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Novel three-layer TiO_2 nanoparticle stacking architecture for efficient dye-sensitized solar cells

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ABSTRACT

In this work, we report a novel three-layer TiO_2 nanoparticle photoelectrode for dye-sensitized solar cells (DSSCs). In such a DSSC, a very thin front scattering layer (~1 μm thick) composed of small nanoparticles (~20 nm) and larger scattering nanoparticles (>100 nm) is inserted in front of the typical small-nanoparticle absorption layer and the large-nanoparticle back-scattering/reflection layer. Such a very thin front scattering layer having mixture of small/large nanoparticles provides a larger haze (i.e., stronger scattering) and yet still retains a high integrated transmittance. With effectively scattering portion of the incident light into larger oblique angles and therefore increasing optical paths and absorption, DSSC efficiencies are enhanced by 15.2%, compared to the conventional two-layer DSSCs.

1. Introduction

Increasing global concerns about energy and environments have encouraged scientists to develop low-cost and easily accessible renewable energy sources in recent years. As such, dye-sensitized solar cells (DSSCs) first reported by Grätzel et al. immediately attracted much attention due to their advantages of relatively high efficiencies, simple device structures, cost-effective manufacturing, and variety and flexibility in applications [1–14]. A typical DSSC consists of a transparent conductive substrate, a porous thin-film electrode consisting of TiO_2 nanoparticles, dye, electrolyte, and a platinum counter electrode. In dye-sensitized solar cells (DSSCs), the nanoporous thin-film electrode composed of TiO_2 nanoparticles is a critical component, in terms of creating transport pathways for photo-generated electrons, providing high surface areas for the adsorption of dyes, and providing pores for the electrolyte solution to permeate. In the early past, DSSCs used planar electrodes for dye adsorption and only dye molecules on the surface of the electrode could generate photocurrent, resulting in a power conversion efficiency of lower than 1% [15]. Grätzel and his colleagues utilized porous TiO_2 nanoparticle thin-film electrodes to increase the surface areas for enhancing dye adsorption on the surface of the TiO_2 working electrode [1]. As such, the power conversion efficiency of the DSSCs was dramatically improved.

As the compositions and architectures of the TiO_2 electrodes are critical for preparation of efficient DSSCs, researchers had been engaged in investigating influences of the structures of TiO_2 electrodes on DSSC characteristics and performances [16–18]. In designing/optimizing the TiO_2 electrodes, usually there is a tradeoff between the optical absorption/charge generation and the electrical/transport properties (e.g. series resistance, charge recombination, open-circuit voltage, etc.) [19]. The optimized TiO_2 electrode thickness is thus typically less than the desired optical absorption length [20], and different compositions and architectures of the TiO_2 electrodes had been studied to enhance absorption and yet not degrading electrical/

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transport performances of DSSCs [21]. For instance, a typical architecture for the TiO_2 nanoparticle electrode is composed of a layer of small nanoparticles (tens of nm) for larger surface areas and dye uptakes and a layer containing larger nanoparticles (hundreds of nm) as the back optical scattering/reflection layer for enhancing usage of the incident light [22–24]. In some other cases, TiO_2 electrodes composed of mixtures of small TiO_2 nanoparticles and significant portions of large TiO_2 nanoparticles are also used as the layer in front of the back scattering/reflection layer [25–27]. In such cases, even stronger scattering could be induced by the added large particles such that the originally weak absorption in some wavelength ranges (e.g. longer wavelengths) could be enhanced, yet with the risk of degrading originally efficient absorption in other wavelength ranges (e.g. shorter wavelengths) due to significant

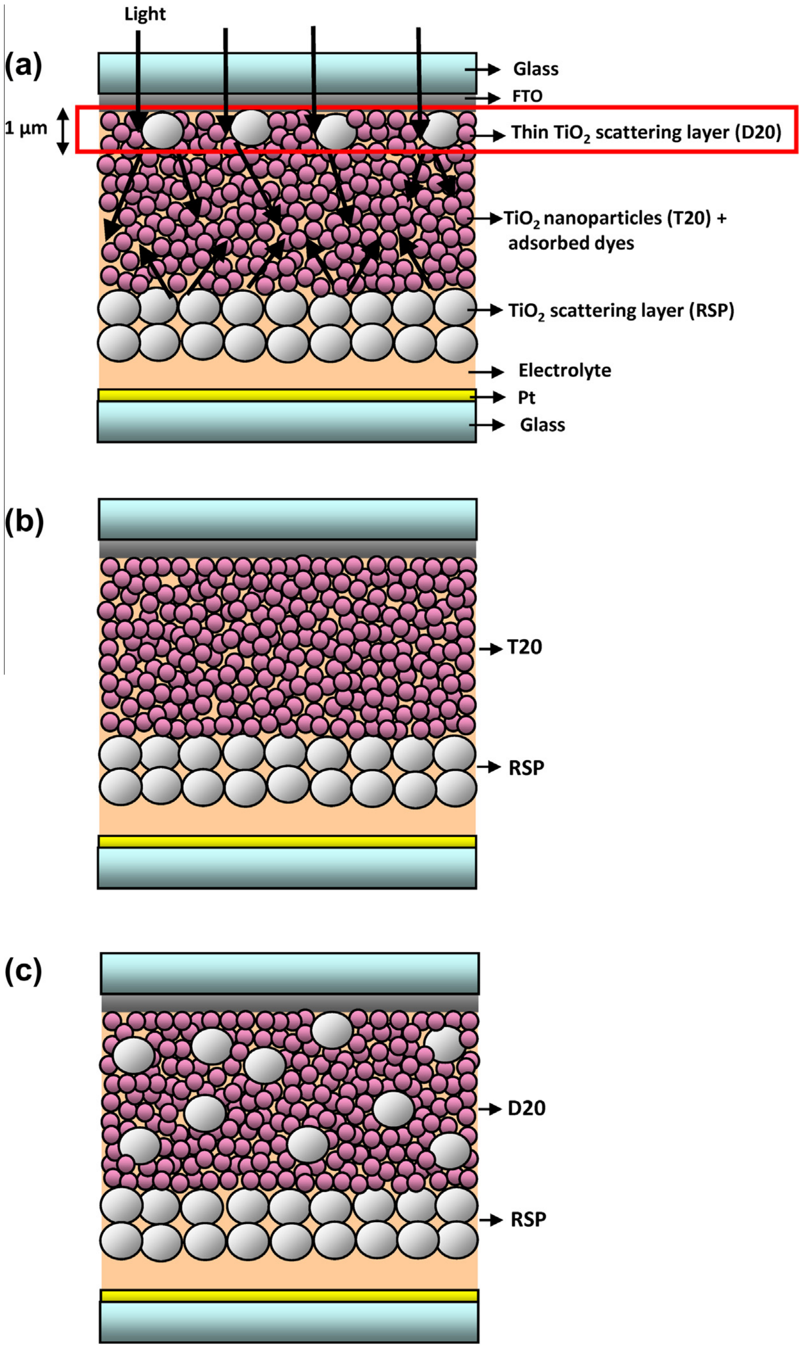

Fig. 1. Schematic device structures of DSSCs having different TiO_2 nanoparticle stacking architectures: (a) device D20 + T20 + RSP, (b) device T20 + RSP, and (c) device D20 + RSP.