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Photoconducting and electrical properties of Al/TIPS-pentacene/*p*-Si/Al hybrid diode for optical sensor applications

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ABSTRACT

Schottky diode based on 6,13 bis (triisopropylsilylethynyle) (TIPS) pentacene was fabricated using spin coating. The junction properties and photoconductivity of the Al/TIPS-pentacene/*p*-Si/Al diode were studied. The ideality factor and barrier height of the diode were calculated using *I*–*V* characteristics and obtained to be 1.97 and 0.65 eV, respectively. The photocurrent of the diode depends on the illumination intensity and increases with increasing photo-illumination intensity. The transient photocurrent results indicate that photocurrent under illumination is higher than the dark current and increases with increase in light intensity. The capacitance of the diode decreases with increasing frequency due to a continuous distribution of the interface states. The linear dependence of the double log plot of photocurrent and light intensity suggests that the Al/TIPS-pentacene/*p*-Si/Al diode could be used as an optical sensor.

1. Introduction

Organic semiconductors have attracted considerable research interest for realization of thin films electronics. Among them, solution processable small molecules have several advantages such as easy processing, low fabrication cost, easy to get high purity form, and potentially tunable properties compared to synthetic polymeric semiconductors [1]. These solution processable organic semiconductors are potential candidate for low cost, large area electronic applications [2]. Pentacene is an organic crystalline semiconductor with limited solubility in common organic solvents, which restricts its application as soluble organic semiconductor [3]. The solubility of the pentacene could be modified by functionalization [4]. Among functionalized pentacene, 6,13 bis (triisopropylsilylethynyle) (TIPS) pentacene is a prospective candidate for thin film device applications [3]. The TIPS-pentacene is a *p*-type organic semiconductor which is soluble in common organic solvents [5]. Additionally, it shows outstanding 2D π-stacking, high mobility (>1 $cm^2\,V^{-1}\,s^{-1}$), and good absorption in visible region of solar spectrum [5].

The effect of annealing on the mobility of field effect transistors (FETs) based on TIPS-pentacene has been reported [6]. The annealing was observed to suppress both the development of the cracks and increase of the off-current with time, which improves the mobility of the device. This functionalized pentacene has been used for fabrication of solar cell [7]. The solar cell based on TIPS-pentacene and C_{60} showed a solar cell efficiency of 0.52%. Vacuum-processed TIPS-pentacene solar cells have been reported with a power conversion efficiency of 0.42% produced by a double layer structure [8]. Lee et al. [9] have improved the performance of organic thin film transistors (OTFTs) with TIPS-pentacene by inkjet printing. The OTFT on plastic substrate showed an on/off current ratio of $\sim 10^7$, a threshold voltage of −2.0 V, and field effect mobility of 0.24 $cm^2\,V^{-1}\,s^{-1}$ in the saturation region. The influence of thickness of the TIPS-pentacene on OTFTs was studied [10]. It was reported that increasing the thickness decreases the channel mobility for both *n*- and *p*-channel OTFTs. The phototransistor based on TIPS-pentacene as an active layer of light sensitive material was fabricated [11]. Tokumoto et al. [12] have studied the photoresponse of the conductivity of TIPS-pentacene single crystal. It was observed that the electrical conductivity of the single crystal was very sensitive to ambient light changes. The transient photoconducting behavior of TIPS-pentacene has been studied [13–15]. The transient photoconductivity shows fast (<400 fs) photogeneration of mobile charge carriers.

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The focus of present research is to investigate the effect of illumination on the current–voltage (I–V) characteristics of Al/TIPS-pentacene/p-Si/Al Schottky diode for optical sensing applications. The detail direct current (DC) and alternating current (AC) measurements were performed to understand the junction properties.

2. Experimental details

High purity TIPS-pentacene was purchased from Sigma–Aldrich and used without further purification and its chemical structure is given in Fig. 1a. Firstly, the native oxide layer on silicon substrate was removed by HF and then rinsed in deionised water using an ultrasonic bath for 10–15 min. Finally, the silicon wafer was chemically cleaned according to method based on successive baths of methanol and acetone. Ohmic contact was made by depositing aluminum on the back of Si substrate using a Vaksis thermal evaporation system. The ohmic contact was annealed at 570 °C for 3 min to reduce contact resistance. TIPS-pentacene was dissolved in chlorobenzene and it was coated on cleaned p-type Si substrate using a spin coater at 500 rpm. After the coating process, the film was baked at 100 °C for 30 min. The thickness of the film was measured by Atomic Force Microscope (AFM) and was found to be ~100 nm. After the coating of TIPS-pentacene onto silicon the front surface, the top contact of diode was prepared by evaporating of Al. The diode contact was found to be 3.14×10^{-2} cm^2. The I–V characteristics of the Al/TIPS-pentacene/p-Si/Al diode were performed with KEITHLEY 4200 semiconductor characterization system. Photoconductance measurements were performed using a 200 W halogen lamp. The light intensity of the lamp was controlled by change of the current across the lamp and the intensity of light was measured using a solar power meter (TM-206).

3. Results and discussion

3.1. DC current–voltage characteristics of the Al/TIPS-pentacene/p-Si/Al diode

Energy-band diagram of the TIPS-pentacene/p-Si diode is shown in Fig. 1b. Fig. 1c shows the I–V characteristics of the Al/TIPS-pentacene/p-Si/Al. As seen in Fig. 1c, the I–V characteristics show rectification behavior. The rectification ratio at 2 V and 5 V was estimated to be 9.0×10^2 and 6.0×10^3, respectively. The I–V characteristics of such type of rectifying contact can be analyzed by the thermionic emission theory [16]

$$I = I_o \exp\left(\frac{q(V - IR_S)}{nkT}\right)\left[1 - \exp\left(-\frac{q(V - IR_S)}{kT}\right)\right] \quad (1)$$

where V is the applied voltage, q is the electronic charge, n is the ideality factor, k is the Boltzmann constant, T is the temperature,

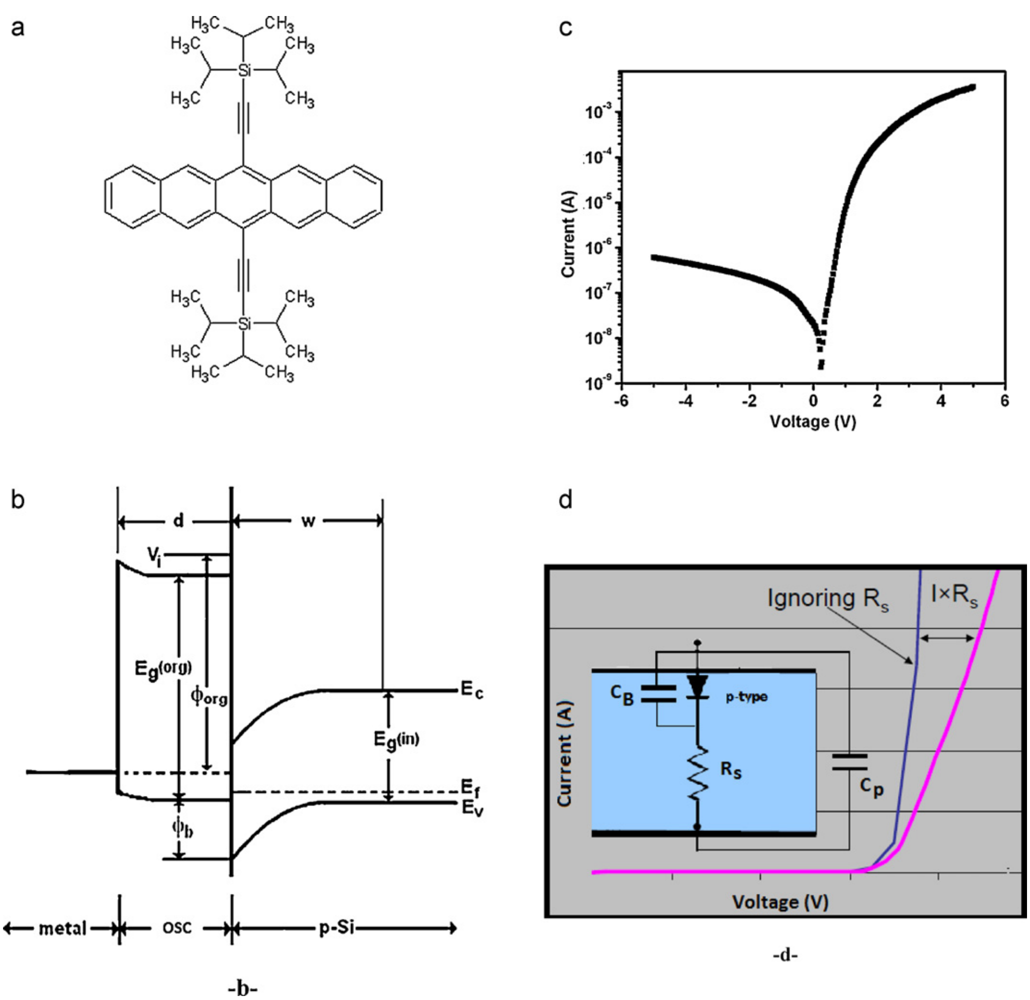

Fig. 1. (a) The chemical structure of TIPS-pentacene, (b) energy-band diagram of the p-Si/TIPS-pentacene diode, OSC is the organic semiconductor, E_f is the Fermi level, d is the thickness of organic layer interfacial layer, ϕ_b is the barrier height, ϕ_{org} is the work function of the organic material, V_i is the potential drops across the interfacial layer, E_g(org) is the band gap of the organic material, E_g(in) is the band gap of inorganic semiconductor, w is the width of the depletion region. (c) I–V characteristics of the Al/TIPS-pentacene/p-Si/Al diode, (d) equivalent circuit of the diode.