the studied device.

1. Introduction

In recent years, the use of organic semiconductors in low-cost/disposable electronics has gained considerable interest because of their potential in large areas and light weight [1]. Interest in organic solar cells stems primarily from the promise of ease of processing. This is because, to date, many organic solar cell devices have used polymers as integral parts of their construction [2]. Moreover, organic semiconductors can conduct charges due to partial delocalization or charge hopping through the molecules that are coupled by relatively weak Van der Waals forces [3].

It is well known that organic electronics has several advantages over the inorganic technology [4]. Organic semiconductors thin films have been the focus of numerous investigations over the past few years in view of their promising technological applications in optoelectronic devices in organic photodiodes, photovoltaic (PV) devices and phototransistors [4,5]. Among them, perylene derivatives have attracted much attention. *N*,*N*′-ditridecylperylene-3,4,9,10-tetracarboxylic diimide (PTCDI) (Fig. 1a) belonging to this group of compounds is an n-type organic semiconductor with a high photosensitivity, employed in organic solar cells [6,7] and light emitting diodes [8]. Due to the relatively low cost and relatively good electronic properties, metal phthalocyanines (MPc) are the most promising materials for these organic devices. Many studies using various phthalocyanine (Pc) derivatives have been reported especially in fields of photovoltaic (PV) cells, light emitting diodes (LED), field effect transistors (FETs) and finally gas sensors (GS) [9]. Among these, aluminum phthalocyanine chloride (AlPcCl) (Fig. 1b) as phthalocyanine derivative is used in this study.

The dc electrical measurements play an important role in characterization of device parameters and have extensively been studied [9]. Alternatively, ac measurements proved to be a powerful technique for identifying and characterizing the charge transport phenomenon in various materials. However, the field of surface science has begun to play an important role in developing a more basic understanding of organic materials and their interfaces such as inorganic semiconductor/organic [10,11], metal/organic [10] or organic/organic interfaces [10]. The most important factors that control the charge injection process are the energy barrier which the charge carrier has to overcome at the interfaces are the choice of organic molecule, the structure and thickness of the organic film and the preparation method [10].

Moreover, it is very important to have knowledge about intrinsic properties, particularly the charge transport and charge injection properties in order to optimize the device performance [12]. In

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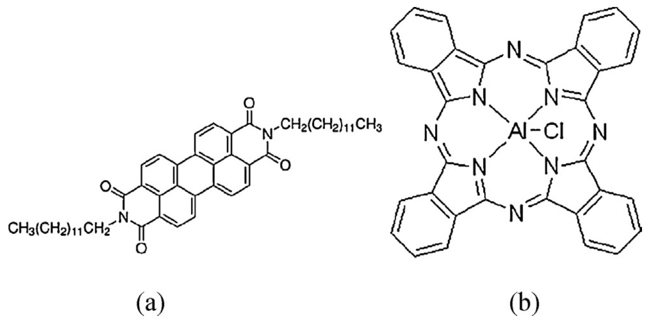

Fig. 1. Molecular structure of: (a) PTCDI and (b) AlPcCl.

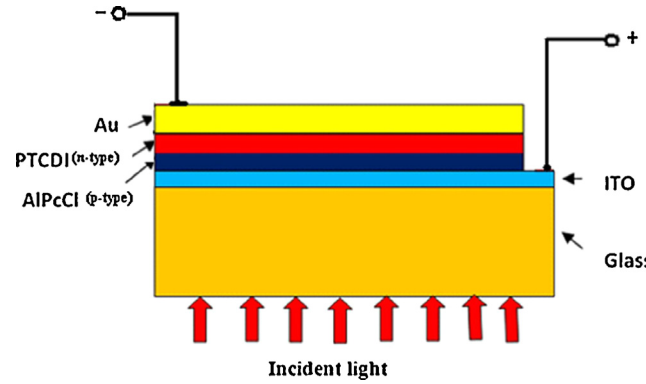

Fig. 2. Schematic diagram of ITO/AlPcCl/PTCDI/Au thin film device.

spite of this rapid progress, the conduction mechanism and interface study of ITO/AlPcCl/PTCDI/Au and device performance are still not fully understood and there remains a need for detailed studies. In this study we use PTCDI as the electron acceptor and aluminum phthalocyanine chloride (AlPcCl) as the electron donor [3] to fabricate a donor/acceptor (D/A) heterojunction (HJ) PV cell with the configuration ITO/AlPcCl/PTCDI/Au (Fig. 2). However, basic organic solar cell research and device development still have a long way to go to compete with inorganic solar cells [13]. Nevertheless, progress is being made and much research effort is being spent to better understand the operation of organic solar cells and their structure/property relationships.

The present communication deals with the design and characterization of organic p–n heterojunction thin films having configuration Au/AlPcCl/PTCDI/ITO. In this device, the structure, electrical, interface and photovoltaic properties based photocurrent generation were reported. Various electrical and photoelectrical parameters for the device have been determined and discussed in details under dark, illumination and temperature.

2. Experimental procedures

2.1. Materials

Aluminum phthalocyanine chloride (AlPcCl) and *N*,*N*′-ditridecylperylene-3,4,9,10-tetracarboxylic diimide (PTCDI) were purchased from Aldrich-Segma Co, with purity ≥98%. These organic materials are characterized as good processability, environmental stability and electroactivity. The chemical structure of both PTCDI and AlPcCl are shown in Fig. 1(a) and (b), respectively. Glass squares (2.5 cm × 2.5 cm) coated with ITO were used as substrates. The ITO-coated glass was purchased from Delta Technologies with the sheet resistance of 8–12 Ω/square and a layer thickness of 150–200 nm.

2.2. Processes and fabrication of the Au/AlPcCl/PTCDI/ITO device

The ITO-coated glass substrates were cleaned successively with distilled water, acetone, and ethanol and finally dried with an air gun. Thin films of PTCDI and AlPcCl were prepared by thermal evaporation technique using a high vacuum coating unit (Edward, E-306A). The films were evaporated from quartz crucible source charged by PTCDI for the first evaporation followed by AlPcCl as second one and heated by a tungsten coil in a vacuum of 10^{-4} Pa during deposition. The films were deposited onto pre-cleaned glass coated ITO–coated glass substrates maintained at room temperature (about 300 K) and the deposition rate was controlled by using a quartz crystal thickness monitor (Edwards, FTM4). The thicknesses of the prepared films of PTCDI and AlPcCl are approximately 420 nm and 150 nm, respectively.

Finally, a mask was used on the prepared films to define device suitable for electrical measurements. Gold was used as ohmic contact with AlPcCl using a high vacuum coating unit (Edwards, E-306 A), kept at room temperature (300 K) during the deposition using a tungsten filament under vacuum better than 2×10^{-4} Pa. The thickness of Au is approximately 100 nm. The schematic diagram of the prepared device is shown in Fig. 2.

2.3. Measurements and characterization tools

Scanning electron microscope (SEM) images were taken using a JEOL JSM-6360A Electron Microscope operating at 25 kV for examining the surface topography of the device.

Dark current–voltage, capacitance–frequency and conductance–frequency characteristics in the temperature range 300–425 K were made in a closed furnace under the environmental conditions. The current flowing through the device was determined using a stabilized power supply and high impedance Keithley 617A Electrometer. The temperature was measured directly by Type-K thermocouple connected to the temperature controller (Eurotherm model No. 390-200) to avoid the sudden drop in the heater temperature.

Photovoltaic characteristics were carried out by using tungsten halogen lamp containing iodine vapor and tungsten filament. The intensity of light was measured with a solar power meter (TM-206, Taiwan). The intensity of light was varied by changing the distance between the device and the halogen lamp.

The fill factor and power conversion efficiency of the cell is calculated from photovoltaic power characteristics. The short circuit current (I_{sc}) and open circuit voltage (V_{oc}) are measured as a function of light intensity.

The measurements of the frequency dependence of the capacitance and conductance of ITO/AlPcCl/PTCDI/Au were measured using programmable automatic LCR Bridge (model Hioki 3532 Hitester). The measurements were carried out on the parallel circuit mode. The measurements were performed in the temperature range 300–425 K and frequency range 100 Hz–100 kHz.

3. Results and discussions

3.1. Surface and interface morphology characteristics

It is well known that the surface properties of the films influence their optical and electrical properties which are important factors in applications to optoelectronic devices. Thus, it is very important to investigate the surface morphology of the films.

Fig. 3 shows the surface morphology of ITO/AlPcCl/PTCDI/Au films using scanning electron microscope. As observed, the surface is homogeneous, free of cracks, uniform adherence of the film to