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a-Si:H Solar Cell with Hexagonal Nano-Cylinder Array on Glass Substrate

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1. Introduction

Effective light trapping is an important way to enhance efficiency in hydrogenated amorphous silicon (a-Si:H) solar cells due to the low absorption in long wavelength and short optical path length of thin absorbing layer. Typically, surface texturing [1,2] such as pyramidal structure has been employed to enhance light absorption in wafer based Si solar cell because light scatters into the solar cells over a large angle. However, it is not suitable for thin film solar cell because of large–scale geometries. Recently, the field of plasmonics has emerged as a new method for the efficiency enhancement [3-5]. The localized surface plasmon polaritons (LSPPs) arise from the electromagnetic field enhancement near the metal surface and then improves optical absorption of incident photons in the absorbing layer near the metal film. The resonant wavelength depends on the size, shape, metal type and localized dielectric of nanostructures, so many researchers vary the nanostructures to magnify specific light scattering [9, 10]. One major challenge of this plasmonic solar cell is to pattern period nanostructures of large-area thin film solar cells. Electron beam lithography is used to fabricate nanostructures with well controlled size, shape and spacing, but it is characterized by low sample output and high sample cost.

In this study, a simple method of light trapping by hexagonal nano-cylinder array on the glass substrate in p-i-n a-Si:H solar cells was investigated experimentally. We utilized self-assembled SiO_2 nanoparticles and nanosphere lithography [11-13] to pattern the glass substrate and reported an efficiency improvement compared to the solar cell with flat glass substrate. The depths of nano-cylinder were tuned from 60 to 105nm to optimize the efficiency. Compared to reference cell, the solar cell with 75nm-depth nano-cylinder has 29% enhancement in efficiency.

2. Experiment

The hexagonal nano-cylinder patterned glass substrate was prepared by self-assembled nanoparticles and nanosphere lithography. First, the substrate was dipped into the solution containing 450nm-diameter SiO_2 nanoparticles, DI water and isopropyl alcohol. The SiO_2 nanoparticles coated on the substrate where they self-assembled into a hexagonally close-packed array that served as an etching mask. The cross-sectional view of particle coated substrate is shown in Fig. 1(a). After the SiO_2 coated substrate was dried, the substrate was etched by reactive ion etching (RIE) with different etching time to vary the diameter and depth of nano-cylinders. As illustrated in Fig. 1(b), the SiO_2 particles acted as an etching mask; meanwhile, the plasma penetrated the space of every nano-particle and then etched the substrate. After SiO_2 particles were removed, as shown in Fig. 1(c), a 200nm Ag layer as a back contact was then deposited on the substrate by e-gun. The depths of Ag coated nano-cylinder on glass substrate contained 60, 75, 90 and 105nm. Fig. 1(d) shows the AFM picture of Ag nano-cylinder array with 75nm in depth and 450nm in diameter on the glass substrate. The Ag coated glass substrates were back contacts of solar cells and we measured their reflectance to study the light scattering effect. The reflectance measured by SHIMADZU spectrometer UV-1650PC is shown in Fig. 3.

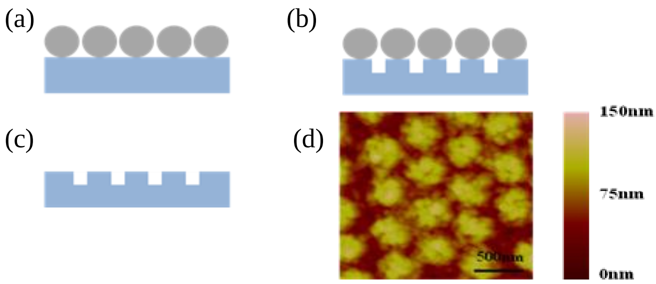

Fig. 1 Process of patterning the hexagonal lattice glass substrate. (a) self-assembled particles on the glass substrate (b) etching the substrate by RIE (c) remove particles and clean the substrate (d) AFM picture of patterned hexagonal nano-cylinder array substrate with Ag back contact.

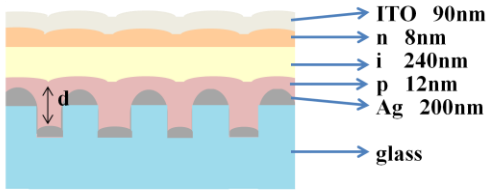

Fig. 2 The side view of solar cell on nano-cylinder glass substrate.

Figure 2 shows the cross-sectional view of a-Si:H solar cell on patterned glass substrate. The thin film a-Si:H solar cells were deposited by plasma enhanced chemical vapor deposition (PECVD) on Ag coated flat and patterned glass substrate with 60,75, 90, 105nm-depth nano-cylinders, respectively. All solar cells were placed side-by-side and fabricated of the same process to ensure the identical growth conditions. The thickness of intrinsic layer in all p-i-n solar cells was 240nm. To form the anti-reflection coating layer and top contact, 90nm ITO layer was then sputtered on the n-type layer of solar cells. The open-circuit voltage (V_{OC}) and short-circuit current (J_{SC}) were measured under a simulated AM1.5 spectrum, and the measured results are also present in Table I. and Fig. 4.

Table I. Measured results of flat and patterned solar cells.

Depth (nm)	Jsc (mA/cm^2)	Voc (V)	FF (%)	Efficiency (%)
Flat	12.34	0.76	52.47	4.92
60	16.44	0.74	51.34	6.21
75	16.39	0.75	51.61	6.34
90	15.91	0.76	51.97	6.28
105	14.16	0.76	53.00	5.70

3. Results and discussion

Figure 3 presents reflection spectra of Ag film on flat and patterned 75nm-depth nano-cylinder substrate. The dip at 320nm is the position of Ag surface plasmon. The dip at 507nm is LSP position of patterned 75nm-depth nano-cylinder, and the LSP position can be adjusted by changing metal size on nano-cylinder [9].

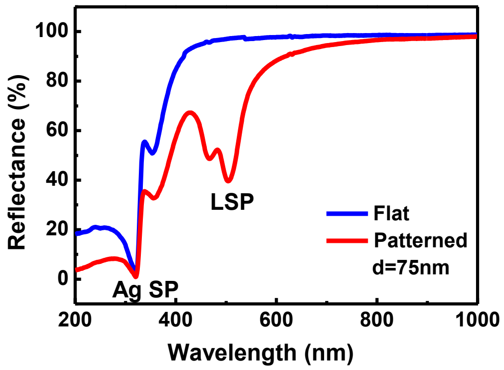

Fig. 3 Reflection spectra of Ag film on flat and patterned 75nm-depth nano-cylinder substrate.

The I-V curves of flat and patterned solar cell (Fig. 2) with a simulated AM1.5 spectrum are presented in Fig. 4. The measured values of V_{OC} and J_{SC}, and the calculated values of fill factor (FF) and efficiency by the values of V_{OC} and J_{SC} are shown in Table I. The results demonstrate that the patterned solar cells with different depths of nano-cylinder have higher efficiency than the flat solar cell due to significant improvement in J_{SC}. The patterned nano-cylinder solar cell with depth of 75nm exhibits a 33% higher J_{SC} than the flat substrate cell, demonstrating increased optical path length. Enhanced photocurrent is observed within red spectrum region. The V_{OC} of patterned solar cell is slight decreased from 0.76V to 0.75V. Nevertheless, the efficiency of solar cell with 75nm-depth hexagonal nano-cylinder array is increased from 4.92% to 6.34%, exhibited a 29% increase compared to the flat solar cell. The efficiency of solar cell increases, suggest that the excitation of localized surface plasmon polaritons (nonradiative) using a nano-cylinder integrated on top of the solar cell absorption region [9].

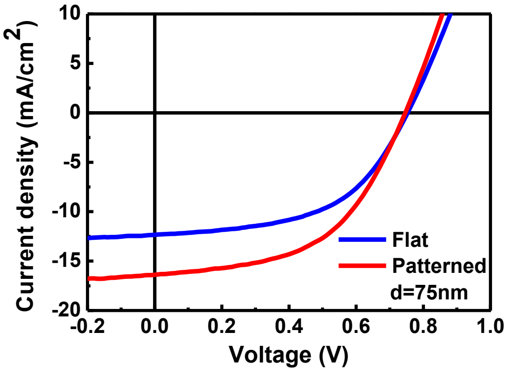

Fig. 4 I-V curves of the flat and patterned solar cells. The depth of nano-cylinder on glass substrate is 75nm.

4. Conclusions

In conclusions, solar cells with different depth hexagonal nano-cylinder on glass substrates by self-assembled SiO_2 particles and nanosphere lithography method were developed. The solar cell with nano-cylinder 75nm in depth demonstrates a significant improvement in efficiency. Observations suggest that the excitation of LSPP at long wavelengths using a nano-cylinder integrated on top of the solar cell absorption region. Compared to the solar cell of flat substrate, the J_{SC} of patterned solar cells with 60 to 105nm depth nano-cylinder increases 15% to 33%, and the efficiency increases 15% to 29%.

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