Improved electric energy production of solar cell using small silver nanoparticles

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Abstract. The influence of small Ag nanoparticles (NPs) on the all-day electric energy production of solar cells has been investigated. The small Ag NPs were deposited on the cell surface by the magnetron sputtering system. The cell without NPs is used as a reference cell. The external quantum efficiency (EQE) curves indicate that the performance of cell with 8% nanoparticle coverage is better than that of other cells in the long wavelength band. The maximum power-angle curves indicate that the small Ag NPs can effectively improve the all-day electric energy production of solar cell. Comparing with the values of reference cell, the half peak height of maximum power for cell optimized increases by 65%, and the half peak breadth of maximum power for cell optimized broadens by 3%. The enhancements of optimum operating current and optimum operating voltage lead directly to the enhancement of maximum power.

Keywords: small Ag nanoparticle, solar cell, external quantum efficiency, electric energy production

1. Introduction

Photovoltaic is emerging as an important technology for future energy production. Thus, it is necessary to realize a high conversion efficiency of the solar cells [1]. In recent years, surface plasmon has been taken as one of the best solutions to achieve this object [2-4]. Many studies have demonstrated that the NPs coating on solar cell surface can improve the photoelectric performance of solar cells [5-12]. However, most of these studies about the influence of large NPs coating on the optical absorption and conversion efficiency of solar cells are reported. Few studies about the influence of small NPs coating on the all-day electric energy production of solar cells are reported. In our previous work, we have demonstrated that the use of small Ag NPs can greatly enhance the conversion efficiency for solar cells [13]. In the present work, we have applied the small Ag NPs to achieve an enhancement in electric energy production for solar cells. Here, the all-day electric energy production for solar cells is explored by varying the incidence angles.

2. Experiment

In our experiments, the crystalline Si solar cell of 125 mm×125 mm was cut into several square pieces of 20 mm×20 mm, as shown in figure 1. The photovoltaic performance for solar cells was decreased obviously owing to the mechanical damage in cutting process. The performance parameters for solar

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cells before and after cutting are shown in table 1. To improve nanoparticle adhesion, the solar cells were washed in ethanol, and then blown dry with cold-blast air. Ag NPs were deposited on solar cell surfaces using the magnetron sputtering system (Model: JGP600). The base pressure of vacuum chamber was better than 5×10^{-5} Pa. The working pressure was 0.3 Pa. The deposition rate was 0.05 nm/s. The surface coverage of 5%, 8%, 14% and 23% were obtained respectively by controlling the deposition times.

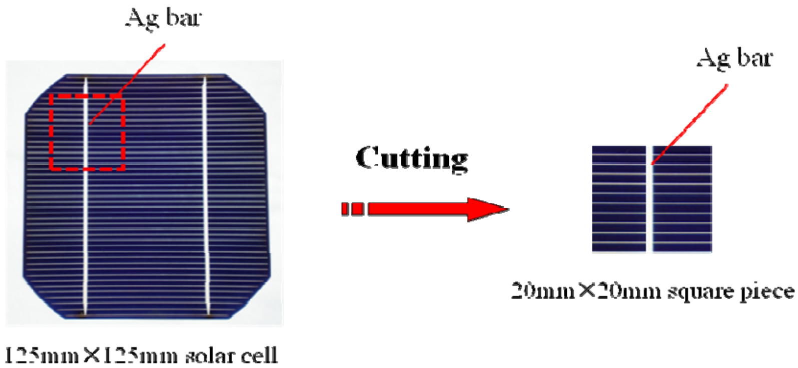


Figure 1. Schematic diagram of solar cell cutting.

Table 1. Performance parameters for solar cells before and after cutting.

Parameter	Short-circuit current (mA)	Open-circuit voltage (V)	Fill factor (%)	Efficiency (%)
125mm×125mm	441.0	9.28	73.0	17.5
20mm×20mm	114.2	0.56	42.2	7.9

Scanning Electron Microscopy (SEM) was used to measure the nanoparticle size. Current-voltage (I-V) characteristics were obtained using the *I-V* characteristic test system (Model: Solar IV-500A). External quantum efficiency (EQE) characteristics were obtained using the quantum efficiency test system (Model: Solar Cell Scan 100).

3. Results and discussion

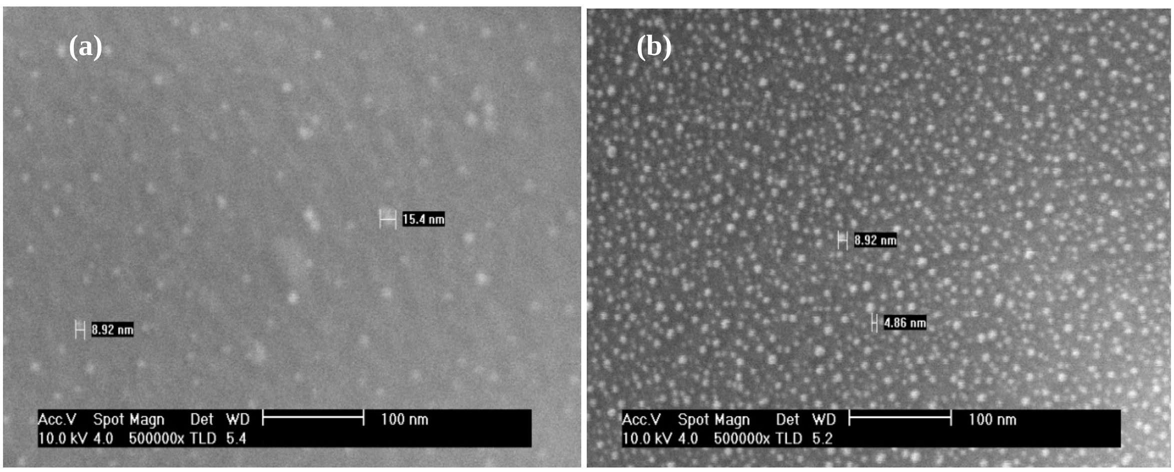


Figure 2. SEM images of solar cells with different nanoparticle coverage (a) 5 % and (b) 23 %.

Figure 2 shows the SEM images of solar cells with different nanoparticle coverage. Figure 2(a) and figure 2(b) show the SEM images with surface coverage of 5% and 23%, respectively. The coverage can be calculated as

$$\text{coverage} = \frac{S_{\text{NPs}} \times n}{S_{\text{sight}}} = \frac{\pi\left(\frac{d}{2}\right)^2 \times n}{S_{\text{sight}}} \tag{1}$$

Where S_{NPs} is the average vertical projecting area of nanoparticle, S_{sight} is the selected area used for statistics, n is the average amount of nanoparticles in unit area, and d is the average size of nanoparticles. Figure 2 shows that the change of average nanoparticle size is very small when the surface coverage increases, which is due to the similar nucleation rate and growth rate. The nanoparticles are present predominantly as single particles. There are very few nanoparticles in the presence of multiparticle clusters.

Figure 3 shows the EQE curves of solar cells with different nanoparticle coverage. In our experiments, the solar cell without NPs is used as the reference cell. We can find that the EQE of solar cells increases firstly, and then decreases when the nanoparticle coverage increases. This is mainly because the nanoparticle scattering is less than the light absorption of area covered by the nanoparticles. In the short wavelength band, the EQE of solar cells with nanoparticle coverage are decreases obviously in comparison with the reference cell, which indicates that the nanoparticle cover accelerates the front surface recombination. In the long wavelength band, the EQE of solar cells with nanoparticle coverage enhances obviously in comparison with the reference cell, which indicates that the nanoparticle cover can effectively reduce the back surface recombination of solar cell. When the nanoparticle coverage is 8%, the EQE of solar cell reaches the best in the long wavelength band, which is up to 95%. The use of Ag NPs can effectively improve the EQE of solar cells in the long wavelength band.

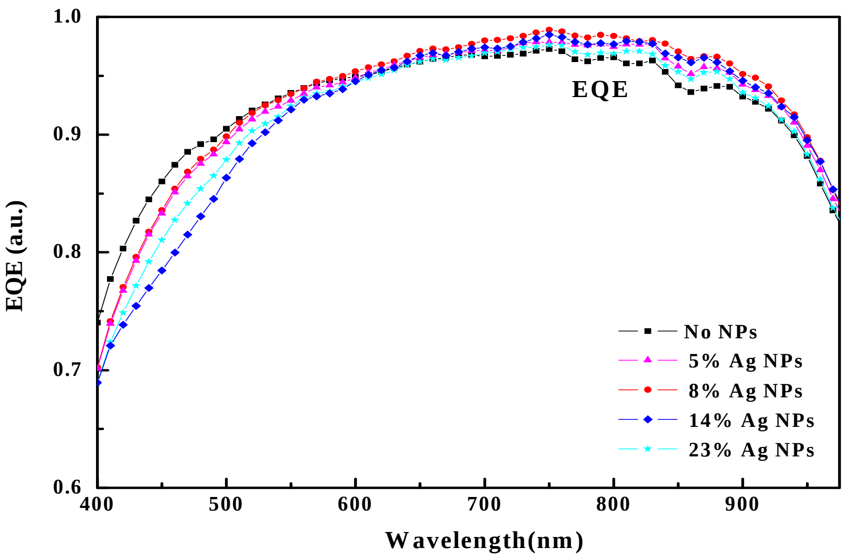
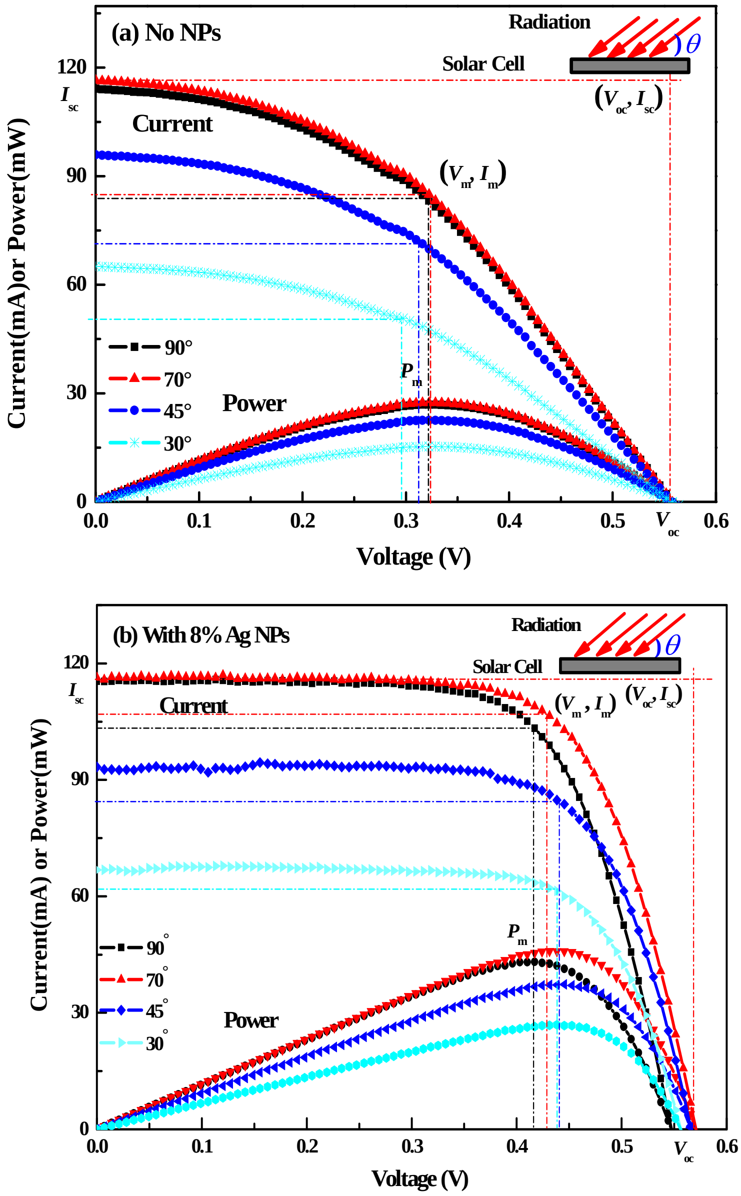


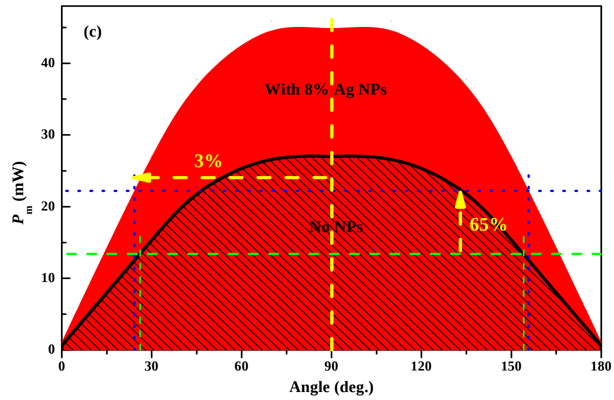
Figure 3. External quantum efficiency curves of solar cells with different nanoparticle coverage.

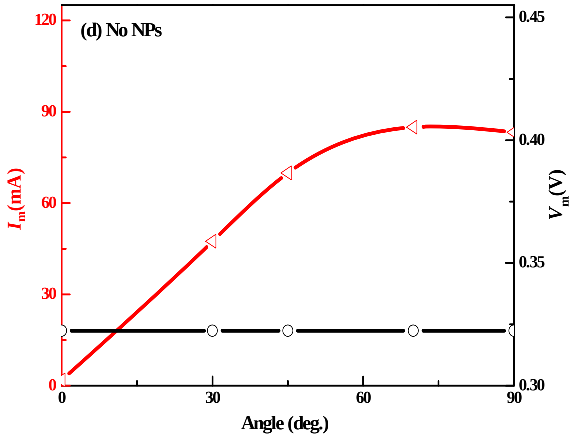
To simulate the all-day electric energy production of solar cells, the angle of incidence is varied from 0° to 180°. The solar cell without NPs is also used as the reference cell. Figure 4(a) shows the current–voltage and power output curves of the reference cell illuminated at different incidence angles. Figure 4(b) shows the current–voltage and power output curves of the optimized cell illuminated at different incidence angles. Figure 4(c) shows the maximum power (P_m) as a function of angle for the reference cell and optimized cell. Figure 4(d) shows the optimum operating current (I_m) and the optimum operating voltage (V_m) as a function of angle for the reference cell. Figure 4(e) shows the optimum operating current (I_m) and the optimum operating voltage (V_m) as a function of angle for the optimized cell. In comparison with the reference cell, the half peak height of Pm for the optimized cell increases by 65%, and at the same time broadens by 3%, as shown in figure 4(c). The use of small Ag NPs can effectively improve the all-day electric energy production of the optimized cell. The all-day electric energy production of the optimized cell is much superior to the values of the reference cell. Combining figure 4(d) and figure 4(e), we can find that the enhancements of I_m and V_m lead directly to the enhancement of $P_m = I_m \cdot V_m$. The distribution of peaks for I_m and V_m is reasonable between 30°and 80°, which is confirmed in theory [14]. The enhancement of half peak height for P_m can be calculated as

$$\frac{\Delta P}{P_m(\mathrm{ref})} = \frac{P_m(\mathrm{NPs}) - P_m(\mathrm{ref})}{P_m(\mathrm{ref})} \tag{2}$$

Here, P_m (ref) is the half peak height of P_m for the reference cell. P_m (NPs) is the half peak height of P_m for the optimized cell.







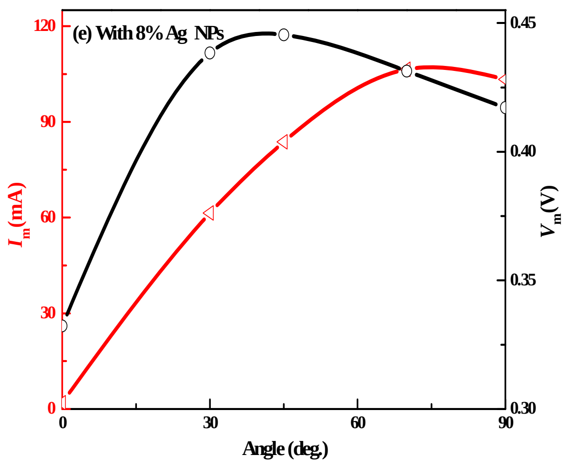


Figure 4. (a) Current-voltage and power curves of the reference cell illuminated at different incidence angles. (b) Current-voltage and power curves of the optimized cell illuminated at different incidence angles. (c) Maximum power as a function of angle for the reference cell (black slash-area) and optimized cell (red area). (d) Optimum operating current (red) and optimum operating voltage (black) as a function of angle for the reference cell. (e) Optimum operating current (red) and optimum operating voltage (black) as a function of angle for the optimized cell.

4. Conclusion

In summary, this study has provided an efficient approach to improve the all-day electric energy production of solar cells via using the small Ag NPs. Comparing with the value of the reference cell, the half peak height of P_m for the optimized cell increases by 65%, and the half peak breadth of P_m for the optimized cell broadens by 3%. The all-day electric energy production of the optimized cell is much superior to the value of the reference cell. The enhancements of I_m and V_m lead directly to the enhancement of P_m.

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