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Semitransparent Perovskite Solar Cells with Thin Metal Electrodes

Chintam Hanmandlu[1,2], Karunakara Moorthy Boopathi[2] , Chao Sung Lai [2]*, Chih Wei Chu[1]*
[1] Research Center For Applied Science, Academia Sinica, Taipei 115, Taiwan.
[2] Department of Electronics, Chang Gung University, Taoyuan City, Taiwan (R.O.C.).
Phone: +886-2-2787-3183 *E-mail: gchu@gate.sinica.edu.tw, cslai@mail.cgu.edu.tw

Abstract

Semitransparent perovskite solar cells have a shown great promise as advanced window integrated photovoltaics for architectural. In this report, we fabricated the semitransparent perovskite solar cells by thin metal electrodes fabricated by thermal vapor deposition. By optimizing the processing conditions, the devices show the average power conversion efficiency (PCE) up to 1.07 and 8.33 % when the devices are illuminated from the bottom and top electrodes, respectively. Furthermore, we fabricated flexible PSCs with this metal electrode on a PET substrate with 11.02 % PCE.

1. Introduction

Inorganic-Organic perovskite solar cells have attracted much attention in past seven years due their convenient fabrication, and low cost [1,2]. These materials have shown a high light absorption coefficient, long diffusion length and high carrier mobility [3,4]. Dramatic progress of PSCs has been made on the device efficiencies and versatile applications, especially in the stability area not applicable for silicon solar cells [5]. Besides the perovskite active layers, the electrodes, especially transparent electrodes, in the PSCs are critical to the device performance, which can significantly influence the device PCE, stability and mechanical stability. Indium tin oxide (ITO) is a popularly used electrode for PSCs [3,4]. However, in commercial applications ITO have some drawbacks, including high cost, less availability of indium on the earth, fragility and instability with acids base [6]. To replace the ITO other function materials like PEDOT: PSS and Graphene have been demonstrated in PSCs fabrication[7,8]. These electrodes have a very good transmission properties in the visible range wavelength, but the conductivity is very poor. Therefore, the transparent top electrode is critical to the performance of semitransparent PSCs. An ideal transparent electrode must have good transmission, mechanical stability, low sheet resistance and low cost and effective charge collecting ability. In this regard-metal electrode probably best candidate for transparent electrodes due to their low cost, good bending stability and excellent charge collection ability.

In this report, we demonstrate efficient semitransparent PSCs using silver thin film sandwiched between the BCP and MoO_3 as a transparent rear electrode prepared by the thermal vapor deposition method. The performance of PSCs with different thickness of Ag and MoO_3 was studied. By optimizing the thickness of Ag and MoO_3 the devices show power conversion efficiencies (PCE) upto 12.07% and 8.33 % when the devices illuminated from ITO and BCP/Ag/MoO_3 respectively.

2. Results and discussions

Figure 1 (a) presents the schematic structure of semi-transparent PSCs with BCP/Ag/MoO_3 as a top transparent electrode. When a thinner metal layer Ag (9 nm) directly deposited on top of BCP (8 nm)/Glass, it forms into discontinuous metallic islands, these metallic islands create a localized surface plasmon resonance and scattering losses in between the metal and dielectric layer, resulting an increase the electrode sheet resistivity (~ 250 Ω/□) [9]. In contrast, when a 15 nm of Ag on BCP/glass, grow continuous and smooth film and sheet resistivity reduce to ~9 Ω/□. If thicker, Ag (18 nm) deposited on the BCP/Glass the electrode conductivity increases and sheet resistivity reduce to ~ 6 Ω/□, but the transmission in the visible range wavelength is decreased as shown in Figure 1 (b). There for higher thickness of Ag is not suitable for semitransparent electrodes in PSCs. The transmission through BCP/Ag electrode in visible range wavelength is less because Ag and air interface high light reflection. To increase the transmission of electrode here we deposited high refractive index material MoO_3 on top BCP/Ag electrode. This capping layer (MoO_3) has a excellent optical properties in the visible range wavelength 300-800 nm. Different thicknesses of capping layer deposited on top of the Ag cathode UV-visible transmission through electrode is increased as well as it is shifted to the red wavelength side shown in Figure 1 (c). By optimizing different thicknesses from 20-60 nm, we notice that 40 nm shows highest transmission

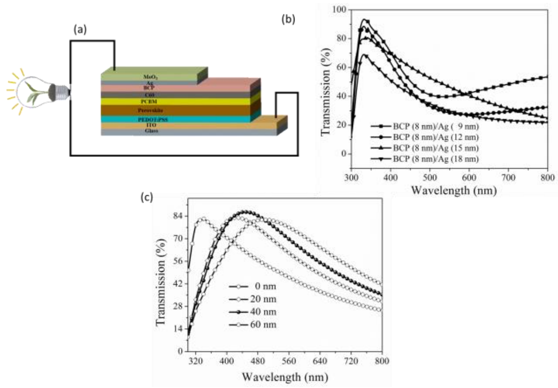

Figure1 (a) Schematics device structure of semitransparent PSCs, (b) UV-Visible transmission of different thickness of Ag thin films, (c) UV-visible transmission of different thickness of MoO_3 on BCP/Ag electrodes.

Figure 2 (a), (b) depicts J-V characteristics of PSCs devices with a different capping layer thicknesses on the top of Ag cathode and the corresponding photovoltaic parameters are shown in Table 1 when light illuminated from ITO and BCP/Ag/MoO_3 electrodes. The device without capping layer exhibits the low device performance from ITO and BCP/Ag electrodes. The device with different capping layer thicknesses improves Jsc and PCE when illuminated from the

ITO and BCP/Ag/MoO_3 electrodes.

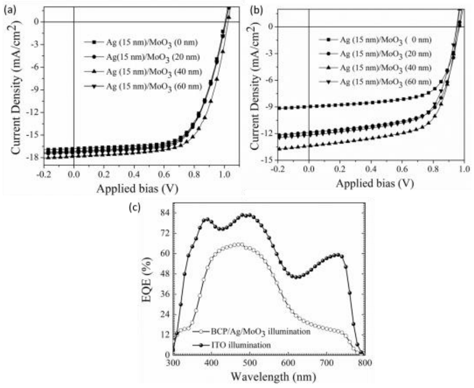

Figure 2: J-V characteristics of PSCs devices with different MoO3 thicknesses on BCP/Ag illuminated from (a)ITO (b) BCP/Ag/MoO_3 (c) EQE of PSCs device with illumination ITO and BCP/Ag/MoO_3 electrodes.

We noticed that if we increase capping layer thickness more than 40 nm the device performance is decreased for BCP/Ag/MoO_3 sides illumination because light transmission through electrode is decreased. Therefore the device with 40 nm capping layer exhibits best device performances of 12.07 % and 8.33 % when light illuminated from ITO and BCP/Ag/MoO_3 electrodes, respectively. The device with 40 nm capping layer shows best EQE and integrated Jsc for both illumination side as shown in figure 2 (c). The device shows high EQE of 80 % in the wavelength region from 350 nm to 550 nm and lower values in the 550-800 nm wavelength region when light illuminated from ITO. The lower EQE value occurs because the light cannot reflect from the top electrode which is transparent. In the case of BCP/Ag/MoO_3 illumination side, the device 40 nm of capping layer show high EQE in the wavelength region from 350 to 550 nm and less value of EQE in the longer wavelength region as shown in Figure 2 (c), due to light absorption in this wavelength range.

In additionally, to verify our strategy is applied to flexible PSCs cells, we fabricated the $MAPbI_3$ based PSCs with BCP/Ag/MoO_3 as a rear electrode on ITO coated PET substrate. Figure 3 (a) displays the J-V characteristics of flexible PSCs, the cell displays the PCE 11.02 % which is comparable with the glass substrate.

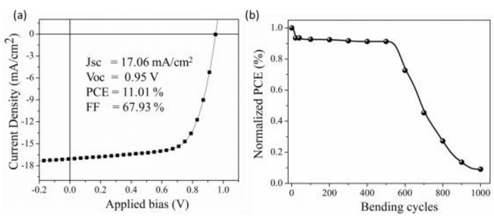

Figure 3 (a) J-V characteristics of the flexible PSCs device (b) PCE of flexible PSCs mechanical bending stability with bending radius 6 mm.

One of the most important characteristics of flexible device is their operational stability against the mechanical bending. Figure 3 (b) displays the bending stability of with a 6 mm bending radius. The PCE of device has dropped 8 %, 90 % for 50 and 1000 cycles, respectively. This demonstrates that perovskite solar cells with ITO as a poor stability against for bending.

Table 1: Photovoltaicsperformace of PSCs with different thickness of MoO_3 on BCP/Ag

Top electrode	Illuminination side	Jsc (mA/cm^2)	Voc (V)	FF (%)	PCE (%)
BCP/Ag	ITO	16.80	1	65.4	10.99
	BCP/Ag	8.98	0.97	65.5	5.71
BCP/Ag/MoO_3 (20 nm)	ITO	17.31	1.01	67.7	11.85
	BCP/Ag/MoO3	11.86	0.97	64.6	7.44
BCP/Ag/MoO_3 (40 nm)	ITO	17.83	1.02	66.3	12.07
	BCP/Ag/MoO3	13.38	0.95	65.5	8.33
BCP/Ag/MoO_3 (60 nm)	ITO	17.18	1.01	64.1	11.13
	BCP/Ag/MoO3	12.16	0.95	63.9	7.39

3.Conclusions

In summary semitransparent PSCs were fabricated with BCP/Ag/MoO_3 transparent electrode on perovskite active layers for the first time. The device with 40 nm capping layer thickness electrodes shows maximum PCEs of 12.07 % and 8.33 %, when illumination from ITO and BCP/Ag/MoO_3 electrodes, respectively. Finally, we fabricated the device on flexible substrate with 11.01 % PCE and studied successfully its mechanical bending stability. This work indicates BCP/Ag/MoO_3 transparent electrode is an ideal candidate for semitransparent PSCs devices because of its good transmission properties in the visible range wavelength and its easy fabrication.

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