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Electrical properties of Π-conjugated Fe-TPP molecular solar cell device

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Abstract

A heterojunction device of Au/Fe-TPP/n-Si/Al was assembled by thermally evaporated deposition. The dark current density–voltage characteristics of device were investigated. Results showed a rectification behavior. Measurements of thermo electric power confirm that Fe-TPP thin film behaves as p-type semiconductors. Electronic parameters such as barrier height, diode ideality factor, series resistance, shunt resistance were found to be 0.83 eV, 1.5, $7 \times 10^5\ \Omega$ and $2 \times 10^{10}\ \Omega$, respectively. The Au/Fe-TPP/n-Si/Al device indicates a photovoltaic behavior with an open circuit voltage V_{oc} of 0.52 V, short circuit current I_{sc} of 2.22×10^{-6} A, fill factor FF of 0.49 and conversion efficiency 1.13% under white light illumination power 50 W/m^2.

Keywords: Physical vapor deposition; Organic semiconductor; Solar cell

1. Introduction

The development of organic-based devices applicable to microelectronics and macroelectronics light-energy conversion has considerable attention over the past view years [1–7]. We have reported that a better energy conversion yield of solar to electrical energy in thin film cells made from porphyrin and its corresponding metal complexes. Thin films of metalloporphyrins are generally prepared by chemical or physical methods, such as vapors deposition, spin coating and Langmuir–Blodgett (LB) deposition techniques [8–10].

Tetraphenylporphyrin (TPP) is a free-base porphyrin, has an extended π-conjugation system leading to a wide range of wavelengths for light absorption. TPP ring is highly flexible and a number of structural changes involving different central metal ions and peripheral substituents can be introduced without compromising its excellent chemical and thermal stability. In addition, the combination of organic materials, with metal may give interesting optoelectronic effects. In this context the covalent attachment of monolayer to reactive metal could be beneficial. The basic structure of Fe-TPP is centro-symmetrical with two independent pyrrole and phenyl groups as shown in Fig. 1.

In the photovoltaic cells consisting of porphyrin, a maximum photocurrent is obtained when the thickness of porphyrin is small. In spite of its small absorbance, Yamashita et al. estimated a small value of the Schottky barrier and the exciton diffusion length in an Al/Zn-Tpp/Au cell [11]. Of such organic molecules, we are especially interested in metal-tetraphenylporphyrin because: (i) they are well on porphyrins molecular solids, a new class of functional materials applicable to solar cells, display devices, sensors known as important players in photosynthetic processes and in biological systems (ii) the electronic properties of the molecules

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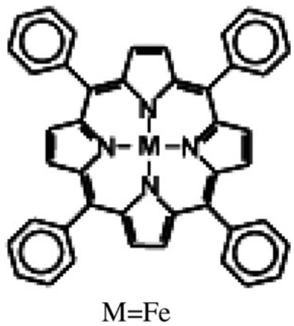

Fig. 1. Molecular structure for metal-tetraphenylporphyrin.

in both their ground and excited states have been well investigated both experimentally and theoretically [12–14], (iii) several porphyrins, including Fe-TPP, have been found to exhibit photocurrent synergism at certain wavelengths, i.e. the total photocurrent resulting from simultaneous illumination by visible (VIS) and near infrared [15–17].

The purpose of this work is to study the electrical transport properties of Au/Fe-TPP/p-Si/Al heterojunction device by recording the variation of static *I–V* characteristics with temperature, as well as the understanding of the fabrication and the photovoltaic properties of heterojunction device.

2. Experimental details

TPP powder used in the present study was obtained from Kodak, UK. A number of Au/Fe-TPP/n-Si/Al heterojunction devices were constructed by using thermal evaporation of Fe-TPP films on etched single crystal of n-type silicon wafer. A thick pure aluminum film was firstly deposited on the rear side of silicon substrate and acts as ohmic contact. At front side of n-type silicon substrate, a thin layer of Fe-TPP compound was deposited followed by depositing a thick film of pure gold in the form of masked network. Rate of deposition and thin film thickness were controlled during deposition by film thickness monitor (model TM-350 Maxtek Inc.). The deposition rate and thickness of the film are 0.25 nm/s and 100 nm, respectively.

The *I–V* characteristics were measured in air at dark condition for different temperatures ranging from 298 to 373 K using stabilized power supply and high impedance Keithley 617 electrometer. The photocurrent–voltage characteristics were carried out by using halogen lamp. The incident light falls normally through the gold window on the organic film side of photoactive area 1×10^{-6} m^2 with an intensity of 50 W/m^2. Device current and voltage output measurements were recorded by Keithley electrometer.

3. Results and discussion

The dark *I–V* characteristics at different temperatures ranged from 298 to 373 K for a Au/Fe-TPP/n-Si/Al device of thickness (100 nm) are depicted in Fig. 2. The results show that curves have the same *I–V* rectification behavior. For the same applied voltage, current increases with increasing temperature, indicating a negative temperature coefficient for the resistance.

Fig. 3 shows semi-log current–voltage curve for the device at 298 K, room temperature. The ideality factor of the diode was determined from the slop of the linear portion of forward current region and was found to be 1.5, which suggests that the characteristic of the diode cannot be analyzed by thermionic theory. It is evaluated that the diode behavior is affected by parasitic resistances such as series resistance and shunt resistance. R_s resistance is related to the interface between two semiconductors, while R_{sh} resistance is associated with semiconductors–electrode interface properties. The series and shunt resistances (R_s) and (R_{sh}), respectively, were determined [18], as

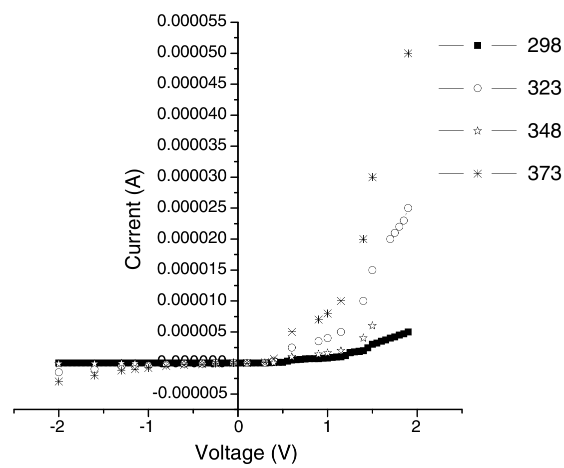

Fig. 2. Dark *I–V* characteristics at different temperatures (298–373 K) for Au/Fe-TPP/n-Si/Al device.

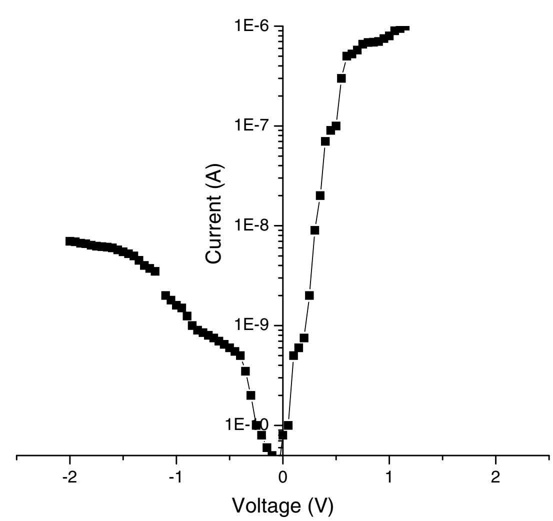

Fig. 3. Semi-log current–voltage characteristic for Au/Fe-TPP/n-Si/Al device at 298 K, room temperature.