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Electrical and photovoltaic properties of Gaussian distributed inhomogeneous barrier based on tris(8-hydroxyquinoline) indium/p-si interface

E.M. El-Menyawy *

Solid State Electronics Laboratory, Solid State Physics Department, Physics Division, National Research Center, Dokki, Cairo 12311 Egypt

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ABSTRACT

Hybrid organic/inorganic heterojunction solar cells are fabricated for the first time by depositing tris(8-hydroxyquinoline) indium (Inq_3) films onto p-type silicon (p-Si) single crystals via a thermal evaporation technique. The structural characterization of the films was achieved by X-ray diffraction and scanning electron microscopy. The electrical and photovoltaic properties of the Au/Inq_3/p-Si/Al heterojunction were investigated in terms of the current–voltage (*I*–*V*) measurements. The dark *I*–*V* characteristics of the device are measured at different temperatures ranging from 300 to 400 K in which the operating conduction mechanisms and the basic diode parameters such as ideality factor, barrier height and series resistance are determined. At forward bias voltages $V \leq 0.4$ V, the *I*–*V* characteristics have been analyzed on the basis of the thermionic emission theory. With increasing temperature, the ideality factor is found to decrease, while the barrier height is found to increase. This behavior has been explained in terms of the barrier inhomogeneities at the Inq_3/p-Si interface. At forward bias voltages $0.4 < V \leq 2.5$ V, the conduction mechanism is found to be due to the space charge limited current characterized by exponential distribution of traps. Under illumination, the heterojunction showed photovoltaic behavior from which the photovoltaic parameters are evaluated.

1. Introduction

Organic semiconductors have raised an upsurge of interest in the field of electronics and optoelectronics due to their promising structural features as well as intriguing optical and electrical properties. They are attractive as active components used in various devices due to several distinguishing features such as processability, cost-effectiveness and ease of fabrication. They have been used to fabricate a lot of condensed matter physics devices such as field effect transistors [1,2], light emitting diodes [3,4], solar cells [5,6], photodiodes [7,8] and spintronic devices [9].

Hybrid organic/inorganic heterojunctions based on organic films deposited on inorganic single crystals or inorganic films are considered as promising structures that favorably combine the properties of the organic materials to that of the inorganic one. Consequently, this field appears to be very creative, since it provides the opportunity to invent an almost unlimited set of new devices with a large spectrum of novel interface properties. The interface to the substrate not only mediates the organic film growth and its electronic properties, but also determines the injection efficiency of the contact [10]. Looking back at the previous studies, substantial research works have been made on the preparation and characterization of organic/inorganic heterojunctions [11–16] in which many attempts have been made to realize a modification and control of the barrier height by using a semiconducting organic layer. Campbell

* Tel.: +2 01006021326; fax: +2 0233709310.
E-mail address: emad_elmenyawy@yahoo.com

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et al. [15] have reported that the effective Schottky barrier could be either increased or decreased by using an organic thin layer on an inorganic semiconductor. El-Menyawy [16] has pointed out that the organic interlayer can produce substantial shift in the work function of the metal and in the electron affinity of the semiconductor, which in turn results in increment or decrement in barrier. Organic/inorganic semiconductor heterojunctions showed photovoltaic behavior in which the electrical conversion efficiency is found to have reasonable values [17–19].

Huang et al. [13] have used Alq_3 films to improve the barrier height of conventional Al/p-Si Schottky junction. Inq_3 film with a thickness of 150 nm was found to have refractive index higher than that of the Alq_3 film having the same thickness, indicating that Inq_3 films have higher packing density which is one of the useful parameters of devices stability [20]. In this work, Inq_3 films are used to fabricate a heterojunction in the configuration type of Au/Inq_3/p-Si/Al. A comprehensive study is carried out to understand charge carrier transport by the analysis of temperature dependence of the current–voltage characteristics. The photovoltaic properties of the device are also investigated.

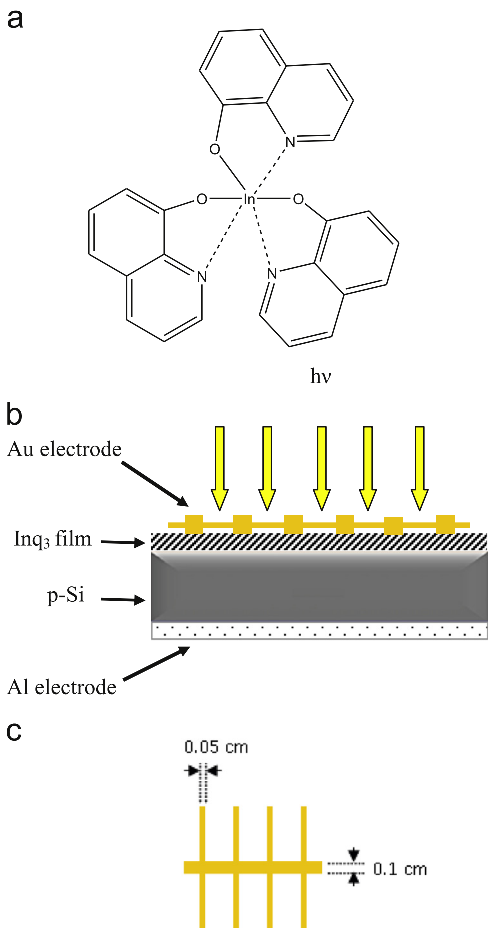
2. Experimental

2.1. Synthesis of organic material

Inq_3 powder was synthesized according to the literature [20]. In a typical synthesis, 8-hydroxyquinoline (0.5 g) was dissolved in a mixture of 10 ml double distilled water and 2.5 ml of glacial acetic acid. It was vigorously stirred until an orange transparent solution was obtained. Indium nitrate hydrate (0.3 g) was dissolved in 20 ml of double distilled water, and stirred until a clear solution was obtained. The two solutions were mixed together and the resulting suspension was stirred for 5 min. Then, ammonium hydroxide was added to the mixture solutions, drop by drop with continuous stirring to get maximum yield. A yellow–green precipitate was filtered out. The obtained precipitate was washed 15 times with double distilled water and dried at 80 °C under argon gas flow. Scheme 1(a) shows the molecular structure of Inq_3 compound.

2.2. Device manufacture and measurements

Organic/inorganic heterojunction was fabricated using one side polished p-Si wafer with < 100 > orientation, 400 µm thickness and 1 Ω cm resistivity. The wafer was chemically treated by boiling in the solution $NH_4OH+H_2O_2+6H_2O$ for 10 min and then in hot solution (60 °C) of $HCl+H_2O_2+6H_2O$ for another 10 min. To remove the native oxide layer formed on Si wafer, the wafer was cleaned in HF:H_2O (1:10) solution for one minute. Finally, the wafer was rinsed in de-ionized water. The wafer was inserted in a vacuum evaporation system in which the ohmic contact was fabricated by depositing Al film (100 nm) on the unpolished side of the wafer. Then, the wafer was followed by a heat treatment at 580 °C for five minutes in argon environment. The wafer was inserted again in a vacuum evaporation system for deposition of Inq_3 film (120 nm) on the polished side of the wafer. The upper electrode was subsequently prepared by depositing Au film (100 nm) through a mesh-shaped metallic mask on the organic film. Scheme 1(b, c) shows a schematic diagram of the fabricated heterojunction and the shape of Au electrode.



Scheme 1. (a) The molecular structure of Inq_3 compound, (b) schematic diagram of Au/Inq_3/p-Si/Al heterojunction and (c) the shape of Au electrode.

Inq_3, Al and Au films were thermally deposited by using a high vacuum coating unit (Edwards Co. England, model E306 A). Before starting the evaporation process, the pressure inside the chamber was pumped down to 5×10^{-4} Pa. Inq_3 powder was evaporated by using a quartz crucible that was subjected to induction heating by a molybdenum heater. The rate of deposition and film thickness were controlled during the evaporation by using a quartz crystal thickness monitor (model, TM-350 Maxtek. Inc.).

The structural characteristics of the powder and films-coated glass substrates were investigated by using a Philips PW 1700 X-ray diffractometer with utilized monochromatic CuKα radiation. The morphology of the Inq_3 films deposited onto p-Si was investigated by using a scanning electron microscope (Quanta FEI 250 Field Emission Gun).

The current–voltage (*I–V*) measurements in dark (at different temperatures (300–400 K)) and under illumination conditions were achieved by using a Keithley 2635A source-meter. The electrical contacts were equipped with copper wires mechanically applied to the two metal electrodes using