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TiO_2 Nanoparticle and ZnO Nanowire Composite for Solar Cell Application

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Dye-sensitized solar cells (DSSC) are one of the most promising photovoltaic devices for solar energy conversion [1]. In an effort to develop a materials system that can efficiently convert light-electricity into power [2], we demonstrate the fabrication of a DSSC by using a nanostructure made of TiO_2 nanoparticles (NP) and ZnO nanowire (NW) arrays, as illustrated in Figure 1a and 1b.

Figure 1c shows a scanning electron microscopy (SEM) image of the brush-like electrode substrate fabricated by growing a ZnO NW array on fluorine-doped SnO_2 (FTO) transparent conducting glass via thermal vaporization of Zn powder. An aqueous solution consisting of 2 g/L TiO_2 NPs (diameter, around 25 nm) and 1 M $Ti(OC_2H_5)_4$ were then coated on the brush-like electrode. After applying one coat of the solution and then allowing the sample to dry at 90 ºC for 2 h, a layer of TiO_2 NPs were formed on the ZnO NW array (inset of Figure 1d). After repeating this process five times, the interspaces of the ZnO NW array were filled with TiO_2 NPs as shown in Figure 1d. The photoanode was soaked in 0.5 mM N 719 dye (from Dyesol) in ethanol for 72 h. The photoanode was then washed once with ethanol and used for photovoltaic measurements. The redox electrolyte was composed of 0.1 M 1-Aminopyridinium iodide, 0.1 M KI and 0.05 M I_2 in acetonitrile. The counter electrode was Pt-coated FTO. Cell measurement was performed using a Keithley 2400 source meter under simulated AM 1.5 G sunlight with an intensity of 100 mW/cm^2. As illustrated in Figure 2a and 2b, the current density-bias (*J-V)* plot of the as-fabricated cell was formed by the overlap of two curves. The first curve resulted from the dye sensitized ZnO NWs showing low open-circuit voltage (V_{oc}) caused by the direct contact to the electrolyte; the second was attributed to the dye sensitized TiO_2 NPs demonstrating low short-cut photocurrent (J_{sc}) because of the slow electron transport in TiO_2 NP layer. This was due to the fact that as-deposited TiO_2 NPs were stacked loosely on the ZnO NW array. An annealing process at 400 ºC for 1 h was conducted to improve the compactness of the TiO_2 NP and ZnO NW composite. This effort resulted in the increase of the light to electricity conversion efficiency (η_{PCE}) from 0.68 % to 2.67 % and the enhancement of the fill factor (*FF*) from 0.21 to 0.29. The high J_{sc} demonstrates the ZnO NW array is an effective antireflection coating material with good transparency, which has been proved by Lee, et al [3]. In addition, the ZnO NWs serve as fast electron paths. This because the band gaps and band edge energies of ZnO and anatase TiO_2 are similar, TiO_2 NP and ZnO NW can therefore form a heterojunction free of band discontinuities and with a built-in potential, neglecting any difference in densities of states [4]. Through this investigation it is expected that the integration of a ZnO NW array on the DSSC leads to the enhancement of η_{PCE} by improving light harvesting as well as charge separation.

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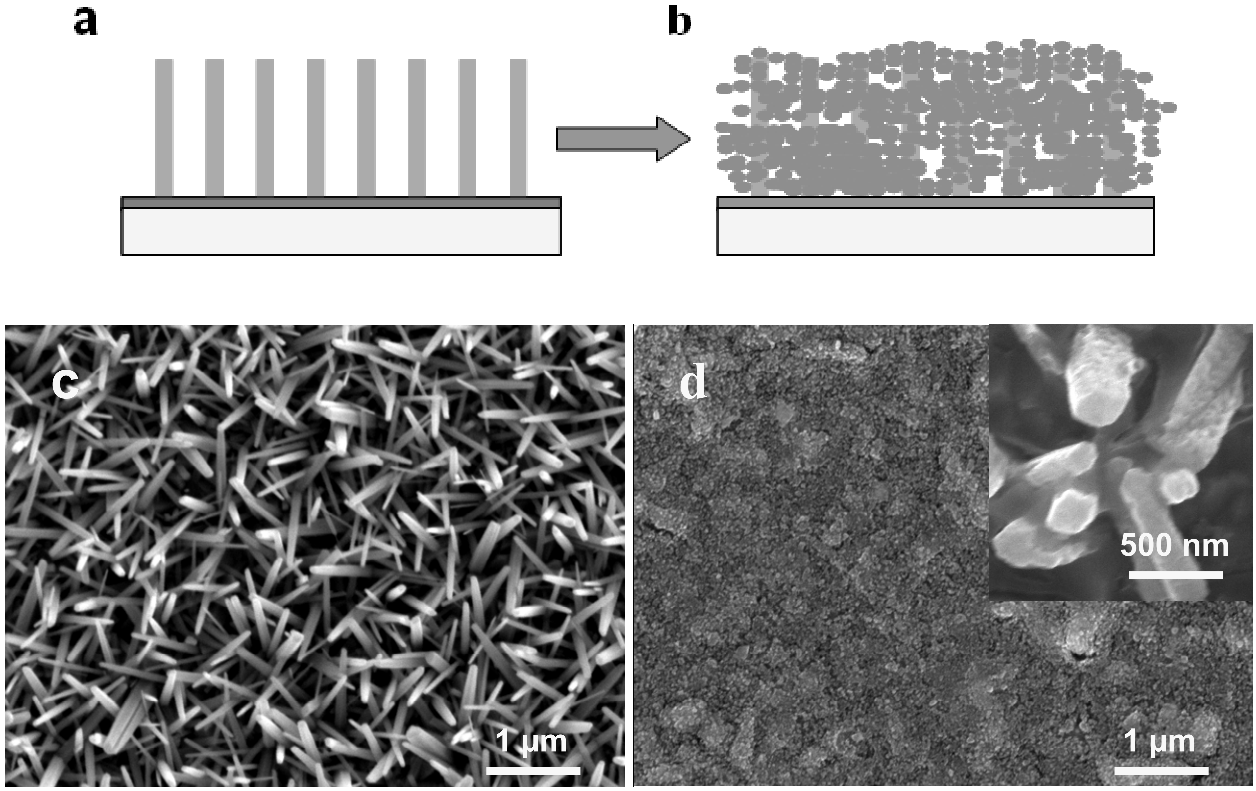

Figure 1 Schematic diagrams of the fabrication process demonstrating the deposition of TiO_2 NPs on a ZnO NW array. (a) ZnO NW array and (b) TiO_2 NP-coated ZnO NW array. (c) and (d) are SEM images of the samples as illustrated in (a) and (b) correspondingly.

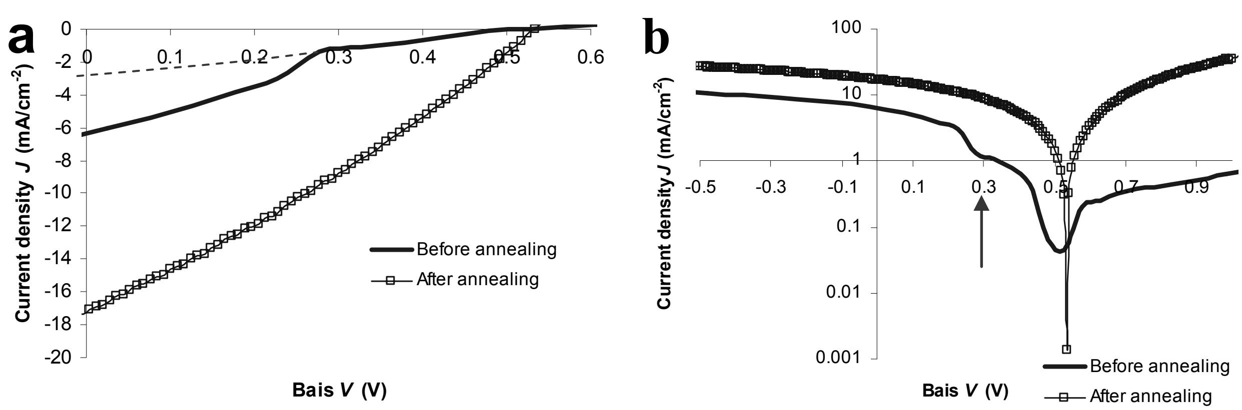

Figure 2 (a) *J-V* plots and (b) semilogarithmic plots of as-fabricated TiO_2 NP/ZnO NW array-based DSSCs. Before annealing, V_{oc} 0.53 V, J_{sc} 6.06 mA/cm^2, FF 0.21, η_{PCE} 0.68 %; after annealing, V_{oc} 0.53 V, J_{sc} 17.06 mA/cm^2, FF 0.29, η_{PCE} 2.67 %.

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