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Microwave assisted synthesis of zinc stannate nanocubes for dye sensitized solar cell application

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ABSTRACT

The ternary complex oxide Zn_2SnO_4 (ZS) has become more essential because of its photonic energy conversion, tremendous stability and higher electron mobility compared to the binary counterparts. The ZS nanocubes were prepared by simple microwave assisted route. The cubic spinel structured ZS was confirmed by X-ray diffraction (XRD) and micro-Raman techniques. Scanning electron micrograph revealed the formation of nanocubes with size of ~90 nm. The Dye Sensitized Solar Cells (DSSCs) were fabricated using the synthesized ZS as photoanode and low cost organic dyes such as Rose Bengal (RB), Eosin Yellow (EY) and Fluorescein sodium salt (FY) as sensitizers to study their light conversion efficiencies. The DSSCs exhibited power conversion efficiency (PCE) of 0.64%, 0.05% and 0.02% for RB, EY and FY sensitized films, respectively.

1. Introduction

The replacement of fossil fuels with renewable energy to sustain the life on Earth is one of the biggest challenges in recent days. The renewable energy resources are solar energy, wind energy, hydro power etc. Among these, solar energy transpires possible solution to defy this problem since

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sun is the most abundant and cheap energy resource. This anxiety leads to the development of solar cells for utilizing the solar energy [1,2].

Different types of solar cells are used to utilize the solar energy such as silicon solar cells (p–n junction), organic based excitonic solar cells (OESCs) and dye sensitized solar cells (DSSCs). The DSSC is one of the most promising candidates for developing the solar energy resource due to its low cost and high efficiency. Generally, a DSSC consists of two sandwiched electrodes (photoanode and counter electrode) with an electrolyte solution between them. The nanostructures of binary semiconducting oxides, such as TiO_2, ZnO, Nb_2O_5, In_2O_3 and SnO_2 are widely used in the field of DSSCs, sensors and batteries etc. The metal oxide TiO_2 is mostly used as photoanode due to its multiple advantages [3–7]. However, the new materials with suitable band positions have been introduced to replace TiO_2 and professionally used for DSSCs. The ternary oxide materials such as $SrTiO_3$, Zn_2SnO_4 have better properties than the binary oxides because the band gap energy, work function and electrical conductivity can be readily tuned by varying their relative component ratios [8,9].

The ternary complex ZS is a semiconductor (E_g = 3.6 eV) and an excellent multifunctional material with high electron mobility and high electrical conductivity. The ZS is simply called as zinc tin oxide and it exists in two phases i.e. zinc stannate ($ZnSnO_3$) and zinc ortho-stannate (Zn_2SnO_4). $ZnSnO_3$ is a metastable form which exists in the temperature range of 300–500 °C and above 600 °C it can be transformed to stable Zn_2SnO_4 (ZS). $ZnSnO_3$ has face-centered cubic perovskite structure, whereas ZS has cubic spinel structure [10–13]. ZS has attracted enormous interest due to their unique optical and electrical properties as well as their potential applications such as photocatalysis, transparent conducting oxides, lithium ion batteries, sensors and DSSCs. Also, the precursor materials which are used for the preparation of ZS are most abundant and low cost which makes it suitable for cost effective DSSCs [14].

There are numerous methods to prepare ZS, such as thermal evaporation, sputtering techniques, spray pyrolysis, hydrothermal, combustion, flex and pulsed laser deposition. These methods are highly sophisticated and require costly precursors, more power consumption and high temperatures. Alternative way to synthesis ZS is microwave route. The microwave assisted synthesis offers many advantages than the conventional methods. The widespread use of microwaves was started with the invention of a device. A magnetron inside the oven that generates the electromagnetic radiation (2450 MHz) of frequency results in rapid heating and thereby leading to homogeneous nucleation, fast super saturation and eventually a shorter crystallization time compared to conventional autoclave heating. Further, the reaction takes place in the aqueous medium, in which the permanent dipoles of liquid phase initiate heating from the molecular rotation. Therefore, the microwave assisted route is an efficient method to synthesize high purity ZS nanostructures [15–18].

In this work, for the first time we present a simple and economically attractive microwave route for the synthesis of cubic spinel ZS nanocubes using the domestic microwave oven. The characterization techniques such as X-ray diffraction, scanning electron microscopy, Raman and Fourier transform infrared (FTIR) spectroscopy have been used to study the structural and vibrational properties of ZS nanocubes. Further, DSSCs were made using low cost organic dyes such as Rose Bengal (RB), Eosin Yellow (EY) and Fluorescein sodium salt (FS) dyes as sensitizer and their photovoltaic effects have been reported.

2. Experimental

2.1. Materials

Zinc acetate Zn $(CH_3COO)_2$ (Merck), Tin (IV) chloride $SnCl_2$ (Alfa), Glycerol (Sigma–Aldrich), Poly ethylene glycol (PEG, Merck), Rose Bengal (Alfa), Eosin yellow (Alfa), Fluorescein sodium salt (Sigma–Aldrich) and Sodium Hydroxide pellets NaOH (Nice) graphite plate (Alfa) and deionized water (Nice) were purchased and used as received without further purification.

2.2. Microwave route

The ZS was prepared from the stoichiometric ratio of Zn $(CH_3COO)_2$ and $SnCl_4{\cdot}5H_2O$ with PEG 600 as capping agent. Initially the zinc acetate and tin chloride (1:1 volume ratio) were dissolved in