Solar Energy Materials & Solar Cells 154 (2016) 65–70

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

journal homepage: www.elsevier.com/locate/solmat

High potential for the optimum designs for a front contact and junction: A route to heterojunction solar cell

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ARTICLE INFO

Article history:
Received 21 November 2015
Received in revised form
10 April 2016
Accepted 19 April 2016
Available online 7 May 2016

Keywords:
Heterojunction solar cell
Transparent conductors
Silver nanowires
Mott Schottky analysis

ABSTRACT

The present work describes a method for the development of an efficient silver nanowire (AgNWs) embedded indium tin oxide (ITO) based silicon heterojunction solar cell. The working mechanism of the heterojunction solar cell is studied by using the current-voltage (J-V) and Impedance spectroscopy (IS) techniques. The charge transfer mechanism and recombination process of the solar cell were explained by resistance, capacitance and ideality factor derived from both these techniques. A relatively high efficiency has been achieved for AgNWs embedded ITO-Si heterojunction solar cell in which AgNWs network acts as a transparent buried contact. This study also provides a new architecture for various heterojunction solar cells with a simple route of fabrication.

1. Introduction

Recently, there has been a growing interest on the development of silicon (Si) based heterojunction solar cells due to their low processing temperature and easy processing steps [1,2]. Generally these devices are fabricated by the deposition of a transparent conducting film on the surface of Si wafer to form a heterojunction structure [3,4]. The power conversion efficiencies of heterojunction cell are approaching 10–15% with the colloidal antireflection coating and chemical doping [5]. Yang et al. developed 8.68% efficient chemically doped graphene – Si solar cell using a silver nanowire network as a buried contact [6]. Zhang et al. reported a 12% efficient upgraded metallurgical grade Si – organic heterojunction solar cell [7].

In general, the performance of Si based heterojunction solar cell mainly depends upon the optoelectronic property of the transparent layer. The methods such as chemical doping are being employed to reduce the sheet resistance and hence improve the efficiency of solar cell. It has been noticed that even by using chemical doping technique, the sheet resistance is not sufficiently lowered mainly in a case where the device active area is scaled [8,9]. Moreover, the chemically doped films are not generally stable which results in the performance degradation of solar cells with time.

The present work describes a method to develop silver nanowires (AgNWs) embedded indium tin oxide (ITO) – Si heterojunction solar cell. AgNWs embedded ITO films exhibit an excellent optoelectronic property by reducing sheet resistance and without compromising much in the transparency of the film. A relatively high efficiency was obtained for AgNWs embedded ITO-Si heterojunction solar cell with an active area of 1.5×1.5 cm^2 which signifies the potential of the fabricated device to be scaled up for a larger area. The study also focuses on (i) the morphological, structural and optical properties of AgNWs embedded ITO layer, (ii) understanding the working mechanism of the cell and (iii) pinpointing interfacial resistive and recombination losses.

2. Experimental

Si wafer (p-type resistivity, 1–10 Ω cm) was used as a substrate for making Si heterojunction solar cells without further doping. Si wafers were sequentially cleaned with acetone, deionized water (DI) and piranha solution. A schematic showing the fabrication process of AgNWs embedded solar cell is presented in Fig. 1. A 100 nm thick ITO deposition on Si wafer was done by using DC sputtering unit with a target of the combination In_2O_3/SnO_2 (90/10 wt%). The deposition parameters were as follows: Gas - Ar 50 sccm, working pressure - 5 mTorr, power - DC 300 W, temperature - room temperature, and

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http://dx.doi.org/10.1016/j.solmat.2016.04.038
0927-0248/

deposition time – 10 min Aluminum back contacts were also formed by using DC. sputtering. The ink solution of AgNWs was then spin coated at a speed of 1000 rpm for 30 s followed by a post-wafer processing at 150 °C. Additional 100 nm-thick ITO layer was coated over AgNWs by DC sputtering. As a comparator, a sole 200 nm-thick ITO Si solar cell was prepared under the same ITO deposition conditions. The fabricated structure was then alloyed in an inert ambient

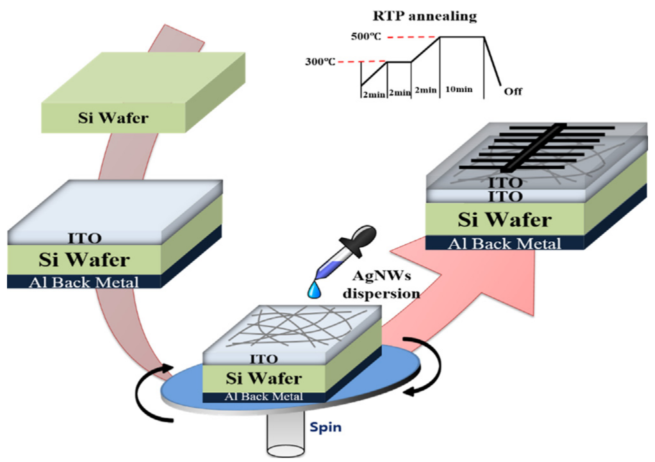

Fig. 1. Process flow to fabricate an AgNWs embedded ITO-Si heterojunction solar cell.

at 500 °C using rapid thermal processing. To investigate the optical properties of AgNWs and ITO, both the films were prepared on glass substrate (Soda lime glass with a dimension of 25 × 25 mm^2) and processed under the same condition as for the solar cell. The morphologies of AgNWs and ITO film were observed by a field emission scanning electron microscope (FE-SEM, FEI Sirion). Transmittance profiles were measured by using UV–vis–NIR photo-spectrometer (V-570, JASCO). Dark current-voltage (J-V) measurements were performed by a source meter unit (2400, Keithley). The irradiated J-V characterizations were obtained under 1 sun illumination (AM 1.5 1000 W/m^2) using McScience solar simulator equipped with 1.5AM-G filter and 2440 Keithley source measuring unit. The Mott-Schottky analysis ($1/C^2$–V characteristics) of photoelectric devices were obtained by applying an AC signal (10 mV) in the frequency range of 10–500 kHz by sweeping the DC bias from −0.4 V to +0.6 V using the Potentiostat/Galvanostat (ZIVE SP1, WonA Tech).

3. Results and discussion

3.1. Morphological, structural and optical analysis

The FESEM image of AgNWs on ITO substrate after annealing at 500 °C is shown in Fig. 2. A closer view of AgNWs shows an average diameter of 110 nm with a length ∼10–15 µm. An embedded view of AgNWs between ITO layers having a total

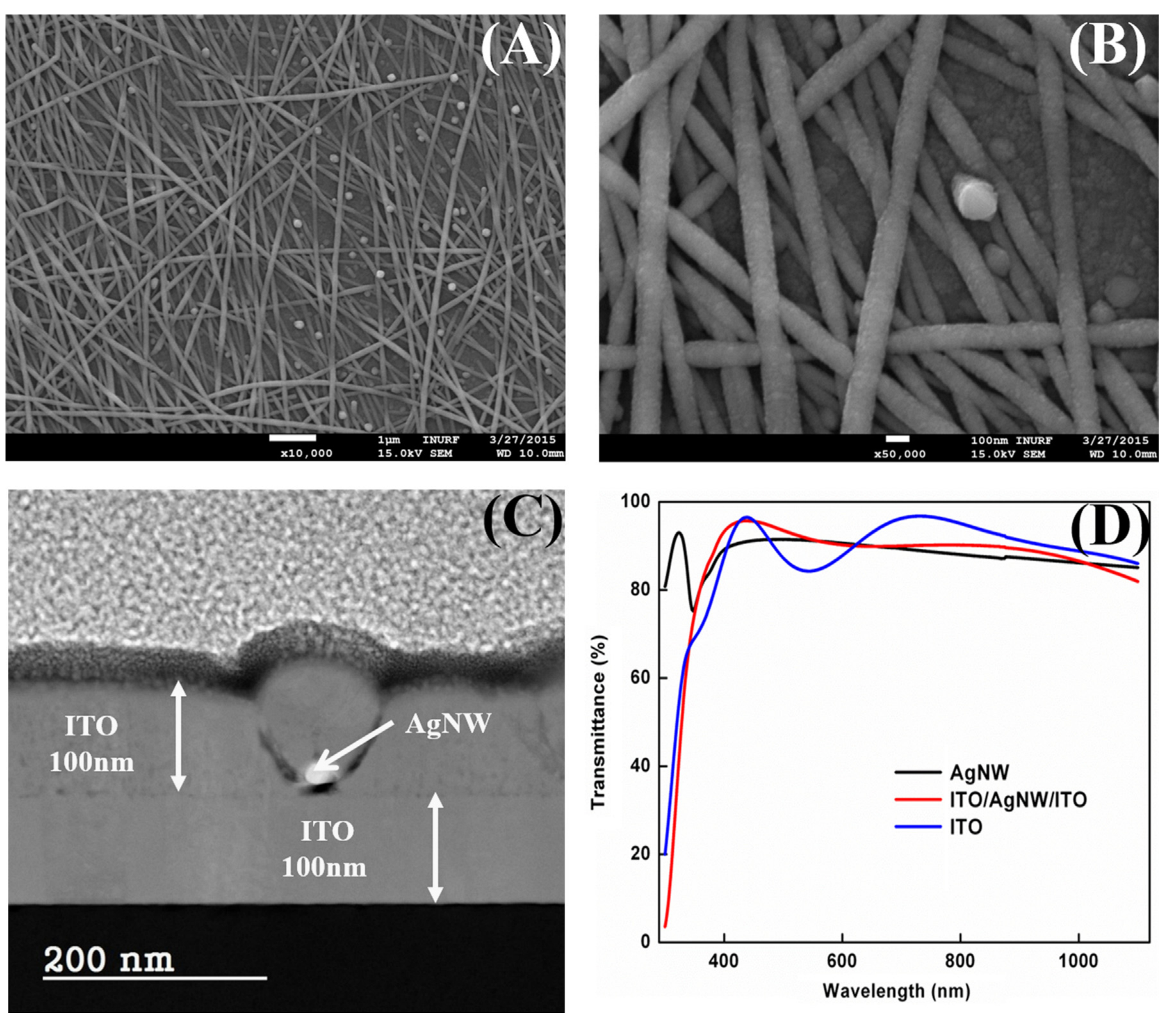

Fig. 2. (A) FESEM image of AgNWs, (B) enlarged view of AgNWs, (C) cross sectional SEM image of AgNWs embedded ITO layer and (D) transmittance spectra of ITO and AgNWs embedded ITO films.