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Letter

Enhancement of the light conversion efficiency of silicon solar cells by using nanoimprint anti-reflection layer

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ABSTRACT

In this report, the results of the fabrication of nanostructured Si molds by e-beam lithography and chemical wet etching are presented. A home-made pneumatic nanoimprint system was used to transfer the mold patterns to a PMMA layer on a Si template using the spin-coating replication/hot-embossing techniques. The patterned PMMA layer was peeled off from the Si template and directly transferred onto the surface of a poly-Si P–N junction solar cell device to serve as the anti-reflection (AR) layer. It provides a simple and low-cost means for large-scale use in the production of AR layers for improving solar cell performance. A drastic reduction in reflectivity of the AR layer over a broad spectral range was demonstrated. In addition, the great improvement on the light harvest efficiency of the solar cells from 10.4% to 13.5% using the nanostructured PMMA layer as the AR layer was validated.

1. Introduction

An anti-reflection (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 the solar cell, planar displays, glasses, prisms, videos, and camera monitors. Surface-relief gratings with the size smaller than the wavelength of light, named sub-wavelength structure (SWS), behave as anti-reflection surfaces. By using a mechanically continuous wavelike grating (e.g., pyramidal, triangular, 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 grating can greatly enhance the anti-reflection effect, since the refractive index value changes smoothly and continuously. Tapered SWSs have been fabricated through different methods [1–3]. 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 sub-wavelength structures. 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], nanorod fabrication [8–10], and nanostructures employing oblique-angle deposition methods [11,12].

Nanoimprint lithography (NIL), which was first demonstrated by Chou et al. [13], is a lithography technique performed by pressing the patterned mold so that it makes contact with the polymer resist directly. The patterns on the mold will transfer to the polymer resist without any exposure source. Therefore, the diffraction effect of light can be ignored and limitation is dependent only on the pattern size of mold rather than the wavelength of exposure light. This technology provides a different way to fabricate nanostructures with easy processes, high throughput, and low cost. It is capable of replicating patterns with a linewidth below 10 nm in a parallel manner [14]. NIL has been used to produce large-area polymer sheets with SWS as AR layers [15,16]. Most of the research presented good anti-reflection properties with the imprinted polymer layers. 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 nanoimprinted SWS as the AR layers. In this paper, we combined the NIL technology with solar cell devices and provided a promising technique for the fabrication of high efficiency solar cell.

2. Material and methods

The flow charts of the mold fabrication and spin-coating replication/hot-embossing NIL processes are shown in Fig. 1. A silicon wafer was used as the substrate for the hot-embossing NIL mold fabrication. The substrate surface was first cleaned up with ACE, IPA, and D.I. water by ultrasonic agitation. A 50 nm SiO_2 was deposited on the surface as the mask of the wet etching. The sample was then coated with ZEP-520A photoresist and exposed to the electron beam (Elionix ELS-7500EX 50 kV Electron Beam Lithography

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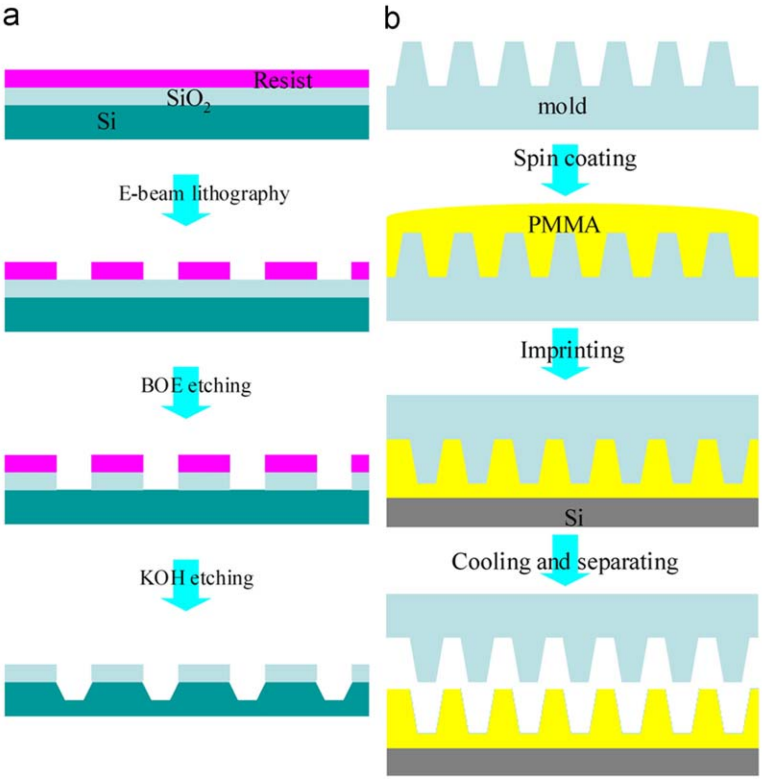

Fig. 1. Steps used for (a) the mold fabrication and (b) the spin-coating replication/hot-embossing processes.

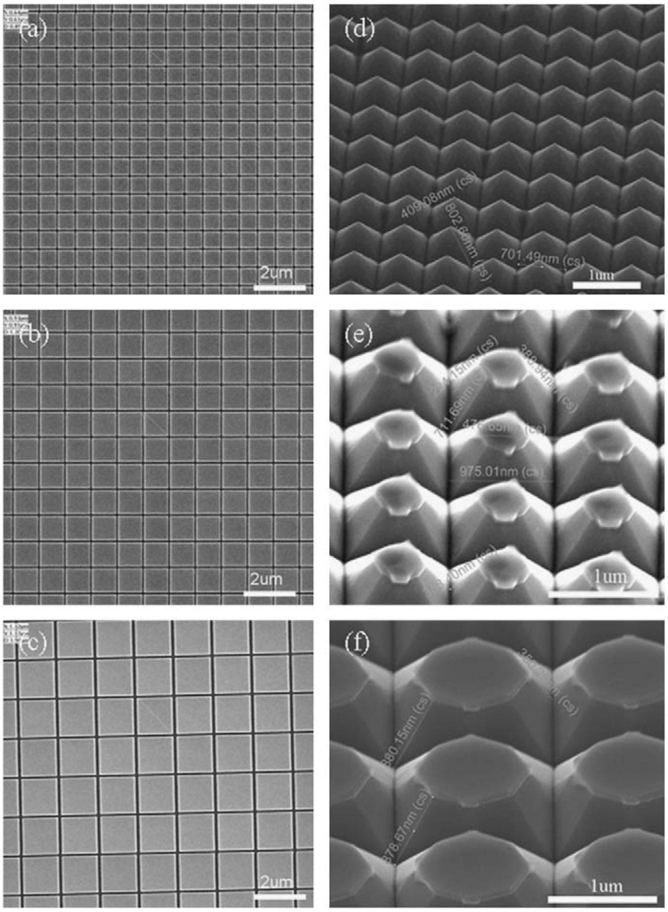

Fig. 2. SEM images of the e-beam defined grating patterns with pitches of (a) 700 nm (b) 1000 nm and (c) 1500 nm. SEM images of the fabricated silicon molds with pitches of (d) 700 nm (e) 1000 nm and (f) 1500 nm.