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Light harvesting efficiency of hybrid nano-composite for photovoltaic application

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ABSTRACT

A composite of polyaniline (PANI) and cadmium sulfide nanoparticles (CdS NPs) has been synthesized electrochemically, which has further been used for the fabrication of photovoltaic cell. The composite (PCdS) has been characterized for its optical and electrochemical behavior. The efficacy of this composite for being used in photovoltaic cell has been studied by measuring its photo-electrochemical and photovoltaic response. The composite based device showed open circuit voltage (V_{oc}) of 0.332 V and short circuit current (I_{sc}) of 284 μA under an illumination of the 590 nm yellow incandescent light bulb having an intensity of 5.3 mW cm^{-2}. The efficiency and fill factor for our proposed solar cell were 0.48% and 27% respectively. Photo-electrochemical response showed excellent photon conversion behavior with respect to light intensity, thus confirming flow of electrons through external load during illumination of the cell.

1. Introduction

Integration of conducting polymers and organic semiconductors has attracted wide interest for the development of opto-electronic devices [1–3]. Such materials are being used not only for light harvesting but are also used for facile transfer of photo-generated charge carriers through conjugated network of conducting polymers [4,5]. If used as single entity, narrow band gap semiconductor nanostructures provide low photocurrent as fast charge recombination limits the photocurrent generation [6]. Such limitations can be overcomed by using hybrid photovoltaic cells which commonly utilizes two different materials that differ in electron donating and accepting properties. Charges are then created by photo-induced electron transfer between the two components. This photo-induced electron transfer between donor and acceptor boosts the photo-generation of free charge carriers compared to the individual, pure materials, in which the formation of bound electron–hole pairs or excitons is generally favored. Polyaniline–cadmium sulfide (PANI–CdS) system has been one of the best studied semiconducting polyaniline–metal sulfide system due to the commercial potential of both the components [7,8]. Ease of synthesis, tunable electrical and optical properties dependent on various degrees of oxidation/reduction and proton doping of the polymer, make polyaniline as one of the most studied conducting polymers [4]. And quantum dots (QDs) are now a day preferred as light harvesters and excited-state electron donors or acceptors, both from a fundamental standpoint and for applications in solar energy conversion and charge-transfer-based sensing. Multiexciton generation and the extraction of non-thermalized charge carriers have the potential to increase the power conversion efficiency of QD-based solar cells.

Current organic electronic devices are mainly fabricated by spin-coating or drop-casting followed by thermal or solvent annealing. The morphologies of these devices are uncontrollable and irreproducible and this affects their electrical performances as well as the prospect for mass production. Moreover, the methods reported for the formation/synthesis of hybrid material are complicated and multistep [9–11]. In present work, a simple approach has been used for device fabrication where hybrid nano-composite was electrochemically synthesized in one step and then sandwiched the material between two conducting electrodes.

2. Experimental

2.1. Materials and methods

Aniline ($C_6H_5NH_2$) was procured from Merck. Cadmium chloride (monohydrate) ($CdCl_2 \cdot H_2O$) and sulfuric acid (98%) were procured

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from LOBA chem. Sodium sulfide flakes (fused) ($Na_2S \cdot H_2O$) were from S.D. Fine Chem Ltd. ITO (8–12 Ω) was obtained from Vico Scientific Sales Pvt.

XRD pattern of polyaniline and its composite was recorded on Bruker D8 diffractometer (Bruker, Germany). SEM images were captured on scanning electron microscope (JEOL, JSM-6610LV, Japan), equipped with EDS (Oxford, INCAx-act, 51-ADD0013). FTIR spectra were recorded on a 670-IR system (Varian, USA), for PANI and its composite. Polymerization, electrochemical characterization and photo-electrochemical response studies of polyaniline and PCdS were carried out on electrochemical analyzer (Model 1100, and 440 CHI instruments). Absorption studies were performed on Hitachi UV–vis spectrophotometer (Model U 3900H). *I*/*V* curves were recorded both in dark (photoactive area was covered with aluminum foil) and in simulated illumination for which an illumination of the 590 nm yellow incandescent light bulb with an intensity=5.3 mW/cm^2 was used. The number of photons striking the ITO surface were 1.5×10^{16} photons/s. The measurement system consisted of a Keithley 2400 SMU source meter controlled by a LABVIEW® measurement program. The measurement started at a voltage of −5.0 mV and usually ended at +5.0 mV. The bulb was placed around 15 cm distance from the cell under observation.

2.2. Synthesis of polyaniline (PANI) and its composite with CdS (PCdS)

Polyaniline and it's composite with CdS has been synthesized electrochemically using three electrode cell design where ITO was used as working, platinum plate as counter and Ag/AgCl as reference electrode. The protocol has been opted from literature [12] and is used with modifications. The electro-polymerization solution consisted of H_2SO_4 (as dopant), 200 μL aniline and 8.0 mM $CdCl_2$. Aniline was polymerized at a constant current of 0.6 mA for 100 s. This was followed with the addition of Na_2S (9 mM) as sulfur source for the synthesis of CdS NPs in between polymerization of polyaniline. Again the polymerization was run at constant current of 1.2 mA for 200 s. On completion of experiment, films were thoroughly washed with copious amount of de-ionized water. Scheme 1 presents pictorial representation of PANI and PCdS synthesis.

Cadmium sulfide (CdS) nanoparticles were also electrochemically synthesized using H_2SO_4 as sulfur source as well as supporting electrolyte, and $CdCl_2$ as cadmium salt and the potential was kept constant at −0.5 V. The polymerization potential has been opted from literature [13]. The electrode after CdS deposition was washed with de-ionized water and used for photovoltaic study.

2.3. Solar cell configuration

The type of solar cell configuration employed in the present study is simple sandwiching the absorber material (CdS) and polymer (PANI) in between two conducting electrodes; ITO and aluminum (Al) electrode; to complete the circuit and to connect the cell, two contacts were made on both electrodes so that short circuit current (I_{sc}) and open circuit voltage (V_{oc}) can be recorded. The schematic of the cell used in the study is given in Fig. 1.

3. Results and discussions

3.1. Synthesis of composite

For photovoltaic applications, efficient charge separation is mandatory, for which the use of two different materials differing in their electron donating and accepting properties is advised. The photo-induced electron transfer between donor and acceptor boosts the photo-generation of free charge carriers as compared to an individual pure material, in which the formation of bound electron–hole pairs, or excitons is generally favored. Thus, for the purpose, we have used composite of PANI with CdS NPs, as nanoparticles provide large surface area for efficient charge transfer.

Generally polymerization process can be carried out in three ways: (i) chemical synthesis and chemical doping, (ii) chemical synthesis and electrochemical doping, and (iii) electrochemical synthesis and doping, depending upon the nature of monomer. Chemical method is most commonly used for polymerization, however method suffers from being tedious to time taking as in

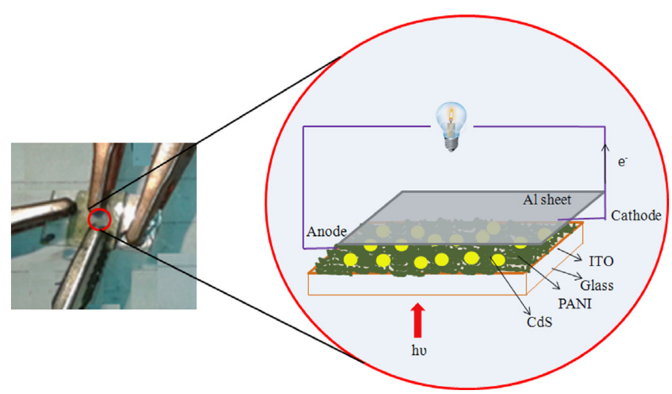
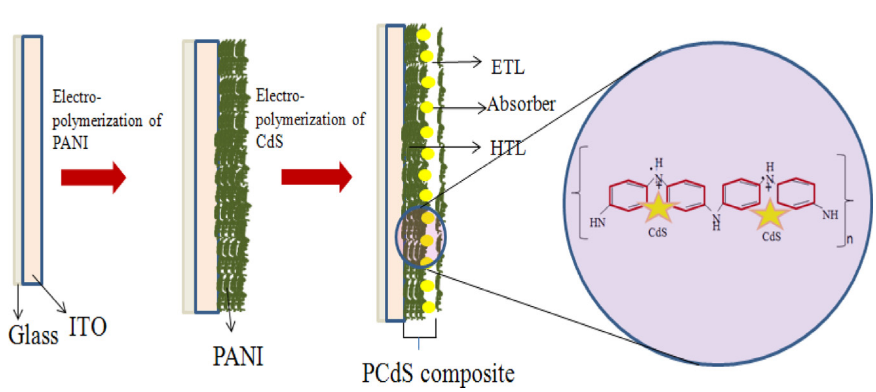


Fig. 1. Solar cell configuration.



Scheme 1. Synthesis of polyaniline–CdS (PCdS) nano-composite, (ETL-electron transfer layer, HTL-hole transfer layer).