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Glass/ITO/In(O,S)/CuIn(S,Se)$_2$ solar cell with conductive polymer window layer

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Abstract

Hybrid solar cells based on the combination of conductive polymer poly(3,4-ethylenedioxythiophene) (PEDOT) doped with polystyrenesulfonate (PSS) and inorganic semiconductor CuIn(S,Se)$_2$ (CISSe) were investigated. The CuInSe$_2$ (CISe) absorber layers were electrodeposited on ITO covered glasses from aqueous solutions with various ratios of elements. The ITO/In(O,S)/CISSe photovoltaic (PV) junctions were prepared by the sulfurization of ITO/CISe precursors at 450 °C in the H_2S atmosphere.

The PEDOT–PSS layer of p-type is considered an alternative to the traditional window top layer on the CISSe absorber layer in the cell structure. The polymer deposition was performed by help of the spin-casting technique. PV properties of the prepared ITO/In(O,S)/CISSe and ITO/In(O,S)/CISSe/PEDOT–PSS structures were studied, with emphasis on the role of conductive polymer layer in the cell structure.

Keywords: Solar cell; CuInSe2; Conductive polymer; PEDOT; Hybrid structure

1. Introduction

Following the current general trend in research and development of low-cost PV elements, the hybrid organic–inorganic thin-film photovolotaic (PV) junctions

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between electrically conductive polymers (ECP) and polycrystalline inorganic semiconductors were intensively studied during the last decades [1–7]. For example, Schottky barrier type PV junctions were formed between the electrodeposited CISe and heavily doped poly(3-methylthiophene) prepared by electropolymerization [2]. Also, Schottky barriers were observed in CdS/poly(3-methylthiophene) and CdSe/poly(3-methylthiophene) junctions. The value of energy conversion efficiency of 1.3%, uncorrected for light losses, was obtained for this CdSe/poly(3-methylthiophene) junction [5]. The multilayer p–i–n structures consisting of $CuInS_2$ (CIS) and ECP (polypyrrole, PEDOT) thin films were prepared and investigated for PV applications by the authors [4,6].

Inorganic nanocrystalline chalcogenides, such as CISe, CISSe have attracted attention as a promising material for high efficiency, lightweight, radiation-resistant solar cells [8,9]. Low-cost methods, such as electrochemical deposition, chemical spray deposition and chemical bath deposition are very beneficial for non-vacuum large-area thin film production. In this study, the direct electrodeposition technique was applied to prepare CISe thin films on glass/ITO substrates. Electrodeposition provides a technique of growing CISe thin-films of variable thickness and stoichiometry [10].

The sulfurization of the CISe absorber layer provides an additional technique to increase the energy conversion efficiency of the solar cells based on CISe [11,12]. At the same time, the sulfurization of the surface of ITO to indium sulfide can be used for the formation of alternative cadmium free buffer layer between the obtained CISSe and ITO layers [13]. This sulfurization method was applied to form the In(O, S) buffer layer in the prepared glass/ITO/CISe structures. Also, a new approach to prepare a CISSe/ECP-based solar cell with organic window layers of PEDOT–PSS was studied.

PEDOT is a well-known conductive polymer. The wide range of associated electrical, electrochemical and optical properties, coupled with good stability, makes this polymer potentially attractive for applications as an active material of PV and others devices. PEDOT–PSS suspension in H_2O is an appropriate initial material for producing very stable, optically transparent, well spin-coated conductive polymer films [4].

2. Experimental

The thin film solar cell studied in this work has the following layer structure: ITO (250 nm) coated glass/In(O,S) (50 nm) buffer layer/CISSe (200 nm) absorber layer/PEDOT–PSS (50 nm) window layer/Au grid (Fig. 1). The obtained In(O,S)/CISSe PV junctions were investigated as front wall structures (through the semitransparent layer of PEDOT–PSS/Au grid) and as back wall structures (through the glass/ITO substrate).

2.1. Electrodeposition of CISe precursor

The CISe precursor films were prepared in a conventional three-electrode electrochemical cell equipped with Ag/3 M AgCl—reference electrode and