Student Paper

Hybrid ZnO Nanowire/a-Si:H Thin-Film Solar Cells on Flexible Substrates

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Radially-structured nanowire solar cells are gaining considerable interest due to improvements in both photon absorption through effective light trapping and in faster charge collection due to shorter carrier diffusion lengths and carrier confinement in the radial direction – major enhancements that would in turn increase the efficiency of a solar cell device. These enhancements are all a fraction of the total costs associated with that of bulk crystalline Si solar cells. An alternative approach to radial solar cells is hybrid thin-film shell/nanowire core structures such as amorphous Si p-i-n diodes conformally coated onto a ZnO nanowire. ZnO nanowires for solar cell devices are an attractive alternative to other types of nanowires due to the low cost advantages already garnered in using ZnO as the window layer of solar cell devices.

In this work, ZnO nanowires (NWs) are grown using a simple, low cost, and low temperature (90°C) hydrothermal process. The precursors in the hydrothermal bath consisted of zinc nitrate hexahydrate and a pH buffer, hexamethylenetetramine (HMTA). Scanning electron microscopy characterization showed well-oriented vertical NWs were grown on sputter deposited ZnO thin film seed layers on glass and plastic substrates where the nanowire growth showed a dependence on the grain size of a 5-200 nm thin-film ZnO seed layer. Vertically aligned nanowires of 200-700 nm length and 70 nm diameter with ~ 100-400 nm pitch were obtained for grains of < 50 nm; the nanowire growth was disordered for seed layers having grain sizes of 50-140nm. Alternative seed layers consisting of ZnO nanoparticles were also used to nucleate nanowire growth with the same hydrothermal approach. The optical properties of a-Si:H coated ZnO nanowires revealed a red shift of ~50 nm and increased absorption by 60% compared to a-Si:H on a planar surface.

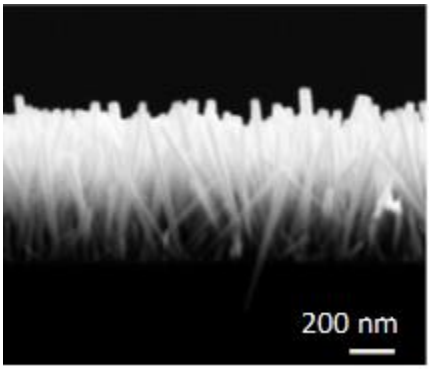

Figure 1a. Uncoated ZnO nanowires

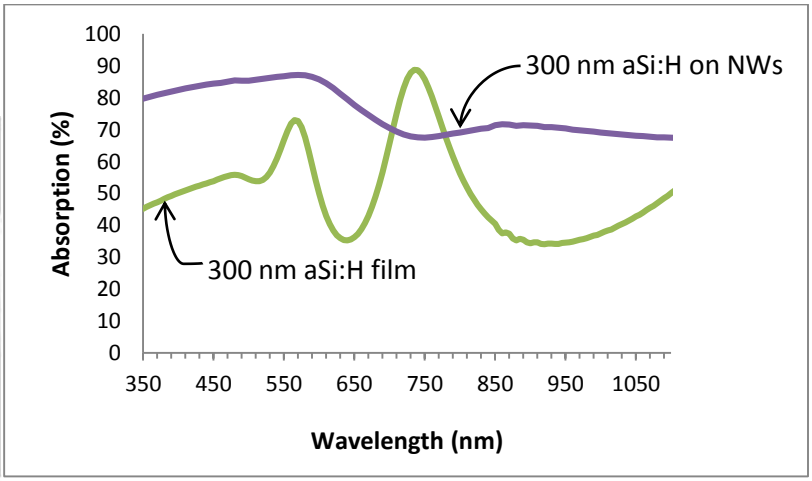

Figure 1b. Reflectance spectra of 300 nm aSi:H coated on nanowires and 300 nm aSi:H planar film

A 3D optical simulation using the finite differential time domain (FDTD) technique showed that ZnO NWs grown to lengths of about 500 nm with a pitch of 400nm-600nm can help garner a-Si:H coated p-i-n diodes having short circuit currents greater than 15 mA/cm^2, which is approximately twice that gained through planar solar cell devices (Fig. 2). By using a low-temperature conformal coating of a-Si:H

for the solar cell around a ZnO nanowire as illustrated in Figure 3, hybrid nanowire a-Si:H p-i-n structures were fabricated on plastic flexible substrates (Fig. 4a-c).

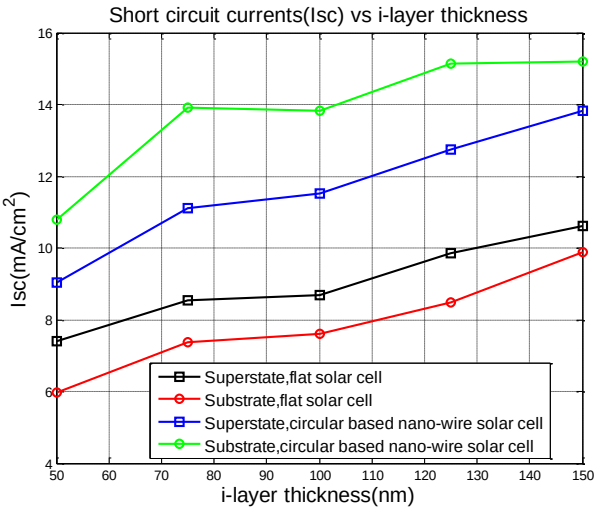

Figure 2. Jsc of different pin diode structures

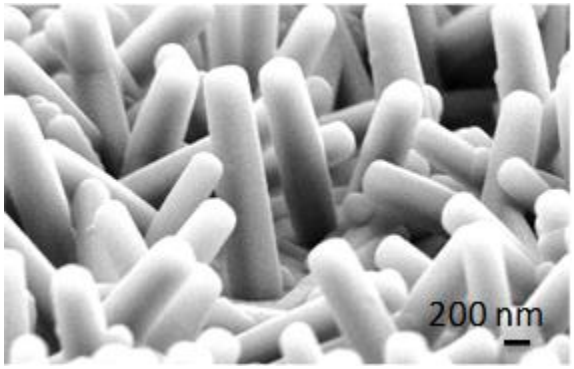

Figure 3. 300 nm aSi:H shell/ZnO core nanowires

However, conformal coating of a transparent top electrical contact to the 3-D nanowire devices is a significant challenge for functioning devices. A spin-coated nano-particle ITO solution was investigated as an electrical contact to the 3-D radial structures. Sheet resistance for the nano-particle ITO was approximately $8x10^4$ Ohm/sq with excellent conformal ITO coverage around the nanowire structures. The resulting hybrid solar cells had measured J_{sc} of approximately 2× the planar thin-film devices on plastic, agreeing well with the FDTD model. Further results and analysis of the optimization to enhance the electrical characteristics of the hybrid ZnO nanowire/aSi:H thin-film solar cells will also be presented.

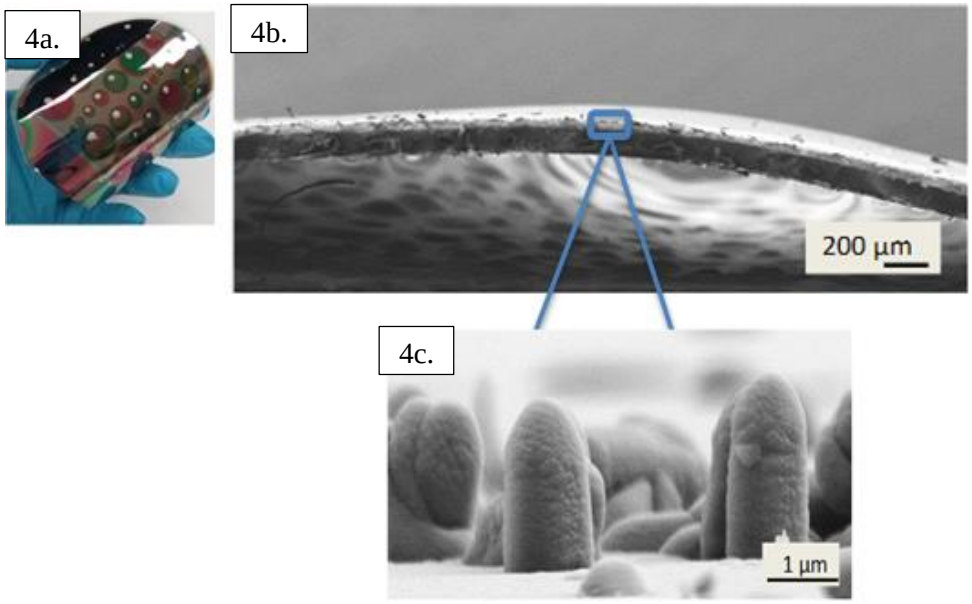

Figure 2a. Optical image of hybrid ZnO nanowire/aSi:H thin-film solar cells on a flexible substrate; b. SEM image of the flexed substrate with hybrid nanowire devices, and c. SEM micrograph of the hybrid nanowire devices.