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Electrical and photoelectrical characterization of an organic–inorganic heterojunction based on quinoline yellow dye

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ABSTRACT

An organic–inorganic contact was fabricated by forming a thin film of quinoline yellow dye (QY) on a p-Si wafer and evaporating Al metal on the film. The current–voltage (*I–V*) and capacitance–voltage (*C–V*) measurements of Al/QY/p-Si heterostructure were applied in dark and room temperature to calculate the characteristic parameters of diode like ideality factor, barrier height and series resistance. Ideality factor and barrier height values were found as 1.23 and 0.87 eV from *I–V* data, respectively. The series resistance value of the device was determined as 1.8 kΩ by using modified Norde function. The *C–V* measurements were carried out at different frequencies and it was seen that capacitance value decreased with increasing frequency. Interface state density distribution was calculated by means of *I–V* measurement. In addition the optical absorption of thin QY film on glass was measured and optical band gap of the film was found as 2.73 eV. Furthermore, *I–V* measurements of Al/QY/p-Si/Al were taken under illumination between 40 and 100 mW/cm^2. It was observed that reverse bias current of the device increased with light intensity. Thus, the heterojunction had a strong response to the light and it can be suitable for electrical and optoelectronic applications like a photodiode.

1. Introduction

Organic materials have been attractive in resent studies for the fabrication of electronic and optoelectronic devices due to the possible capability of an alternative to inorganic counterparts [1,2]. This interest has mainly arisen from their inexpensive and simple preparation methods in the fabrication of devices compared with them [2–4]. Namely, many studies have been focused on the electrical and optoelectrical properties of organic/inorganic devices including photodiodes, photovoltaic cells and Schottky diodes [1–5]. In addition, the modification of charge transport mechanism and band gap can be possible due to presence of dipole layer in organic molecules [5,6]. Among them, organic dyes have been widely used in the fabrication of organic/inorganic heterojunction owing to their low cost, easy of synthesis, structural flexibility and environmental friendly [6–9]. Furthermore, organic materials have been used as interfacial layer for metal-inorganic semiconductor (MS) contacts to modify electrical parameters such as an ideality factor (n) and a barrier height (ϕ_b) of them [8–13]. Many studies have reported that the organic thin layer on the inorganic semiconductor substrate could influence the interface states, modifies the ϕ_b of the MS contact, and converts into metal–insulator–semiconductor (MIS) contact [13,14]. For instance, Tombak

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et al. [14] fabricated Al/Coumarin 30/p-Si heterojunction, and reported that the ϕ_b of the Al/Coumarine 30/p-Si device was 0.09 eV larger than that of conventional Al/p-Si contact. They also reported that the device had a strong response to the light compared with the conventional Al/p-Si contact.

The fabrication and characterization of electrical and photoelectrical devices based on organic dyes has risen because of their chemical and thermal stabilities and strong photovoltaic properties [8].

Quinoline yellow (QY), a dye with the empirical formula $C_{18}H_{11}NO_2$, and IUPAC name sodium 2-(1,3-dioxoindan-2-yl)quinolone disulfonate was used in the fabrication of a heterojunction because of its richness in π-electrons. Fig. 1 shows the molecular structure of QY. The aim of this study is to construct Al/QY/p-Si heterojunction, investigate the influence of the organic interfacial layer on the electrical characteristics of device, and examine some electrical parameters such as barrier height and series resistance of the heterostructure. For this purpose, an Al/QY/p-Si structure has been fabricated forming an interfacial layer of QY on a p-Si substrate by a spin coating technique. The electrical parameters of the heterojunction have been determined using its current–voltage (*I*–*V*) and capacitance–voltage (*C*–*V*) measurements at room temperature.

2. Experimental procedure

An Al/QY/p-Si heterojunction was fabricated by using a p-Si with (100) orientation and 1–10 Ω cm resistivity and quinoline yellow (QY) (Sigma-Aldrich). The wafer was first degreased in boiling in trichloroethylene, and ultrasonically cleaned in acetone and isopropanol. In order to get rid of the native oxide layer on the surface, it was etched by H_2O/HF (10:1) solution. Preceding each step, the wafer was rinsed with deionized water with resistivity 18.2 MΩ. It was dried under the N_2 ambient, and inserted immediately into the vacuum system. The ohmic back contact was formed by evaporation of Al metal on the unpolished side of the cleaned wafer, followed by annealing treatment at 570 °C for 3 min in N_2 atmosphere. After ohmic back contact formation, the native oxide in front surface of the wafer was removed in H_2O/HF (10:1) solution, it was washed with deionized water, dried under the N_2 atmosphere. A thin QY layer was coated on front of p-Si for 1 min at 1000 rpm in QY solution of 1×10^{-2} mol L^{-1} by using an SCS G3P-8 spin coater. After that, Al metal was evaporated through a shadow mask in vacuum system at $\sim10^{-6}$ Torr.

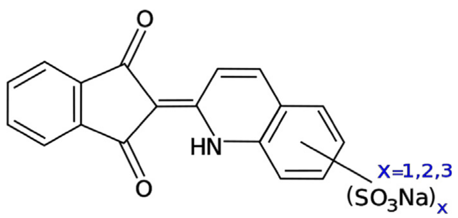

Fig. 1. Molecular structure of Quinoline Yellow dye.

The diameter of circular contacts 1.5 mm. Fig. 2 shows the schematic view of the Al/QY/p-Si structure and cross section SEM micrograph of QY/p-Si junction. The cross-section view of the QY film was obtained using FEI Quanta 250 FEG. It was seen that the thickness of QY thin film was measured as 73 nm. The *I*–*V* measurements were performed at room temperature in dark by Keithley sourcemeter in dark and under a Newport 96000 solar simulator with AM 1.5 global filter for various illuminations. The *C*–*V* measurements at different frequencies were carried out by means of HP Agilent 4294A impedance analyzer. Optical transmission measurements were applied using a Shimadzu UV-3600 spectrophotometer in the range 300–900 nm.

3. Results and discussions

Fig. 3 shows the variation in absorbance as a function of the wavelength for QY thin film on glass. The absorption edge of a single crystal corresponding to the bandgap energy is sharp. However, the absorption of QY thin film shows relatively slow decline with the incident photon energy. This slow decrease may be arising from optical scattering because of defects and grain boundaries. In addition to these, it could also be ascribed to the intrinsic absorption in the regions of thin QY film with highly concentrated defect states. Optical spectrum of the QY molecule give an absorption band in the region between $\sim$347 and 444 nm, and the maximum absorption is located at λ_{max}=389.64 nm in Fig. 3.

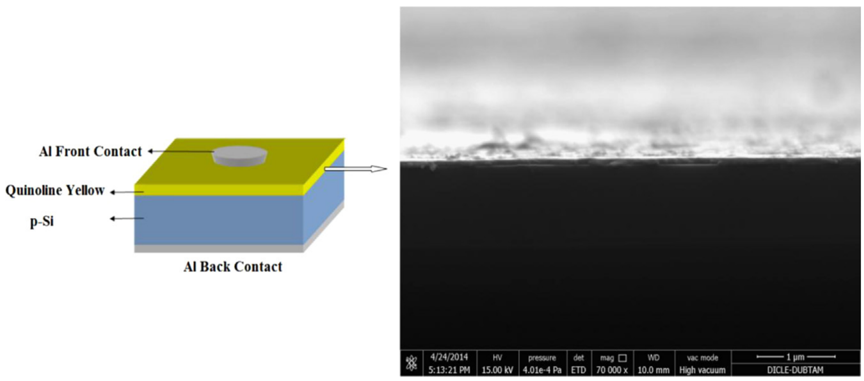

Fig. 2. The schematic view of the Al/QY/p-Si structure and cross section SEM micrograph of QY/p-Si junction.