WAA2 (Contributed Oral)
4:00 PM – 4:15 PM

ZnO Nanorods for Simultaneous Light Trapping and Transparent Electrode Application in Solar Cells

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Abstract— *Efficacy of using vertically grown ZnO nanorod array in enhancing electromagnetic field intensity and serving as the top contact layer (transparent electrodes) for solar cells was investigated.*

Keywords—Energy harvesting, nanorods, ZnO, ITO, transparent conductors, solar cell efficiency, light coupling, flexible solar cells.

I. Introduction

While researchers strive to increase internal quantum efficiency of solar cells, there exists a huge scope to increase the overall quantum yield of these energy-harvesting devices via light trapping. By introducing randomized surface texturing, effective optical path length can be increased significantly. Exploiting this technique, it is possible to increase effective photon lifetime inside solar cells; therefore, electromagnetic energy stays inside the solar cell long enough to get absorbed by the depletion region. Yablonovitch proved that with random Lambertian texturing, maximum path length becomes $4n^2d$, where n is refractive index and d is the thickness of the layer [1]. Enhanced surface recombination and other solar cell processing challenges suggest that texturing the top layer is not ideal [2]. In addition, conventional anti-reflective (AR) coatings do not show high transmission in frequencies over the whole solar radiation spectrum, and thus reduce the efficiency of solar cell drastically [3].

Transparent electrodes allow light to pass through while serving as the top contact layer; transparency and conductivity of the top layer is essential for solar cells. Transparent conducting oxides have been studied extensively in display and photovoltaic devices. However, incorporating light trapping capability and transparent electrode characteristics in the same layer, which may increase overall quantum efficiency significantly, has not been properly explored. Recently, the pulsed-laser deposition (PLD) technique has been used to successfully grow of ZnO nanorods on both sapphire and silicon substrates [4]. As shown in Fig. 1(a) and (b), these nanorods give high degree of randomness and irregular surface facets, which could serve as the transparent electrode, as well as a unique structure that would enhance light trapping in solar cell devices. In this work, a finite-difference time-domain (FDTD) simulator has been employed to investigate the efficacy of this vertically grown ZnO nanorod array in enhancing electromagnetic field intensity, and serving as the top contact layer as transparent electrodes.

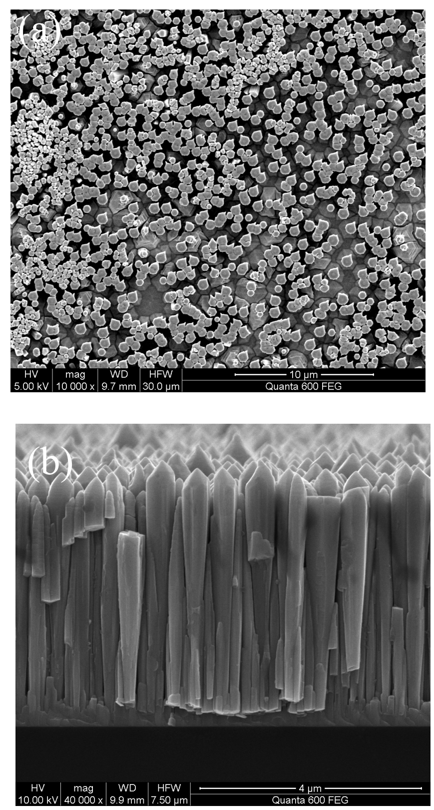

Fig. 1: SEM micrographs of ZnO nanorods grown on sapphire – a) top view and b) cross-sectional view. SEMs show the existence of randomness in the system.

II. Transparency Comparison: ITO vs. ZnO Nanorods

We performed a comparative study on transparency of a uniform ITO (Indium tin oxide) contact layer and a contact layer fabricated using ZnO nanorods. Since ITO is the most

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common form of transparent electrode used in photovoltaic devices and electronics, we chose ITO on glass and ZnO nanorods on glass, and compared their optical response. As seen in Fig. 2, ITO shows higher reflection (Fig. 2(b)), while ZnO nanorod layer depicts good transmission (Fig. 2(e)). These FDTD images were taken for same time separation, i.e. Fig. 2(a-c) and Fig. 2(d-f) were stored 5, 17, 25 time frames of the simulation.

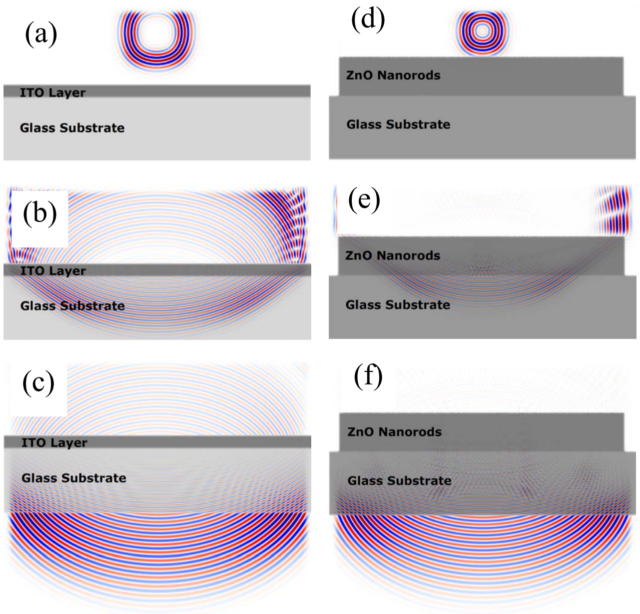

Fig. 2: Simulation of optical response of (a-c) ITO on glass and (d-f) ZnO nanorods on glass. ITO layer thickness 1μm, ZnO nanorod layer thickness 3μm, and glass substrate thickness 5μm and width 25μm.

Since the overall system is a complex random structure, study of complexity is essential to understand realistic system response. Symmetry and complexity were studied to establish correlation between the two. While simulating classic case of symmetry, we observed that Bloch modes travel only in high refractive index (n) region. However, since the shape and spacing of nanorods can be controlled by the seed layer, optimization can lead to a structure, where it will be possible to guide electromagnetic radiation in air, which can reduce loss significantly [5].

III. Results and Discussions

Numerical simulation shows that ZnO nanorod layer depicts significantly better transmission at optical spectrum of solar radiation peaking at 550nm, which can boost overall quantum yield of solar cells dramatically. Transmitted power for fields at a given frequency ω, was taken as the integral of the pointing vector (in the normal direction) over a plane on the far side of the structure. Reflected power was calculated by subtracting the Fourier-transformed incident electric and magnetic fields from Fourier-transformed electric and magnetic fields for every point in the flux plane [6]. From numerical simulations, 7% overall enhancement in transmission were observed for ZnO nanorod layer compared to the ITO layer.

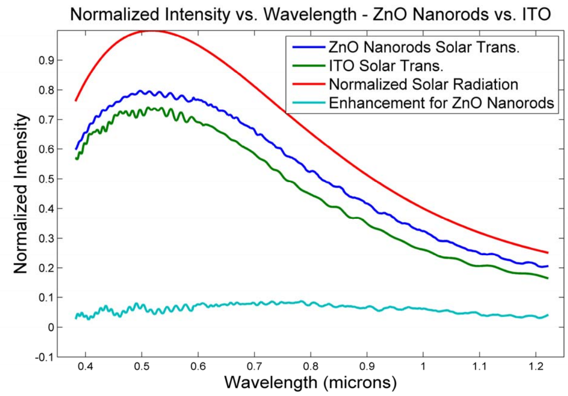

Fig. 3: Transmission spectrum for ITO and ZnO nanorod layer, normalized with AM 1.5 solar radiation. It is apparent from the plots that transmission for ZnO nanorod layer is higher than that of ITO. 7% overall enhancement in transmission were observed for ZnO nanorod layer compared to ITO layer.

IV. Conclusions

ZnO nanorods have 1) transparency, 2) conductivity (when doped), and 3) random facet orientations: exploiting all these features, we can drastically simplify solar cell structure by incorporating three functions in one layer. Beside, ZnO can also be used in the active layer with photo-sensitive dyes for photon absorption in ZnO based solar cells [7]. By using ZnO in different layers, it is possible to create a simplified solar cell structure, which will be cheaper and more efficient. So far, this kind of structure has not been demonstrated in literature. Therefore, further research in this simplistic solar cell structure holds a great promise in scientific significance and uniqueness.

Acknowledgement

This work is supported by a joint program between KAUST and University of Michigan, Ann Arbor, under KAUST-Academic Excellence Alliance (AEA) 2010 Grant.

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