Optical Materials 80 (2018) 138–142

Contents lists available at ScienceDirect

Optical Materials

journal homepage: www.elsevier.com/locate/optmat

Improved performance of organic solar cells with solution processed hole transport layer

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ARTICLE INFO

Keywords:
Cobalt oxide
Hole transport layer
Solution processed
Organic solar cell devices

ABSTRACT

This work is based on Cobalt Oxide as solution processed, inexpensive and effective hole transport layer (HTL) for efficient organic photovoltaic applications (OPVs). In Organic solar cell (OSC) devices ITO coated glass substrate used as a transparent anode electrode for light incident, HTL material Co_3O_4 dissolve in DMF solvent deposited on anode electrode, after that active layer material (donor/acceptor) deposited on to HTL and finally Al were deposited by thermal evaporation used as cathode electrode. These devices were fabricated with PCDTBT well known low band gap donor material in OSCs and blended with $PC_{71}BM$ as an acceptor material using simplest device structure ITO/Co_3O_4/active layer/Al at ambient conditions. The power conversion efficiencies (PCEs) based on Co_3O_4 and PEDOT:PSS have been achieved to up to 3.21% and 1.47% with PCDTBT respectively. In this study we reported that the devices fabricated with Co_3O_4 showed better performance as compare to the devices fabricated with well known and most studied solution processed HTL material PEDOT:PSS under identical environmental conditions. The surface morphology of the HTL film was characterized by (AFM). Lastly, we have provided Co_3O_4 as an efficient hole transport material HTL for solution processed organic photovoltaic applications.

1. Introduction

A need of an electrical energy is increasing worldwide very rapidly for all kind of electronic applications. In fact, in the era of industrialization and globalization demand has increased exponentially. So, we required renewable energy sources in this series solar energy is a most important source of renewable energy. Organic solar cells (OSCs) have drawn great scientific consideration over the last few years, due to its potential to produce flexible, light weight, low cost solar cells using organic materials. However, the power conversion efficiency achieved for these systems is low for extensive implementation of the technology. In different photovoltaic technologies, solution processed bulk-heterojunction (BHJ) concept gained significant attention due to the use of inexpensive materials, high mechanical flexibility and compatibility with low temperature roll-to-roll manufacturing techniques [1]. Bulk heterojunction (BHJ) solar cells consist of many components such as anode electrode, interface layers (IFLs), active layer material (donor/acceptor) and cathode electrode. Each component has its own importance. Interface layers play a very important role in collection and extraction of the charge carriers, these layers are inserted between electrodes (anode/cathode) and active layer interface [2]. To moderate the charge carrier recombination at the electrodes, various interface layer (IFL) materials have been developed to allow desired charge carriers to pass through and block undesired carriers. Therefore, charge carrier recombination at electrodes can be substantially suppressed and PCEs can be significantly improved of the cells. Hole transport layer (HTLs) and electron transport layer (ETLs) are part of Interface layers.

In the field of organic solar cells (OSCs) a number of materials were used as HTLs, out of them solution processable materials are most prefer choice. PEDOT:PSS is a most successfully used solution processed HTL due to its high conductivity, transparency and suitable work function [3]. But due to hygroscopic, acidic and protonation nature of PSS influences the device stability [4] and degradation due to these limitations hole transport layer PEDOT:PSS replaced by the several inorganic materials and organic materials. In inorganic materials, Transition metal oxides were also used, these materials have air stability and high optical transparency but due to insolubility in most of the common solvents, these materials are usually deposited by vacuum deposition technique, which is incompatible with the concept of low-cost OSCs fabrication. To overcome the problem of vacuum deposition of inorganic materials the preference comes to solution processable approach. Several solution processable methods were reported by using

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https://doi.org/10.1016/j.optmat.2018.04.042
Received 11 January 2018; Received in revised form 7 April 2018; Accepted 22 April 2018
0925-3467/

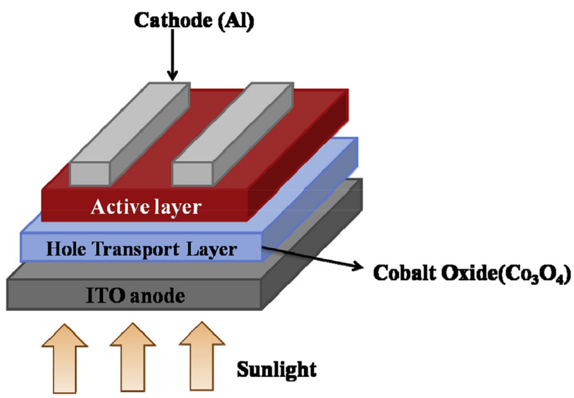

Fig. 1. Schematic illustration of OSCs device structure with Co_3O_4 as a Hole Transport Layer.

different colloidal particles [5], nanoparticles [6], inorganic precursors [7] etc. In recent years, solution processable metal oxides, such as MoO_3 [8], CuO_x [9], VO_x [10], ReO_x [11], SnO_x [12], NiO_x [13] and WO_3 [14] etc have been used for stable Organic photovoltaic's (OPVs). In recent time, copper based materials used as other efficient and robust inorganic hole transport materials for OSCs. CuI [15] and CuSCN [16] are highly transparent and efficient HTL but these materials required selective solvents to dissolve which is very expensive and bad smelly because of these reasons we required inexpensive, easily soluble in common solvents and stable hole transport material for low cost and efficient OSCs fabrication.

In this sequence here we have reported, Co_3O_4 as a solution processed, low cost, robust and easily available or soluble (in common solvent) HTL layer which used in OSCs, gives the better efficiency as compare to well known and conventionally used solution processed HTL material.

2. Experimental

2.1. Materials

Chemicals such as donor material Poly [N-9″-hepta-decanyl-2,7-carbazole-alt-5,5- (4′,7′-di-2-thienyl-2′,1′,3′-benzothiadiazole) (PCDTBT), and acceptor material Phenyl-C_{71}-butyric acid methyl ester ($PC_{71}BM$) were purchased from Ossila Ltd, England. Cobalt Oxide (Co_3O_4) and different solvents used in this study such as 1,2-dichlorobenzene (DCB), Chlorobenzene (CB), Diiodooctone (DIO) were obtained from Sigma Aldrich and used without further purification.

2.2. Solution preparation of hole transport layer/active layer and device fabrication process

In active layer solution, electron donor material PCDTBT and electron acceptor material $PC_{71}BM$ were weighed (1:4 w/w) and dissolved in mixed solvents of chlorobenzene (CB) and 1,2-dichlorobenzene (DCB). The active layer solution was stirred for 12 h at room temperature. The optimized concentration of Co_3O_4 (7 mg/ml) was weighed out and dissolved in DMF solvent. These devices were fabricated on ITO coated glass substrates as anode electrode. ITO coated substrates were patterned using laser ablation technique. The patterned ITO coated substrates were cleaned in sequential with acetone, methanol and isopropanol, followed by drying. After that the Co_3O_4 HTL solution in DMF was spin coated on cleaned ITO substrates at 3000 rpm for 60 s, annealed at 100 °C and then dry for 1 h at room temperature. The other solution processed HTL material, PEDOT:PSS were deposited by spin coating with spin speed of 2000 rpm and annealed. The active layer solution was spin-coated onto the HTL layer with spin speed of 1000 rpm for 90 s and annealed at 70 °C on a hot plate. Finally, the devices were completed by thermally deposited Al as cathode electrode at base pressure of 10^{-6} Torr.

2.3. Device and thin film characterizations

The absorption and transmission of Co_3O_4 thin film was measured by using UV-1800 Shimadzu spectrophotometer and the surface morphology of Co_3O_4 film in DMF solvent on ITO substrates was recorded by using atomic force microscopy (AFM) NT-MDT Solver Pro. The current density–voltage (J–V) characteristics of fabricated devices were measured using a computer controlled Keithley 2400 source meter under dark and illumination conditions.

3. Results and discussions

3.1. Optical studies

Absorption spectrum of solution processed Co_3O_4 films was recorded to study the absorption across the range of solar spectrum. Co_3O_4 shows the absorption in the UV-region around 350 nm, clearly

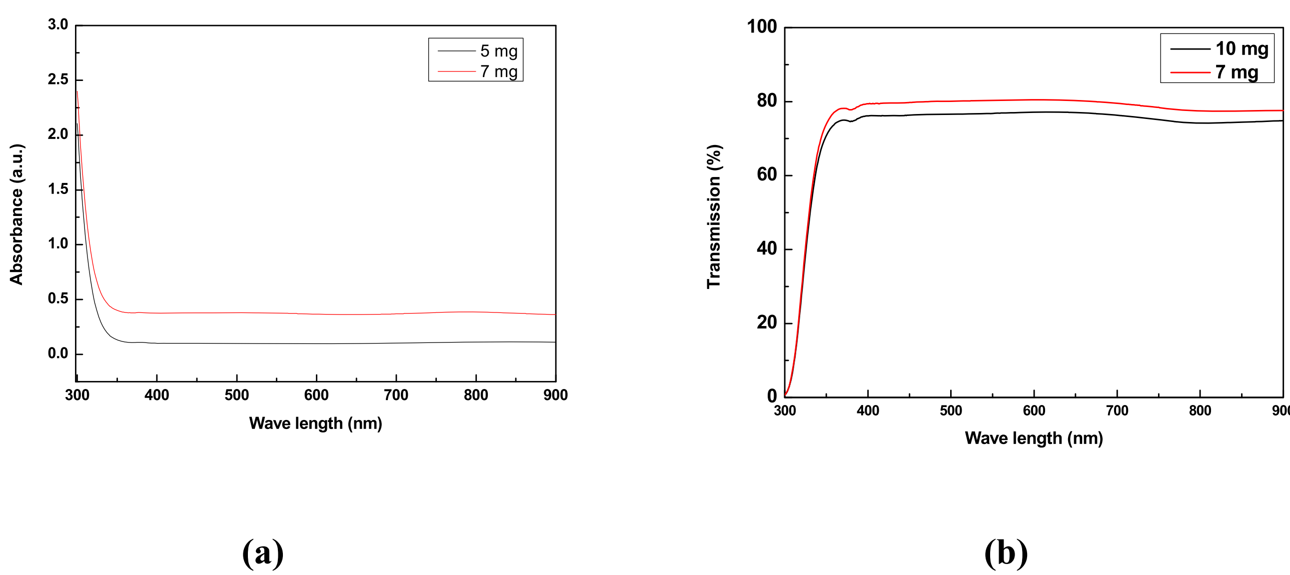

Fig. 2. (a) UV-vis-NIR and (b) Transmission spectra of Co_3O_4.