Hybrid TiO2 Nanoparticles and Vertical-Aligned Nanowires Photoanode for Dye-Sensitized Solar Cells

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1. Introduction

Dye-sensitized solar cells (DSSCs) have been examined eagerly as a new generation of solar cell because of their low cost and high performance [1]. In general, DSSCs based on TiO2 nanoparticles (TiO2 NPs) network has achieved AM 1.5 solar efficiencies more than 10% [2][3]. However, the further enhancement in power conversion efficiency (PCE) is difficult, partly due to charge recombination and reduced electron transport rate through the nanocrystalline photoanodes.

One-dimensinal (1D) TiO2 nanostructure offer direct electrical pathways for photogenerated electrons and could increase the electron transport rate, which in turn may improve the performance of DSSCs [4]. Recently, several approaches have been adopted to achieve 1D TiO2 nanowire (TiO2 NWs) grown directly on fluorine doped tin oxide (FTO) substrate using hydrothermally growth (HTG) method [5][6]. However, one issue of using 1D TiO2 NWs as photoanode for DSSCs is the low light absorption, which is caused by its small specific surface area for dye loading. The further improved the PCE of the DSSCs can be expected by making the photoanode with exhibited both a high surface area and fast electron transport.

Here, we reported a design of hybrid photoanode comprise TiO2 NWs/NPs. The TiO2 NWs provide direct pathway for fast electron transport and crystallite NPs enrich surface area for better dye loading.

2. Experiments

Fig. 1 shows the schematic of the designed photoanode in this study with TiO2 NWs/NPs. The TiO2 NWs provide direct pathway for fast electron transport and crystallite NPs enrich surface area for better dye loading.

3. Results and Discussion

Fig. 2 is the scanning electron microscopy (SEM) with Fig. 2(a) showing the cross-section and Fig 2(b) top-view of TiO2 NWs grown on FTO substrate using HTG. Highly ordered and aligned array with an average length of 1.93 µm were observed. Fig. 2(c) showing the cross-section and Fig 2(d) top-view of TiO2 NPs coating on the top of TiO2 NWs using ultrasonic-assisted dip
coating method, the TiO2 NPs with the average diameter of about 20 nm were partly penetrated and dispersed between of the TiO2 NWs but with the large fraction remained and coated on the surface of NWs.

Figure 3 shows the TEM image and SAED pattern of an individual TiO2 NW obtained from the FTO substrate. It shows clear strips of the lattice plane extending over the whole wire. Lattice fringes with interplanar spacing of \(d_{110}=3.29\ \text{Å}\) and \(d_{001}=3\ \text{Å}\) are clearly observed, which are consistent with that of the rutile phase. The corresponding SAED pattern is shown in the inset, which reveals that the NWs are single-crystalline and their growth in the [0 0 1] direction tends to be preferential.

DSSCs devices were fabricated using photoanodes of pure TiO2 NWs, and hybrid TiO2 NWs/NPs. Sample A-C all have same length of TiO2 NWs about 1.93 \(\mu\)m. Sample B and C were coated different thickness of TiO2 NPs, 1.51 and 3 \(\mu\)m, respectively. Fig. 4 shows current density-voltage (J-V) characteristic of the three cells under AM 1.5G illumination with the light intensity of 100 mW/cm². The PCE of sample A, B, and C were 1.56 \%, 3.32 \%, and 4.12 \%. The increase in PCE and \(J_{sc}\) were contributed to through the use of TiO2 NPs improve surface area for dye loading.

4. Conclusion

In summary, the hybrid TiO2 NWs/NPs photoanode for DSSCs has been fabricated and investigated to improve the PCE. The hybrid photoanode composed of TiO2 NWs to serve as a direct pathway for fast electron transport and TiO2 NPs dispersed and filled the gaps between TiO2 NWs to offer a high surface area for sufficient dye adsorption. The overall PCE of DSSC with the N719 TiO2 hybrid photoanode has reached 4.12\%, with \(V_{oc}\) of 0.69 V, \(J_{sc}\) of 10.28 mA/cm², and a FF of 58\%, far higher than 1.56\% of TiO2 NWs DSSC. The remarkably improved solar cell performance is attributed mainly to the improvement in \(J_{sc}\) which can be explained by the high surface area and fast electron transport of TiO2 hybrid photoanodes.

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