Solar Energy Materials & Solar Cells 94 (2010) 930–934

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

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

Letter

Growth of vertically aligned ZnO nanorod arrays as antireflection layer on silicon solar cells

J.Y. Chen, K.W. Sun *

Department of Applied Chemistry, National Chiao Tung University, Hsinchu, Taiwan

ARTICLE INFO

Article history:
Received 26 November 2009
Accepted 4 January 2010
Available online 22 January 2010

Keywords:
Nanorod array
Antireflection
Solution synthesis

ABSTRACT

In this work we investigated the effects of growth time, spin-coating rates, and solution concentration on the reflection properties of the solution-grown ZnO nanorod arrays. The vertically aligned nanorod arrays were deposited on the surface of the Si solar cells as the antireflection (AR) layer. We found that the nanorod morphology, controlled through synthetic chemistry, has a great effect on the AR layer performance. We also demonstrated that the light harvest efficiency of the solar cells was greatly improved from 10.4% to 12.8% by using the vertically aligned ZnO nanorod arrays as the AR layer on poly-Si solar cells.

1. Introduction

An antireflection (AR) layer is a type of coating applied to the surface of a material to reduce light reflection and to increase light transmission. The AR layers can be used in solar cells, planar displays, glasses, prisms, videos, and camera monitors. Surface-relief gratings with the sizes smaller than the wavelength of light, named subwavelength structures (SWSs), behave as AR surfaces. By using a mechanically continuous wavelike grating (e.g., pyramidal, triangular, and conical shapes), the SWS grating acts as a surface possessing a gradually and continuously changing refractive index profile from the air to the substrate. Deeper SWS gratings can greatly enhance the AR effect, since the refractive index value changes smoothly and continuously. Tapered SWSs have been fabricated through different methods [1–9]. Ishimori et al. used an e-beam lithography technique to generate triangular structures in the photoresist and utilized a focused SF_6 fast atom beam (FAB) to produce tapered SWSs. However, the fabrication costs, which involve either electron-beam lithography or various etching processes, can be significant. Recently, versatile SWSs have emerged as promising candidates for AR coatings such as etching with self-aggregated nanodot mask [4,5], moth-eye-like fabrication [6,7], and nanostructures employing oblique-angle deposition methods [8,9].

More recently, ZnO becomes attractive as a dielectric AR layer material because of its good transparency, appropriate refractive index, and ability to form textured coating via anisotropic growth [10–17]. Various physical, chemical, and electrochemical deposition techniques have been explored to create oriented arrays of ZnO nanorod. For instance, pulsed laser deposition [10], metal-organic chemical vapor deposition [11], and epitaxial electrodeposition [12] have been achieved in the fabrication of ZnO nanorod arrays. However, the fabrication costs can be significant. Recently, the solution synthesis of ZnO nanorod arrays has been demonstrated as a simple, low temperature, and low-cost method [13–16]. Vertically aligned ZnO nanorod arrays have been used to produce AR layers [17,18]. Most of the research presented good AR properties with ZnO nanorod arrays. However, there is no report on the fabrication, nor tests of the properties of the real Si P–N junction solar cell devices incorporated with the ZnO nanorod arrays as the AR layers. In this paper, we report the effects of highly textured ZnO nanorod arrays, fabricated by low-temperature solution growth, on AR layer performance and apply them on the silicon solar cell to provide a promising technique for the fabrication of high-efficiency solar cell.

2. Experimental section

The ZnO nanorods used in the present experiment were grown on Si substrate and poly-Si solar cell by aqueous chemical growth method [13,16]. Before the growth process, the substrates were coated with a ZnO nanoparticle layer by the sol–gel preparation [19] as the seeding layer.

In this work, the poly-Si solar cells were fabricated on boron-doped poly-Si substrates with a thickness of 200 μm. The substrate surface was first roughened by the HF/HNO_3 solution to increase the illumination area. It was then doped to n-type with a Centrothem E-2000 APCVD to fabricate the P–N junction. The ion implanting depth was 80 nm. After the dopant activation, the

* Corresponding author.
E-mail address: kwsun@mail.nctu.edu.tw (K.W. Sun).

0927-0248/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.solmat.2010.01.005

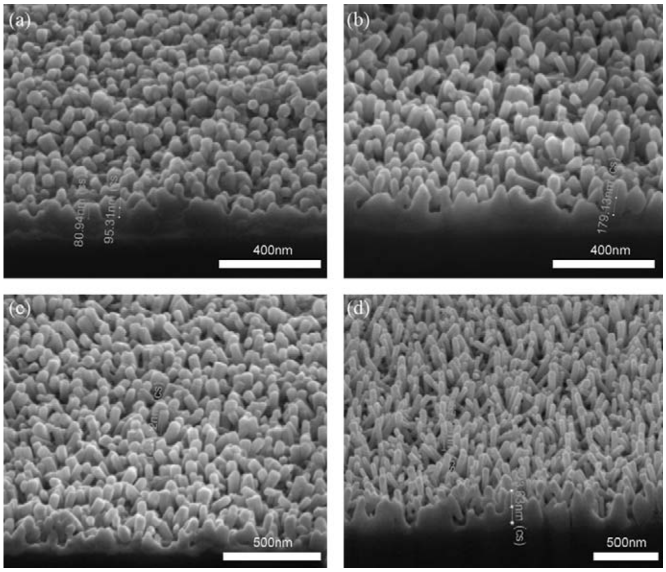

Fig. 1. SEM images of the vertically aligned ZnO nanorod arrays on Si substrates with growth time of (a) 120, (b) 180, (c) 240, and (d) 300 min.

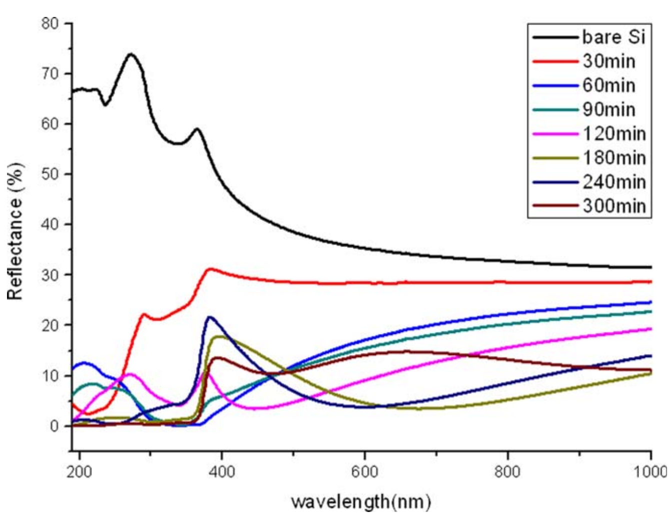

Fig. 2. Reflectance of the solution-grown ZnO nanorods with different growth time.

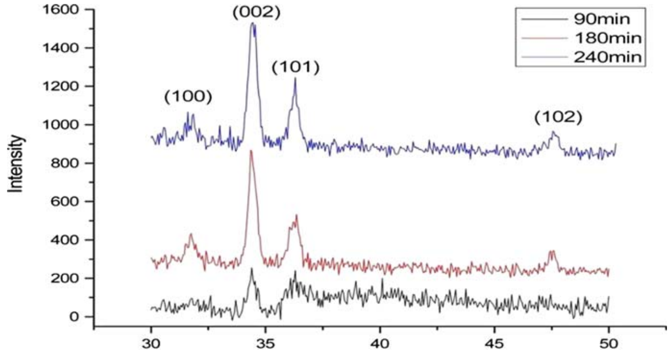

Fig. 3. X-ray diffraction patterns of ZnO nanorods with different growth time.

top and backside contacts were formed by a printer system (Baccini screen printing line) with Ag and Al. Finally, the cell was annealed at 850 °C to form ohmic contacts on both sides.

Both silicon wafers and poly-Si solar cells were used as the templates for the growth of the vertically aligned ZnO nanorod arrays. The substrate surface was first cleaned up with ACE, IPA, and D.I. water by ultrasonic agitation. The decomposition or hydrolysis of zinc salts is a well-established method to fabricate ZnO nanoparticle. First, the zinc acetate dihydrate and monoethanolamine were dissolved in the 2-methoxyethanol solution,

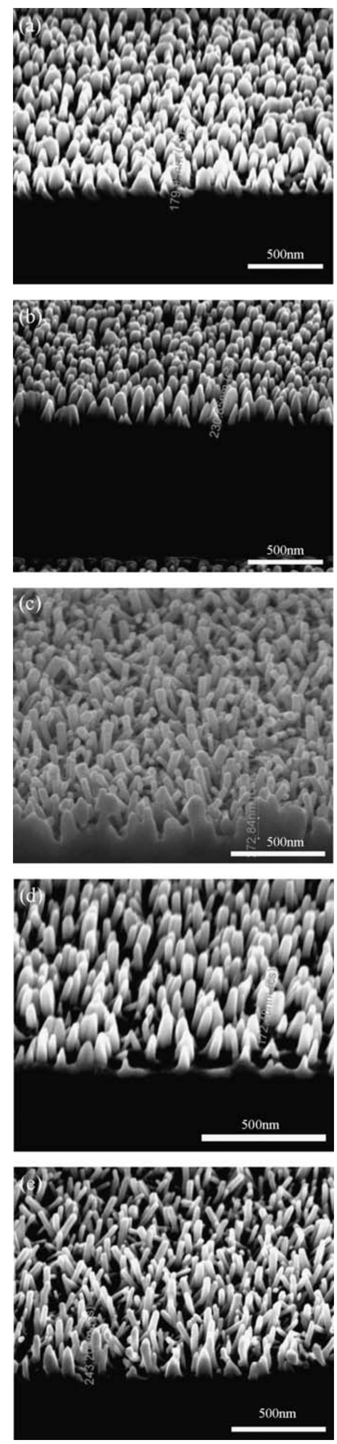

Fig. 4. SEM images of the vertically aligned ZnO nanorod arrays grown on Si substrates with spin-coating rate of (a) 1000, (b) 2000, (c) 3000, (d) 4000, and (e) 5000 rpm.