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Enhancement of the efficiency of GaAs-based solar cells by sol-gel-synthesized ZnO nanowire arrays as the antireflection layer

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1. Introduction

Global-warming issues is a key component lies in the development of high-efficiency and low-cost photovoltaic cells.[1-3] There are a variety of solar cell technologies being studied; the most commercially available technology with the largest installed base on silicon flat panels using single-crystal, polycrystalline, or amorphous materials. Other technologies that use thin-film materials for cost saving, including Cu(InGa)Se_2(CIGS), CdTe, CdSe, and thin-film Si.[4-5] Compared to silicon, GaAs-based solar cells is ideal for absorbing standard solar spectrum and a maximum conversion efficiency of 31% is theoretically predicted..[6-8]

The antireflection layers plays an important role in enhancing the efficiency of photovoltaicby increasing light coupling into the active region of the device. Recently, Y. J. Lee et al.[9] fabricated the ZnO nanostructures respectively as AR layers with an reflective index gradient to achieve extremely low reflectance. In this study, the ZnO nanowire array as an AR layer was synthesized via low temperature solution growth By adjusting the growth condition, we can selectively grow ZnO nanowire array in order, It leads to the continuous vary refractive index to improve the antireflection properties.

2. Experiment method

a. Fabrication of GaAs-based single junction solar cells

In our experiment, the GaAs-based single junction solar cells was fabricated on an n-type GaAs(001) substrate by MOCVD via conventional p-n junction solar cell epitaxial process. The structure scheme of our GaAs-based

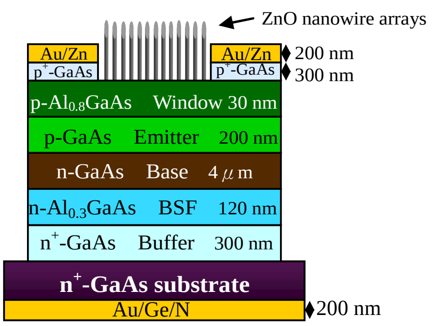

Fig. 1 Scheme of the GaAs solar cell structure.

single junction solar cells was shown in Fig. 1. The thickness of each layer is also depicted.

b. Fabrication of ZnO nanowire arrays as the antireflection layer by hydrothermal method

ZnO nanowire arrays were synthesized on seeded substrate by hydrothermal method. The seed layer was deposited by spin-coated sol-gel of ZnO precursor of zinc acetate dihydrate and 10 ml of EtOH that stirred at 80 ℃ for 30 minutes. Then the ZnO sol-gel was spin-coated onto GaAs substrates and GaAs-based solar cells. Following the hydrothermal method was exploited to synthesize ZnO nanowire arrays by suspending these ZnO seed-coated substrates in aqueous solution of zinc acetate dehydrate and hexamethylenetetramine (HMTA). The growth temperature was maintained at 90 ℃ for 1and 3 hours, respectively. After growth, the morphology of ZnO nanowire arrays were observed by a field-emission scanning electron microscope (FESEM). The crystal structure of ZnO seed layer and ZnO nanowire were analyzed by x-ray diffraction (XRD). Absolute hemispherical reflectance measurement was carried out with UV-visible spectrophotometers for wavelength ranging from 300 to 900 nm. The GaAs-based single junction solar cells were characterized under illumination condition with AM 1.5G.

3. Results and Discussion

The FESEM images of uniform ZnO nanowire arrays grown on sol-gel thin film at annealing temperature of 300 ℃ for 1and 3 hours were shown in Fig. 2. Figs. 2(c), and 2(d) are the magnifications of 2(a) and 2(b), respectively. The morphologies revealed that the nanowire with disordered growth for 1 hour was transferred to

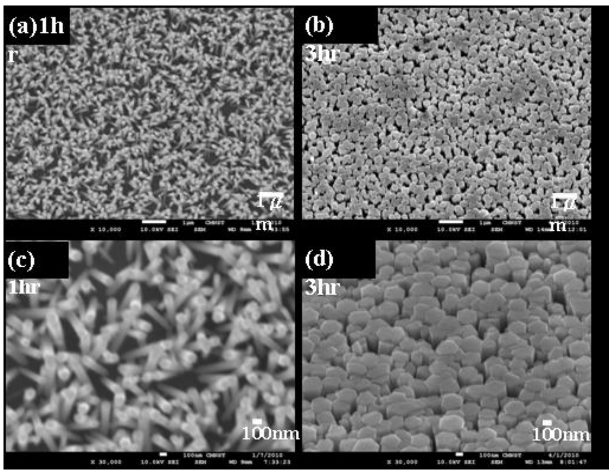

Fig. 2 FESEM images of the uniformly ZnO nanowire arrays on GaAs substrates with growth time of (a)1hr, (b) 3hr, . Images (c) and (d) are the local magnifications of (a) and (b).

well-aligned vertical growth for 3 hours. This result was presumed that the nanowire was disorder initially, and got denser and thicker with grown time increasing. Because of the crush of adjacent thicken nanowires, the disordered arrangement transferred to well-aligned one. In order to realize the effects of ZnO sol gel thin film and annealing temperature on the growth of ZnO nanowire arrays, the thin film was thermal annealed for 1 hour at 200 and 300 ℃, respectively. Fig. 3 shows the FESEM images for the surface morphologies of ZnO sol-gel thin films and thereon ZnO nanowire arrays at different annealing temperatures. The grains of thin films is getting bigger with increasing annealing temperature. Fig. 3(c) and 3(d) show the ZnO nanowire arrays corresponding to Fig. 3(a) and 3(b), respectively. The ZnO nanowires were synthesized at 90 ℃ for 1 hour onto above condition, respectively. Furthermore, it is notable that the ZnO nanowires on the ZnO thin films annealed at 300 ℃ are well-aligned vertically and become

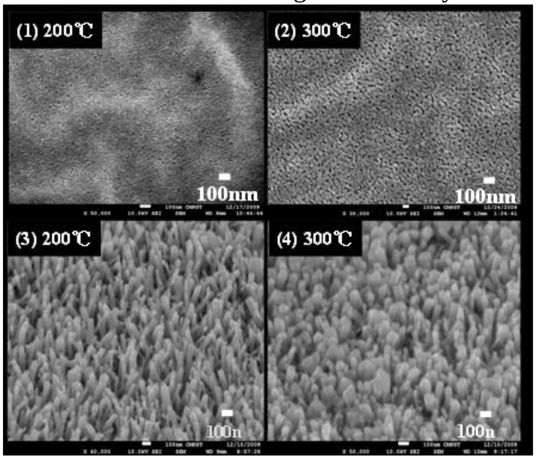

Fig. 3 SEM images of ZnO sol-gel thin films with annealing at (a) 200℃ and (b) 300℃. The (c) and (d) show the ZnO nanowire arrays were grown at 90℃ for 1hr.

thicker.

The x-ray diffraction (XRD) patterns of ZnO nanowire arrays with different growth time are illustrated in Fig. 4. The ZnO nanowire arrays with 300 ℃annealing temperature show a stronger (002) diffraction peak, which implies its perfect c-axis orientation (Fig. 3(d)). The reflectance spectra and the comparison of AR performance of referred GaAs wafer and synthesized ZnO nanowire arrays at various growth times were shown in Fig. 5. The reflectivity was about 4-5% between 650 and 750 nm. The poor reflectance of other samples resulted from disordered arrangement of nanowire arrays and rougher surface with dense ZnO grains. We have demonstrated that the variations in growth conditions strongly influenced the morphology of the textured ZnO nanowire arrays and thus a great effect on the AR layer performance because of regularity and diameter of the nanowires. Finally, the

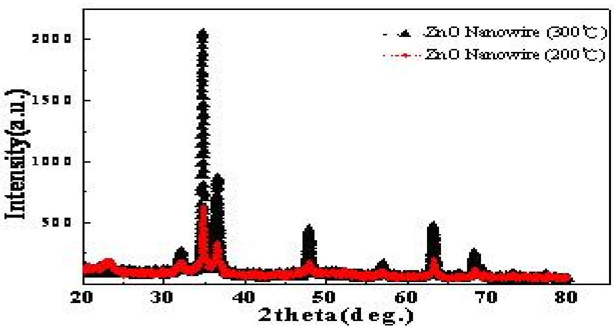

Fig. 4 X-ray diffraction patterns of ZnO nanowires with different seed-layer annealing temperature(200℃ and 300℃).

GaAs-based single junction solar cells with ZnO nanowire arrays were compared to the cells without AR treatment. The measured current-voltage characteristics are shown in table 1. The light conversion efficiency of the solar cell was improved from 5.76 to 8.16 % by employing aligned ZnO nanowire arrays as AR layer.

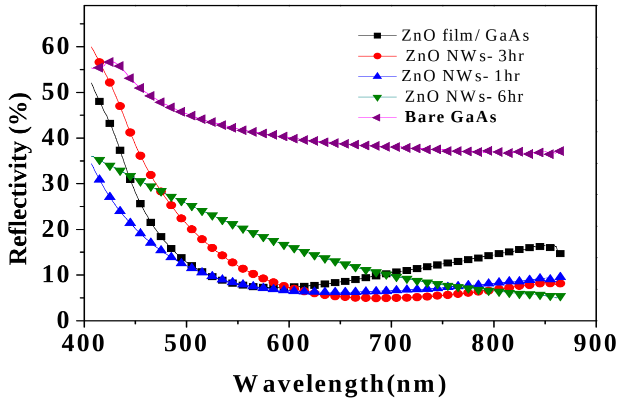

Fig. 5 Reflectance spectra of the solution-grown ZnO nanowires

Solar cell	Voc (V)	Jsc (mA/cm^2)	F.F(%)	Eff.(%)
no ARC	0.77	9.86	74.9%	5.76%
ZnO-ARC	0.78	13.87	74.4%	8.16%

Table 1 The current (I)-voltage (V) characteristics of the solar cells with and without the AR layers

4. Conclusion

By using low-temperature solution growth, our study revealed a simple and low-cost method to synthesize vertically well-aligned ZnO nanowire arrays for enhancing the performance of GaAs-based solar cells. Based on our experimental results, the conversion efficiency of single junction solar cells was improved over 42 %. Actually, this low-temperature process to fabricate AR films can extend its applications to other optoelectronic device.

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