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Efficiency Enhancement of Dye-sensitized Solar Cells by Flower-like Zinc Oxide

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Abstract

The broadband and omnidirectional light harvesting is important in photovoltaic technology. This study reports the fabrication and characterization of the dye-sensitized solar cells with flower-like zinc oxide (ZnO). The fabrication steps of flower-like ZnO involve self-assembled polystyrene (PS) nanospheres and the hydrothermal method. The experimental results reveal that the solar cells with flower-like ZnO enhanced the conversion efficiency by 27.3% while the light incident angle up to 60°.

1. Introduction

Due to the global warming effect and energy ceisis, the energy gets more important in the last few years. Solar energy is thought to be the most of renewable and secure energy in existing energy sources. Many photovoltaic devices have been developed over the past decades. However, widespread use is still limited by two major challenges, which are conversion efficiency and cost. To aim at futher lowering the production, dye-sensitized solar cells (DSCs) promising approach to efficient soalr energy conversion. Furthermore, DSCs are promising devices for environmentally compatible, and also large-scale solar energy conversion as an alternative to conventional solid-state semiconductor solar cells.[1-3]

Recently, zinc oxide (ZnO) has emerged as a promising alternative semiconductor material to titanium dioxide (TiO2) in DSCs with significant performance improvement achieved. ZnO belongs to wide direct band gap (3.37 eV) semiconductor with a high exciton binding energy, excellent chemical, thermal stability and an electron affinity similar to that of TiO_2. Moreover, single-crystalline ZnO exhibits a excellent electron transport collection and a fast charge transfer due to its electron mobility higher by 2–3 orders of magnitude than TiO_2.[4-7]

In this study, we demonstrate a scalable and inexpensive bottom-up approach for self-assembling polystyrene (PS) nanospheres on a transparent conductive glass substrate, and growing folwer-like ZnO on PS nanospheres using a hydrothermal method. Growing flower-like ZnO is suitable for producing nanostructures on large-area patterns. The three dimensional hierarchical flower-like ZnO structure in this study is a combination of PS nanospheres and ZnO nanorods(Fig. 1). This flower structure forms a photoanode that enhances light absorption in the broadband and omnidirectional spectral range.

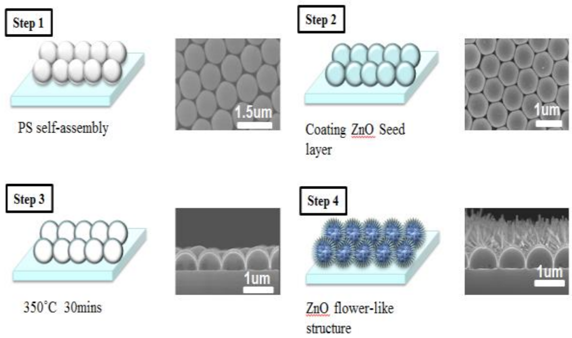


Fig. 1 Schematic process for fabricating the flower-like ZnO on conductive glass substrate

2. Experimentals

The fabrication processes for flower-like ZnO consist of three steps as schematically illustrated in figure 1. A monolayer of self-assembled PS nanospheres with a plurality 10 wt% was spun on the conductive glass substrate, producing a closely packed PS nanospheres monolayer. A two-step method was used to fabricate ZnO nanorods on the surface of the nanospheres on the conductive glass substrate. This method involves the fabrication of seed layers and growth of nanorods. First, a 100 nm-thick ZnO layer was deposited by radio frequency (RF) magnetron sputtering form a seed layer for growing ZnO nanorods. Subsequently, the original PS spheres were removed by calcination in air at 350 ^{o}C for 0.5 h, leaving spherical voids in the ZnO structure. Second, ZnO nanorods were grown by the hydrothermal method. The aqueous solution was prepared by mixing the same concentration of 0.03M zinc nitrate hexahydrate ($Zn(NO_3)_2$ $6H_2O$, Aldrich) and the hexamethylenetetramine ($C_6H_{12}N_4$, HMT, Aldrich) for growing ZnO nanorods.

After the two aqueous solutions were mixed, solar cells were immersed the solution at 90 ^{o}C for 3, 9 and 15 hours. Finally, deionized water was used to clean the sample, which was heated at 60 ^{o}C in air for 1 hour to complete the process of growing the flower-like ZnO.

After that, D-719 dye, cis-bis(isothiocyanato)bis(2,2' bipyridyl-4,4'dicarboxylato) ruthenium(II) bis- tetrabutylammonium (Everlight Chemical Industrial Corp., Taipei, Taiwan), was dissolved in acetonitrile for the preparation of the 0.5 mM dye solution. Solar cells were prepared by immersing the flower-like ZnO on conductive glass substrate into dye solution for 1 hour at room temperature. A sandwich-type configuration was employed to measure the presentation of the DSCs. The area of active electrode was typically 1 cm^2.

3. Results and discussion

Fig. 2 shows the surface morphology of PS nanospheres and flower structures. Monolayers of 1000 nm diameter nanospheres were formed by drying the suspension, and Fig. 2(a) shows the layout of PS nanospheres with a closely packed hexagonal pattern. After we fabricated 100 nm-thick seed layers on the PS nanospheres, ZnO nanorods were grown on the PS nanospheres (Fig. 2(b,c)). The ZnO nanorods had diameters of approximately 50 nm and lengths ranging from 800 nm to 1000 nm (Fig. 2(c)).

In order to more clearly investigate the crystal of ZnO nanostructures, the flowers nanostructure with different lengths on FTO glass substrate are also investigated. Fig. 3 shows an XRD pattern of the ZnO flowers nanostructure on the FTO glass substrate. The strong diffraction peak at 34.4° on the ZnO flowers nanostructure corresponds to the (002) plane along the c-axis. The two peaks at 31.8° and 36.3°in the nanotrees sample represent the (100) and (101) ZnO crystal planes. It is assigned to pure wurtzite ZnO phase as referred to the JCPDS file 36-1451. Therefore, XRD analysis shows that perpendicularly oriented ZnO crystals form the CIGS solar cell surface, as well as other crystal planes. Additionally, the XRD analysis corresponds to the SEM images.

Figure 4 shows the DSCs solar cells with different lengths of ZnO flowers nanostructure in AM1.5G light spectrum. The parameters are shown in Table I. The cell with 15 hour flowers nanostructure has conversion efficiencies (η) of 064% with approximate open-circuit voltages (Voc) of 0.57 V and the fill factor (FF) of 0.33, Jsc of 3.27mA/cm2. One of the approaches to increase surface area for enhanced light conversion efficiency is increase the length of ZnO nanorods. Thus, the photovoltaic efficiency is enhanced because the length of ZnO nanorods is increase.

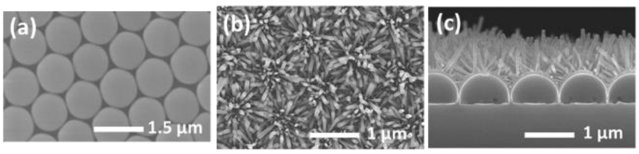


Fig. 2 SEM images of the flower-like ZnO pattern on silicon substrate

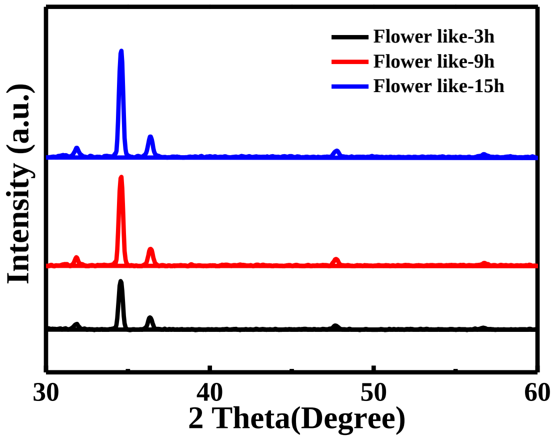
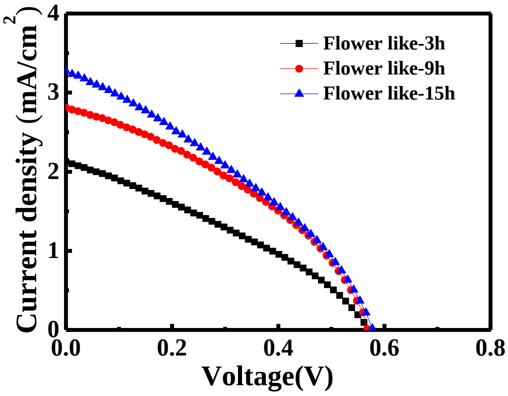


Fig. 3 X-ray diffraction patterns of flower-like pattern

Fig. 4 The current density-voltage curves for DSCs with



different lengths of flower-like ZnO

4. Conclusions

In conclusion, the DSCs with ZnO flowers nanostructure was fabricated and characterized in detail. This study prepared ZnO flowers nanostructure and ZnO nanowires for use as photoanodes in DSCs. DSCs composed of flowers nanostructures were found to show greater photovoltaic performance than DSCs containing nanowires. The low-temperature and cost-efficient fabrication process that find applications in optoelectronic devices.

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