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Enhanced Performance of Nanowire-Based All-TiO_2 Solar Cells using Subnanometer-Thick Atomic Layer Deposited ZnO Embedded Layer

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ABSTRACT

In this paper, the effect of angstrom-thick atomic layer deposited (ALD) ZnO embedded layer on photovoltaic (PV) performance of Nanowire-Based All-TiO_2 solar cells has been systematically investigated. Our results indicate that by varying the thickness of ZnO layer the efficiency of the solar cell can be significantly changed. It is shown that the efficiency has its maximum for optimal thickness of 1 ALD cycle in which this ultrathin ZnO layer improves device performance through passivation of surface traps without hampering injection efficiency of photogenerated electrons. The mechanisms contributing to this unprecedented change in PV performance of the cell have been scrutinized and discussed.

1. Introduction

The projected growth of the silicon photovoltaic (PV) industry has been limited due to the material and manufacturing costs. Over the past decades, considerable studies were focused on finding alternative PV technologies which can offer low cost, mature processing technology together with high efficiencies. TiO_2 nanowire (NW) template-based hybrid solar cell structures are one of these alternatives because of its excellent optoelectronic and chemical properties in addition to providing high specific surface area, better electron transport and ability to strongly scatter light [1]. The n-type high band gap metal oxide such as TiO_2 NWs array has been extensively utilized as the electron transport layer in a wide range of solar cells such as hybrid solar cells, dye-sensitized solar cells [2] and organic solar cells [3]. Recently, in order to provide better absorption of light over the whole solar spectrum, different kind of semiconductors with higher absorption coefficients such as CdS [4,5], CdSe [6,7], CdTe [8–10], PbS [11] have been used to sensitize metal oxide anode in solid/liquid state quantum dot/semiconductor sensitized solar cells. However, the functionality of semiconductor interfaces plays a crucial role in all hybrid solar cells in which trapping or recombination of charge carriers can reduce PV efficiency. In addition to photovoltaic applications, these interfaces have a great influence on the performance of photoelectrochemical and photocatalytic applications such as water splitting in which a better charge separation, transport and collection can be provided through the engineering of the semiconductors surface [12–14]. Controlling the impact of surface or interface-derived electronic states is, therefore, a prime goal in modern semiconductor processing. To this end, utilization of an interfacial semiconductor, typically a metal oxide with high energy band gap, layer is commonly employed [8,15,16]. However, the main drawback associated with such an interfacial layer is the fact that just a couple of nanometers of such a layer can significantly hamper injection efficiency. Therefore, an ultrathin homogeneous coating around the whole surface of NW is required. Among numerous methods available for the deposition of this passivation layer, atomic layer deposition (ALD) is able to coat pinhole-free metal-oxide films with angstrom-scale thickness.

Herein, we demonstrate that ALD coated ZnO embedded layer can efficiently passivate the NWs surface. Although the bare

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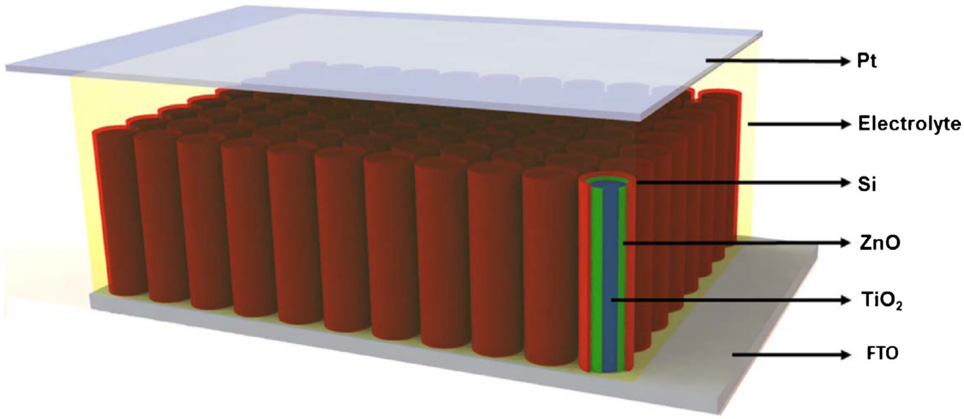

Fig. 1. (a) The 3D schematic of proposed α-Si/ZnO/TiO_2 HJ solar cell.

structure (no ZnO interfacial layer) shows poor efficiency, device performance is boosted remarkably using the ZnO interfacial layer. With this in mind, the thickness of this interfacial layer plays a crucial role in solar cell performance, in that thicker layers of such a high band gap material impede the electron injection noticeably. It is demonstrated that an optimized ultrathin layer paves the way to efficient devices by reducing recombination at the interface without hampering electron injection capability. It should be

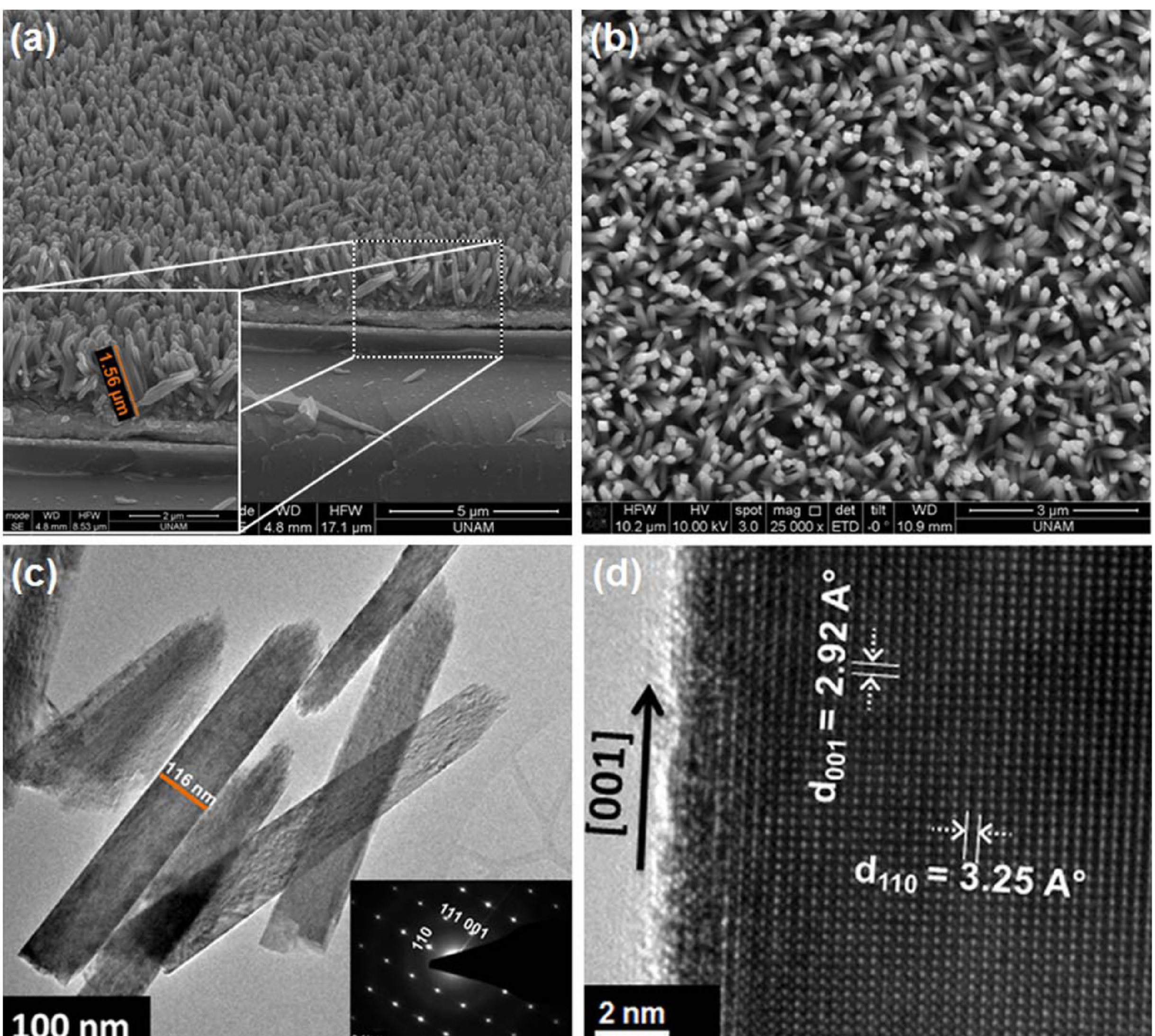

Fig. 2. SEM images of the NWs **(a)** cross section and **(b)** top view. **(c)** TEM image of ZnO coated TiO_2 NWs. Inset shows the SAED pattern of the sample. **(d)** HR-TEM image of the NWs showing the direction of growth and lattice spacing.