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Enhancement of Light Harvesting and Power Conversion Efficiency in GaAs Solar Cell Using Flexible Nano-pattern PDMS Film

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1. Introduction

Because of the seriously global warming effect and oil extinction, the usage of solar energy gets more and more important issue in recent years. GaAs-based solar cells have been regarded as a promising candidate to provide high power conversion efficiency (PCE) because of their direct band gap and strong absorption over the entire visible part of the solar spectrum, as compared with conventional Si-based solar cells. So far, a record of over 40% PCE has been demonstrated in a triple-junction InGaP/GaAs/Ge solar cell under concentrated illumination [1]. For highly solar cell power conversion efficiency, the development of ARC or nanostructures can effectively eliminate surface Fresnel reflection. However, the fabrication of these structures requires expensive equipment and vacuum system to achieve the anti-reflection effect. In this work, we demonstrate a platform to combine the flexible nano-patterned PDMS film with GaAs solar cell. The advantages of using PDMS film are the low-cost, non-vacuum system and simple process. The PDMS film provides a refractive index gradient to serve as an anti-reflection layer and the nano-pattern of PDMS film provides extra benefits of light trapping and scattering. Then we demonstrate the great effect of PDMS film on GaAs solar cells from the measurement of photovoltaic current density-voltage (J–V) and the external quantum efficiency (EQE) characteristic.

2. Fabrication

Fig. 1 shows the process plot of a single-junction GaAs solar cell with nano-patterned PDMS film. First, the polystyrene (PS) nanospheres with a plurality of 10 wt.% and diameter of 600 nm was spun-coated on the surface of the SiN_x layer, and the PS nanospheres naturally formed a close-packed monolayer mask, as schematically shown in Fig. 1(a). Next, the ICP-RIE was performed on SiN_x and PS spheres and etched the SiNx surface into the nano-tip shapes, then the residual PS nanospheres were then removed by dipping into acetone with sonification for 5 min, as schematically shown in Fig. 1(b). Third, Fig. 1(c) shows the PDMS pre-polymer solution was spun on nano-tip SiNx mold-pattern surface and then the substrate was baked at 100 ℃ for one hour [2]. Finally, after detaching from the SiNx mold, the flexible nano-patterned PDMS film was pasted up on the surface of GaAs solar cell, as shown in Fig. 1(d). Fig. 2(a) and 2(b) show the scanning electron microscopic (SEM) images of the top view and cross section of the fabricated nano-tip nanostructure SiNx mold-pattern, respectively. The nano-tip nanostructure SiNx mold-pattern exhibits a periodicity of 600 nm in a hexagonal close-packed (hcp) lattice and a height of 400nm. Fig. 2(c) shows the SEM images of the detached PDMS film, then the PDMS film was successfully obtained and the height of the nano-patterned structure was also about 400nm. Fig. 2(d) shows the large area of imprinted PDMS film.

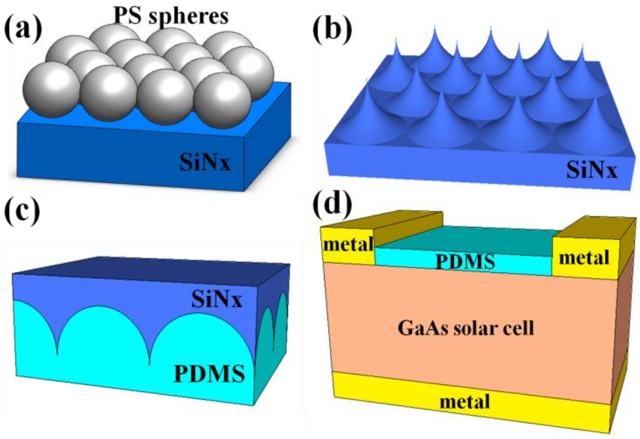

Fig. 1 The process plot of the fabricated single-junction GaAs solar cell with nanp-patterned PDMS film.

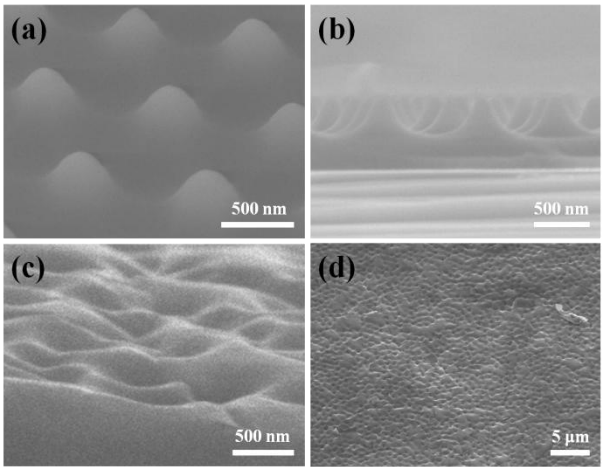

Fig. 2 (a)(b) is the SEM images of nanostructure SiNx mold-pattern and (c)(d) is the SEM images of nano-patterned PDMS film.

2. Results and discussions

To understand how the scattering light capability of the flexible nano-patterned PDMS varies in the far-field pattern, we first measured the angle-dependent intensity of transmittance by bidirectional transmittance distribution function (BTDF) system with an incident light of 380 nm and ultraviolet-visible spectrophotometer. In order to more clearly understanding the performance of light scattering by the nano structure of PDMS, we let the spectrum of nano-patterned PDMS film to minus the one of flat PDMS, as shown in Fig. 3. As the results, the introduction of the flexible nano-patterned PDMS film can deflect the photons to much wider angle and lengthen the traveling distance in the cell, which implies higher possibility of getting absorbed.

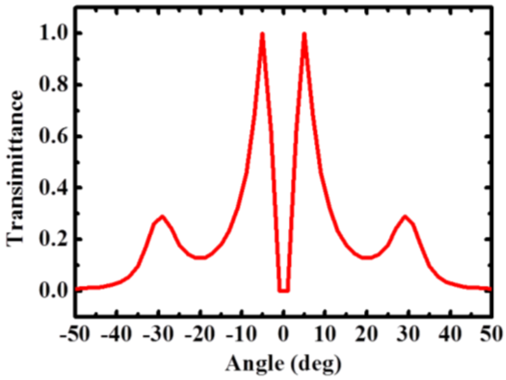

Fig. 3 The measured angular-dependent intensity of transmittance of the nano-patterned PDMS film.

Fig. 4(a) shows the photovoltaic current density-voltage (J–V) characteristics of the GaAs solar cell with nano-patterned PDMS film and the conventional SiO_2 AR coated GaAs solar cell. The GaAs solar cell with nano-patterned PDMS layer can effectively enhance the short-circuit current density from 18.60 to 21.43 mA/cm^2 and the power conversion efficiency from 15.36 to 17.64 %, corresponding to 15 % enhancement compared to the GaAs solar cell without PDMS, and even better than the AR coated one. The open-circuit voltage (V_{oc}) and the fill-factor (FF) in GaAs solar cell exhibit negligible change, because the textured PDMS film was pasted up on the surface of GaAs solar cell and did not interfere with the diode operation. We also measured the spectral response of the external quantum efficiency (EQE), as shown in Fig. 4(b). The sample with nano-patterned PDMS exhibits a higher EQE than the others in the all range of GaAs absorption spectrum. And this outstanding EQE enhancement is because of the lower reflection, as shown in Fig. 5(a)(b). The reduction of reflectance means more photons can get into the devices due to suitable refractive index of PDMS film (n~1.42) and the increase of light scattering due to the introduction of the nano-patterned of PDMS film. Therefore, more carriers can be generated and the photocurrent can be raised accordingly. With this way, the cost of device could be effectively reducing and replace conventional SiO_2 ARC of solar cell.

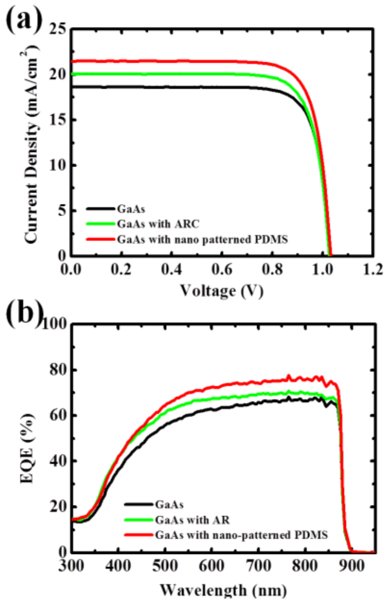

Fig. 4 (a) Photovoltaic I–V characteristics and (b) external quantum efficiency of nano-patterned PDMS, No textured PDMS, and ARC of GaAs solar cells.

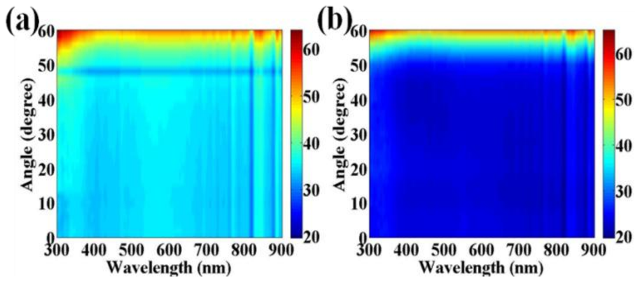

Fig. 5. The measured angular reflection spectra for (a) GaAs solar cell and (b) GaAs solar cell with nano-patterned PDMS film.

3. Conclusions

In conclusion, we successfully improve power conversion efficiency by combining a flexible nano-patterned PDMS film with GaAs solar cell. The main mechanism of the enhancement can be attributed to anti-reflection and light scattering. Consequently, the overall current density and power conversion efficiency enhance about 15% compared to the GaAs solar cell without PDMS. From the reflection color maps, it can be clearly seen that the GaAs solar cell with nano-patterned PDMS exhibits lower reflection and less dependency on wavelengths and incident angles than the one without PDMS film. Finally, we believe this technology shall be a great candidate for next generation of highly efficient and low-cost photovoltaic devices.

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