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Enhanced conversion efficiency in nanocrystalline solar cells using optically functional patterns

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ABSTRACT

The lower conversion efficiency of nanocrystalline silicon (nc-Si:H) solar cells is a result of its lower photon absorption capability of nc-Si:H. To increase photon absorption of nc-Si:H, the Ag substrates were fabricated with optically functional patterns. Two types of patterns, with random and regular structures, were formed by direct imprint technology. Owing to these optically functional patterns, the scattering of reflected light at the surface of the patterned Ag was enhanced and the optical path became longer. Thus, a greater amount of photons was absorbed by the nc-Si:H layer. Compared to flat Ag (without a surface pattern), the light absorption value of the nc-Si:H layer with a random structure pattern was increased at wavelengths ranging from 600 to 1100 nm. In the case of the regular patterned Ag, the light absorption value of the nc-Si:H layer was higher than the flat Ag at 300 to 1100 nm. Subsequently, nc-Si:H solar cells constructed on the optically functional pattern exhibit a 15.7% higher J_{sc} value and a 19.5% higher overall conversion efficiency, compared to an identical solar cell on flat Ag.

1. Introduction

Nanocrystalline silicon (nc-Si:H) is a very attractive candidate for application in thin film solar cells. Compared to amorphous silicon (a-Si:H), it has higher absorption in the red and near-infrared light spectral region, and is more stable than hydrogenated a-Si:H [1–6]. However, because of the low absorption of the indirect band gap, light absorption of nanocrystalline silicon is less than that of a-Si:H in the short and visible wavelength range. Light scattering is an effective method that can compensate the low absorption of the indirect band gap [7]. In order to compensate the demerits of nc-Si:H and to increase the conversion efficiency of nc-Si:H cells, optical losses such as surface reflectance and insufficient light absorption in the active layer must be minimized, and the optical path of light must be increased for effective absorption [8–12].

Optically functional patterns can be fabricated in two types for effective light absorption: irregular and regular. The random shape, size, and pitch of the irregular pattern structures increase light scattering by changing the incident angle of light due to the irregularity of the pattern [13,14]. 3-D photonic crystal patterns can selectively increase the reflectance and scattering of light within a specific wavelength band depending on the shape, size, and pitch of the structures [15–18]. Periodic arrays of conical structures have also been used as LED substrates for effective reflection light scattering [19].

The conversion efficiency of thin-film solar cells on optically functional patterned Ag substrates can be increased by increasing the light absorption with severe scattering of light reflected on the substrate. The patterns on substrates can be fabricated using direct printing technology. The direct printing technology is an additive method in which patterns can be formed by depositing materials such as a heat-resistant polymer, metal ink, or spin-on glass. This method has several advantages, such as being a simple and low cost process, providing easy control over the residual layer thickness, ability to use various functional resists, eliminating the need for an adhesive layer in the printing process, and transferring a high fidelity pattern onto the substrate [20–23].

In this study, we fabricated two types of functional patterns: one was a random pattern that had the random morphology of a wet etched Al-doped ZnO (AZO) surface; the other was a regular pattern that had a micro conical structure from a patterned sapphire substrate (PSS). The patterns were fabricated by a direct printing technique which has advantages of a simple process, high throughput and low process cost. The direct printing process consisted of three steps. In first step, resin was coated on a pattern mold. In second step, the coated pattern mold was aligned with substrate. In third step, resin was patterned on a substrate after removing the pattern mold. The two patterns were fabricated on nc-Si:H substrates for reflected light scattering. The optically functional patterned Ag substrates were fabricated by depositing

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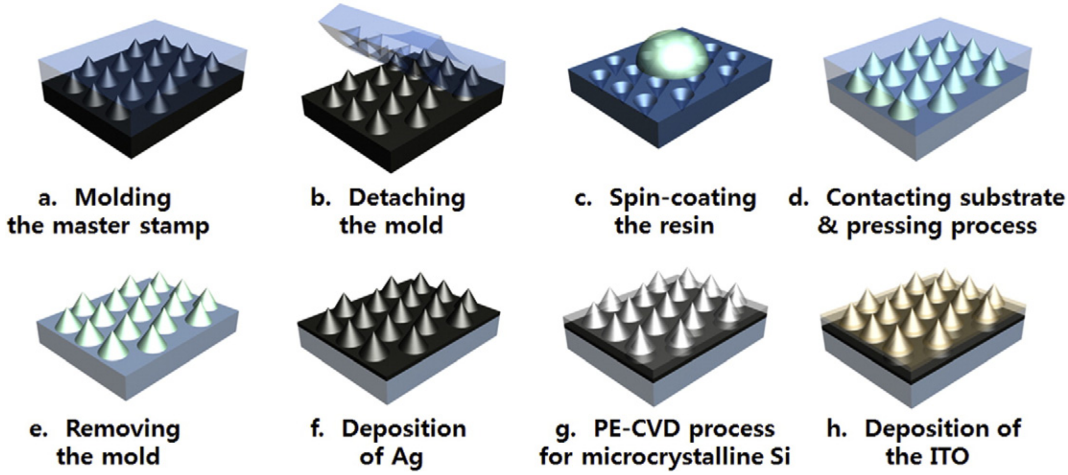

Fig. 1. Schematic process of fabricating the optically functional pattern and nanocrystalline silicon solar cells on the patterns.

Ag on the patterns. Reflected light was strongly scattered at the patterned Ag surface, and thus, more reflected light could be effectively absorbed in the nc-Si:H layer, increasing the cell conversion efficiency.

2. Experimental section

The overall experimental process flow is shown in Fig. 1. Prior to the pattern fabrication process, a wet-etched AZO master stamp for random patterns was prepared by wet-etching an AZO film with 5% HCl in DI water. The PSS master stamp, consisting of microstructures with 2.5 μm diameter and 1.0 μm height, was prepared by photolithography and wet etching processes. The master patterns were replicated into polydimethylsiloxane (PDMS) molds, which were mixed by a 10:1 volumetric ratio of Sylgard 184A and Sylgard 184B from Dow Corning. The PDMS mixture was poured in a master stamp and then the PDMS/master stamp was annealed at 120 °C for 2 h (Fig. 1a). The PDMS mold was released from the master stamp and hydrogen silsesquioxane (HSQ, Dow Corning) was spin-coated on the patterned surface of the

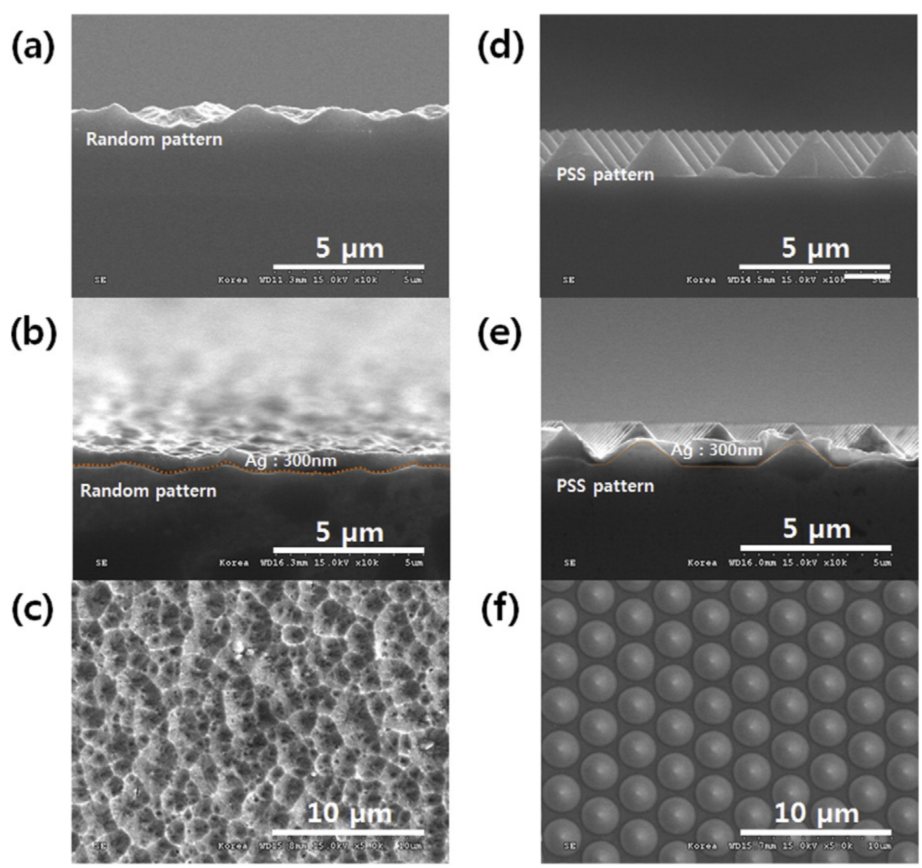

Fig. 2. Scanning electron microscopy (SEM) images of optically functional patterns on Ag substrates: (a–c) random pattern-replicated wet etched AZO and (b) regular pattern-replicated PSS.