Effect of Ag Nanoparticles on the Performance of Inverse Polymer Solar Cells

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Abstract: Ag nanoparticles were added to the inverted polymer solar cell based on narrow-band material PSBTBT: PC71BM heterojunction in this paper. After the addition of Ag nanoparticles into MoO_3 HTL (Hole Transport Layer), the photoelectric conversion efficiency of the device was improved to 3.15%, with an increase of 41%. The active layer material devices with different mass ratios showed different performance, and the standard device with a mass ratio of 1:1 showed relatively better performance. The performance of the device with a mass ratio of 1:1.5 was improved after the addition of Ag nanoparticles.

1. Introduction

People have paid more and more attention to renewable energy on account of the increasingly serious problems of fossil energy exhaustion and environmental pollution. Solar energy has become a hot topic in the current scientific research field owing to its advantages of large area acquisition, cleanness and renewability, etc. After years of research, great progress has been made in the development of solar cells. Due to the unique characteristics, heterojunction polymer solar cells have attracted more and more attention [1-4]. The application of metal nanoparticles in solar cell devices has great potential for improving photoelectric performance [5, 6].

In this paper, Ag nanoparticles were added to the inverted polymer solar cell based on narrow-band material PSBTBT: $PC_{71}BM$ heterojunction. The addition of metal nanostructure at the device's bottom made the incident light bound onto the surface by metal nanoparticles instead of being emitted directly from the back, which increased the concentration of photons in the active layer material inside the cell, and improved the absorption of the device, thus increasing the efficiency of energy conversion.

2. Device Manufacturing

The narrow-band PSBTBT (1.5ev) polymer material was selected as the donor material [7-9], with the LUMO level and HOMO level of PSBTBT to be 3.5ev and 5.0ev respectively, and $PC_{71}BM$ was used as the receptor material [10,11], so as to manufacture the inverted heterojunction polymer solar cell device.

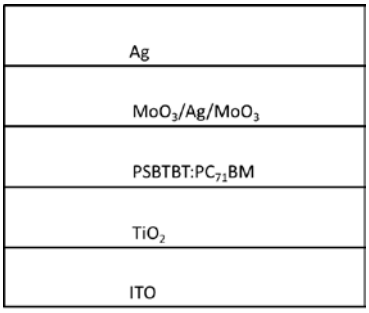

Fig 1. The device structure

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The physical structure of photovoltaic device is successively the substrate glass, ITO electrode, electron transport layer TiO2 film, PSBTBT: PC71BM heterojunction active layer, HTL (Ag nanoparticles) MoO3, and electrode Ag. The structures of standard devices and experimental devices are shown in Fig. 1.

Main materials required for the experiment: ITO base electrode, MoO3, Ag powder, o-dichlorobenzene. Weigh 10mg of PSBTBT and 15mg of PC71BM with an electronic balance respectively, and then put it into the dispensing bottle which had been wiped in advance. Draw 1 ml of o-dichlorobenzene solvent into the vial with a pipettor. Then place the bottle containing the materials on the magnetic stirring table. Stir at a constant temperature of 25 degrees for 48 hours. The prepared liquid above was PSBTBT: PC71BM dichlorobenzene solution with a mass ratio of 1:1.5. PSBTBT: PC71BM dichlorobenzene solution with a mass ratio of 1:1 and a concentration of 15mg/ml was prepared in accordance with the same operation procedure. Place the prepared medicine materials into the glovebox for use.

The coating rate of active layer material was 1500rpm, with the spin coating time of 15s. Put the spin-coated samples in the glovebox on the heating stage for thermal annealing treatment, with annealing temperature of 110 ℃, and the annealing time of 20 min; then obtain the active layer film. The structure of experimental device is as follows: ITO / TiO2 / PSBTBT: $PC_{71}BM/MoO_3$ (2.5nm)/Ag(0,1,3nm) / MoO_3 (2.5nm) /Ag (100nm).

3. Device testing and Analysis

3.1. PSBTBT: PC71BM was 1:1.5.

The mass ratio of active layer material PSBTBT: $PC_{71}BM$ was 1:1.5, the spin coating rate was 1500rpm, and the spin coating time was 15s. The annealing temperature was 110 ℃, and the annealing time was 20 min.

The current-voltage characteristic curve of device ITO/TiO_2/PSBTBT:$PC_{71}BM$/ MoO_3(2.5nm)/Ag(0nm,1nm,3nm)/MoO_3 (2.5nm)/Ag(100nm) was tested by Keithley 2601 current density-voltage test system under the condition that the sunlight simulator provided AM 1.5G (100 mW/cm^2, light intensity measured by photometer), as shown in Fig. 2. As seen from the figure, the short-circuit current density of standard contrast device without Ag nanoparticles was 9.75 mA/cm^2, the open circuit voltage was 0.66 V, the filling factor was 36.36%, the series resistance was 25.70Ω·cm^2, and the photovoltaic conversion efficiency of the device was 2.34%. After the addition of 1nm Ag (i.e., Ag nanoparticles) into MoO_3 HTL, the short-circuit current density of the device was 14.12mA/cm^2, which was significantly improved; the open circuit voltage was 0.67V, with a little change; the filling factor was still not high, namely, 37.52%; the series resistance dropped to 17.47Ω·cm^2, while the photoelectric conversion efficiency was improved to 3.55%, increasing by about 52%. After the addition of 3nm Ag (i.e., Ag nanoparticles) into MoO_3 HTL, the short-circuit current density of the device was 10.82mA/cm^2, the open-circuit voltage was 0.67v, and the filling factor was 39.58%; the series resistance dropped to 18.30Ω·cm^2, while the photoelectric conversion efficiency of the device increased to 2.87%. The specific performance values are shown in Table 1.

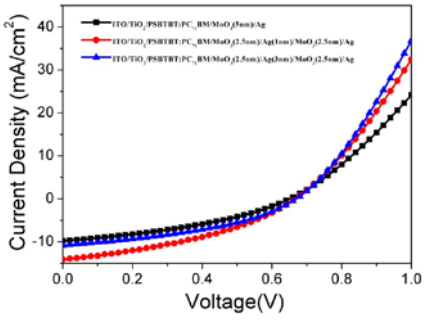

Fig 2. J-V characteristics of Devices ITO/TiO2/PSBTBT:PC71BM/MoO3(2.5nm)/ Ag(0nm, 1nm,3nm)/MoO3(2.5nm)/Ag(100nm)

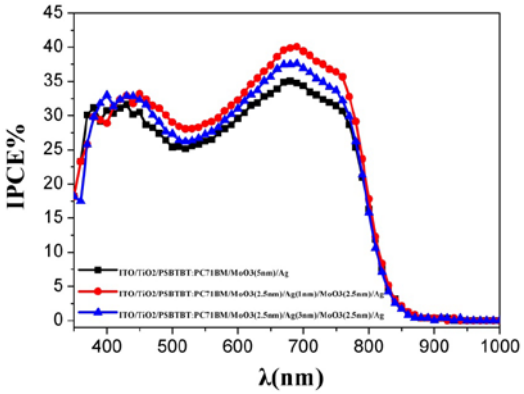

Fig 3. IPCE characteristics of Devices ITO/TiO2/PSBTBT:PC71BM/MoO3(2.5nm)/Ag(0nm, 1nm,3nm)/MoO3(2.5nm)/Ag(100nm)

Table 1 The detail performance parameter of Devices ITO/TiO2/PSBTBT:PC71BM/MoO3(2.5nm)/Ag(0nm,1nm,3nm)/MoO3 (2.5nm) /Ag(100nm under100mW/cm2 simulated AM1.5G.

The device structure	Jsc(mA/cm^2)	Voc (V)	FF (%)	η (%)	RsA (Ω.cm^2)
ITO/TiO_2/PSBTBT:$PC_{71}BM$/MoO_3 (5nm)/Ag(100nm)	9.75	0.66	36.36	2.34	25.70
ITO/TiO_2/PSBTBT:$PC_{71}BM$/ MoO_3(2.5nm)/Ag(1nm)/MoO_3 (2.5nm)/Ag(100nm)	14.12	0.67	37.52	3.55	17.47
ITO/TiO_2/PSBTBT:$PC_{71}BM$/ MoO_3(2.5nm)/Ag(3nm)/MoO_3 (2.5nm)/Ag(100nm)	10.82	0.67	39.58	2.87	18.30

The external quantum efficiency characteristic curve of device ITO/TiO_2/PSBTBT:$PC_{71}BM$/MoO_3(2.5nm)/Ag(0nm,1nm,3nm)/MoO_3(2.5nm)/Ag(100nm) is shown in Fig. 3. As can be seen from the curve in the figure, the device added with Ag nanoparticles (1nm) was significantly enhanced in the wavelength range of 450nm-750nm compared with the standard contrast device, and the range of increase was within the 350nm-800nm absorption band of PSBTBT: $PC_{71}BM$, which also offered sound experimental evidence for the improvement of short-circuit current density.

3.2. PSBTBT: PC71BM was 1:1.

The mass ratio of PSBTBT: PC71BM was 1:1, the coating rate was 1500rpm, and the spin coating time was15s; the annealing temperature was 110 ℃, and the annealing time was 20 min.

The current-voltage characteristic curve of device ITO/TiO_2/PSBTBT:$PC_{71}BM$/ MoO_3(2.5nm)/Ag(0nm,1nm)/MoO_3(2.5nm)/ Ag(100nm) under the condition that AM 1.5G was provided by sunlight simulator is shown in Fig. 4. It can be seen from the figure that, the short circuit current density of standard contrast device without Ag nanoparticles was 10.25 mA/cm^2, the open circuit voltage was 0.65 V, the filling factor was 38.57%, the series resistance was 25.39Ω·cm^2, and the photovoltaic conversion efficiency was 2.57%. The short-circuit current density of the device was 11.57mA/cm^2 after the addition of 1nm Ag (i.e., Ag nanoparticles) into MoO_3, the hole transport layer, which was greatly improved. The open circuit voltage was 0.67V, with a little change; the filling factor was 40.64%, and the series resistance dropped to18.36 Ω cm^2, while the photoelectric conversion efficiency of the device was improved to 3.15%, increasing by about 41%. The specific performance values are shown in Table 2.

The short-circuit current density of the device was mainly determined by the optical absorption of heterojunction PSBTBT: PC71BM mixture in the active layer of organic solar cell. The addition of 1nmAg into MoO_3 HTL could effectively increase the optical path propagated in the active layer due

to the local surface plasma effect and the strong scattering effect of Ag nanoparticles, thus improving the absorption and utilization of incident light by the device. Moreover, the decrease of series resistance from 25.39Ω·cm2 to 18.36Ω·cm2 showed that the interface contact performance of organic layer and electrode was improved, as well as the collection efficiency of device electrode, thus enhancing the photoelectric conversion efficiency of the device.

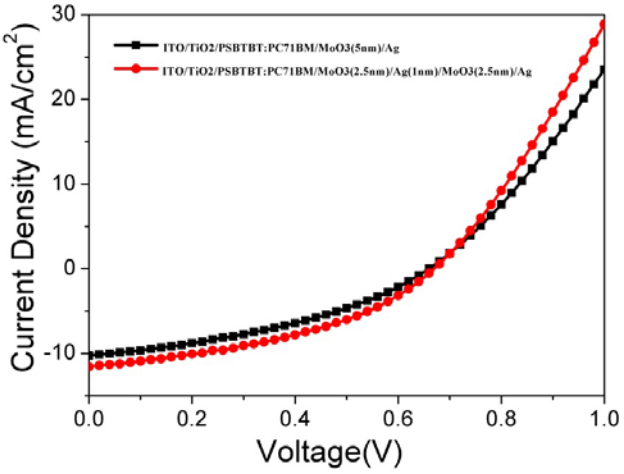

Fig 4. J-V characteristics of Devices with or without Ag nanoparticles

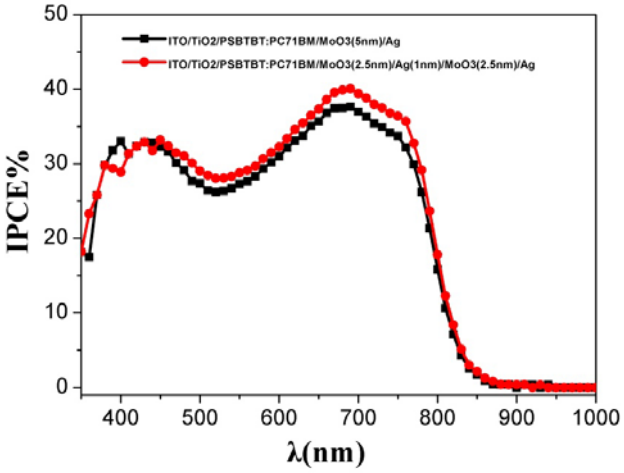

Fig 5. IPCE characteristics of Devices with or without Ag nanoparticles

Table 2 The detail performance parameter of Devices with or without Ag nanoparticles under100mW/cm2 simulated AM1.5G

The device structure	Jsc(mA/cm^2)	Voc (V)	FF (%)	η (%)	RsA (Ω.cm^2)
ITO/TiO_2/PSBTBT:$PC_{71}BM$/ MoO_3 (5nm)/Ag(100nm)	10.25	0.65	38.57	2.57	25.39
ITO/TiO_2/PSBTBT:$PC_{71}BM$/ MoO_3(2.5nm)/Ag(1nm)/MoO_3 (2.5nm)/Ag(100nm)	11.57	0.67	40.64	3.15	18.36

The external quantum efficiency characteristic curve of device ITO / TiO_2 / PSBTBT: $PC_{71}BM$ / MoO_3 (2.5nm) / Ag(0nm/1nm) / MoO_3 (2.5nm) / Ag (100nm) is shown in Fig. 5. As can be seen from the curve in the figure, the device added with Ag nanoparticles (1nm) was significantly enhanced in the wavelength range of 450nm-750nm compared with the standard comparison device, which was also a strong verification of the improvement of short-circuit current density in the absorption band range of PSBTBT: $PC_{71}BM$.

4. Conclusion

As can be seen from Table 1, the short-circuit current density of the device was mainly determined by the optical absorption of heterojunction PSBTBT: PC71BM in the active layer of organic solar cell. On the one hand, the addition of 1nmAg in MoO3 HTL could enhance the local photoelectric field owing to the local surface plasma. On the other hand, due to the strong scattering effect, Ag nanoparticles could effectively increase the optical transmission path in the active layer, and make the scattering light contact with the cell on the back electrode at a certain incident angle, so that the reflected light could contact with nanoparticles again, and part of the light could enter into the active layer in the same mechanism once again, namely, the incoming light transmitted back and forth in the active layer of thin film, thereby effectively increasing the length of the light propagation path, and increasing the absorption of photon in active layer, so as to improve the current density of the device. In addition, the decrease of series resistance from 25.70Ω·cm2 to 17.47Ω·cm2 indicated the improvement in the interface contact performance of organic layer and electrode, as well as the increase in the ability of electrode to collect charge carriers, thus improving the collection efficiency, as well as the short-circuit current density and photoelectric conversion efficiency of the device. When 3nm Ag was added into MoO3 HTL, the short-circuit current density of the device still increased compared with the standard device, and the efficiency was also improved, but it decreased compared with the addition of 1nmAg. As can be seen from the series resistance, with the increase of Ag thickness, the series resistance also increased, which affected the conductivity of the device; therefore, the performance of the device added with 3nmAg began to decline.

Through the comparison between Table 1 and Table 2: we could see that the active layer material devices with different mass ratios showed different performance, and the performance of standard device with a mass ratio of 1:1 was relatively better. After the addition of Ag nanoparticles, the device with a mass ratio of 1:1.5 showed relatively better performance. This also showed the properties of surrounding materials could affect the surface plasma action of metals.

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