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A proposed organic Schottky barrier photodetector for application in the visible region

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ABSTRACT

The fabrication and characterization of an organic photodetector (OPD) in the form of ITO coated glass/polycarbazole (PCz)/Al Schottky contact is reported. The device has been fabricated in our laboratory for the first time using the polymer synthesized by us. The device has been subsequently characterized in respect of electrical and optical properties in order to explore its potential for possible use as a detector in the visible region at 650 nm. It is observed that the detector exhibits a reasonably high value of peak detectivity ($\sim 6 \times 10^6$ cm $Hz^{1/2}$ W^{-1}) near zero bias voltage at $V = 0.2$ V.

1. Introduction

Organic molecular devices such as organic light-emitting device (OLED) [1–3], organic thin-film transistor (OTFT) [4] and organic photodetector (OPD) [5–8] have drawn considerable attention of the researchers working in the field of optoelectronics. There exists a tremendous potential of these devices for use in electrical-to-optical (E/O) and optical-to-electrical (O/E) conversion applications such as in flat panel displays electrical paper, flexible image sensors, transparent photo-reflector devices [9] and in the application of optical interconnections in data transmission systems [10]. The high frequency response and detectivity of OPD need to be investigated in order to explore the potential of optically flexible organic devices in data transmission and reception system. The photo-responses of OPDs utilizing various types of metal-phthalocyanine thin films [11] have been reported by Kaneko et al. [11]. The performance of polymer based photodetectors has matured significantly in the recent years in terms of high efficiency, wide dynamic range and high speed, so as to match the required custom specifications for practical applications. Because of the advantages of easy solution processing, low production cost of large area detectors or detector arrays, this technology has matured fast for a variety of commercial applications including biomedical and medical sensing and analysis, controlling automation, full color picture recognition, security applications, environmental monitoring, UV and visible sensing and in various fields of information technology including optical communication.

The metal/organic semiconductor junction has emerged as an alternative to the metal/inorganic semiconductor junctions. This has opened the new possibility of replacing conventional inorganic devices by organic ones. The fabrication and characterization of Schottky barrier diode using organic semiconductor and their derivatives have been carried out by various researchers in recent years. Conducting polymers like polyacetylene [12], polyaniline and their derivatives [13,14], polypyrrole [15,16] and polythiophene [17] have been investigated for Schottky diode characteristics.

In the recent past polycarbazole (PCz) has been studied extensively for application in various semiconductor devices [18]. The absorption spectrum of the detector reveals that the material can be used to fabricate visible photodetector operating in the 650 nm region. A possible application of this detector could be in the receiver unit of a free space optical communication system based on AlGaInP light-emitting diode (LED) or injection laser diode (ILD) operating at 650 nm [19] and references therein. The low-cost polycarbazole based photodetectors supported by a large bandwidth tariff and license free space optical system would enable one to develop a cost-effective high speed optical link. In this

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article, we report the fabrication and characterization of an organic photodetector (OPD) in the form of ITO/polycarbazole (PCz)/Al Schottky contact.

2. Experimental

2.1. Preparation of sample

The polycarbazole film was electrochemically polymerized under ambient condition by using Electrochemical Work Station from CH Inc., USA by potentiostatic (1.3 V) technique in three electrode system on ITO glass substrate (with surface resistance of 12 Ω/cm^2) as working electrode, Pt as counter electrode and Ag/AgCl as reference electrode. The reaction solution consists of 60 mM carbazole, 0.1 M tetrabutyl ammonium perchlorate (TBAP) and dichloromethane. After polymerization of the polymeric film on the ITO coated glass electrode it was washed by dichloromethane to remove unreacted monomer. Subsequently the sample was dried and preserved for the various characterizations. The polycarbazole (PCz), a semiconducting polymer was characterized for optical and electrical properties. UV–vis study was done by using the spectrophotometer from Perkin Elmer, Germany (Model No. -Lamda 25). The details are not the subject of discussion in the current article.

2.2. Device fabrication and measurement

The schematic structure of fabricated device ITO/polycarbazole (PCz)/Al Schottky junction is shown in Fig. 1. The metal Al was deposited with area of 16 mm^2 using mask on different samples of ITO/polycarbazole (PCz) by using vacuum coating system from HIND HIVAC (Model No. -12A4D). The thickness of polymer was of the order of 400 nm as estimated from the AFM measurement. The electrical leads from the Al and ITO contacts were obtained by bonding wires on the contacts using silver paste (Fig. 1). The current–voltage (*I–V*) characteristics were measured using HP Semiconductor Parameter Analyzer (SPA) from Hewlett–Packard, USA make, Model No. -4145B, at room temperature (27 °C) in air for the applied voltage ranging −6.0 V to +4.0 V. For optical characterization the device was tested under illumination of red light (λ = 650 nm, optical power = 10 mW/cm^2) through the rear end using an ILD source driven by the LD drive unit from Benchmark (Model No. FOSM-D600).

3. Result and discussion

3.1. UV–Vis spectra and estimation of bandgap

The measured absorbance spectra of the polycarbazole (PCz) is shown in Fig. 2a. The bandgap of the polymer is evaluated from the absorbance spectra of polymer coated on optically transparent ITO/glass substrate. The substrate absorbance was corrected by introducing an uncoated ITO/glass of the same size as the reference. The optical bandgap of the polymer was estimated by fundamental relation given by [20]

$$\alpha h\upsilon = B(h\upsilon - E_g)^n, \quad (1)$$

where α is the absorption coefficient, $h\upsilon$ is the energy of absorbance light, $n = \frac{1}{2}$ for direct allowed transition and B is proportionality constant. Energy gap (E_g) was obtained by plotting $(\alpha h\upsilon)^2$ versus $h\upsilon$ and extrapolating the linear portion of $(\alpha h\upsilon)^2$ intersect the $h\upsilon$ axis, as shown in Fig. 2b. The bandgap of polycarbazole (PCz) was estimated to be 2.88 eV by using the above method.

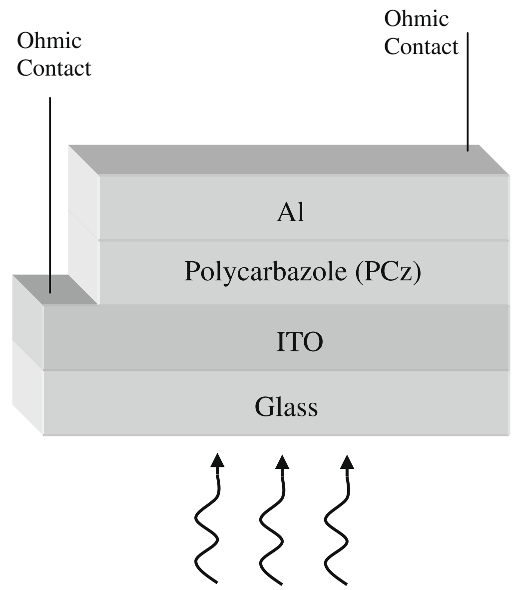

Fig. 1. Device configuration showing the direction of incident light.

3.2. Junction properties and optical characteristics

The measured *I–V* characteristics of the device reveals that ITO/polycarbazole (PCz)/Al forms a Schottky barrier diode. The current density versus applied bias (*J–V*) characteristics of the devices as extracted from the measured *I–V* data is shown in inset of Fig. 3. The *J–V* characteristics of the device under reverse biased condition in dark and illuminated conditions are shown in Fig. 3 and variation of photocurrent with applied bias is shown in Fig. 4. The measured value of photocurrent was of the order of 800 μA at an applied bias of −6 V for an incident optical power of 10 mW/cm^2 at 650 nm.

3.3. Extraction of electrical and optical parameters

The metal–semiconductor rectifying contacts can be described by thermionic emission–diffusion theory [21]. The current is assumed to be controlled by transfer of charge carriers across the interface of polycarbazole (PCz)/Al. The ideality factor and reverse saturation current density have been calculated from the slope of and the intercept of ln (*J*) versus *V* plot governed by the equation

$$\ln(J) = \frac{qV}{\eta kT} + \ln(J_0) \quad (2)$$

where J is the current density, J_0 is the reverse saturation current density in absence of external bias, q is electronic charge, V is the applied voltage, T is temperature in Kelvin, η is diode ideality factor and k is the Boltzmann constant. J_0 is related to the Schottky barrier height, ϕ_B as

$$J_0 = A^* T^2 \exp\left(\frac{-q\phi_B}{kT}\right), \quad (3)$$

where A^* is the effective Richardson constant. The barrier height ϕ_B was evaluated from J_0 at room temperature. The extracted electrical parameters of the device are listed in Table 1. The deviation of ideality factor from unity is due to barrier inhomogeneity at the surface of polymer film. The reverse saturation current exhibited by the diode is relatively high as compared to its inorganic semicon-