Efficiency Enhancement of Organic Solar Cells by Suppressing Recombination at Cathode Interface

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Great progress in power conversion efficiency (*PCE*) for organic solar cells (OSCs) has been achieved in recent years while they still suffer from instability issues. One feasible approach of overcoming the instability issues is to construct an inverted structure, where indium tin oxide (ITO) serves as cathode and a high work function metal as anode. In an inverted OSC, ITO cannot directly serve as cathode without interfacial modification.[1] In this work, we use an ultra-thin Ca layer (2 nm) to modify ITO, aiming to improve the performance of OSC. The structures of the devices are ITO/Ca (without or with)/bathocuproine (BCP)/boron subphthalocyanine chloride (SubPc)/fullerene (C_{60})/MoO_3/Ag, where BCP and MoO_3 act as electron and hole transporting layer, respectively. The current density-voltage (*J-V*) characteristics of the devices were measured with an Advantest R6245 *J-V* source meter under AM 1.5G 100 mW/cm^2 simulated sunlight. The light intensity dependent *J-V* measurements were carried out to get insight into the recombination mechanism.[2,3] The light intensity was measured via an optical power meter (THORLABS, PM 100D). Fig. 1 shows the *J-V* characteristics of the devices without/with Ca interlayer under a 100 mW/cm^2 illumination. The device without Ca exhibited short circuit current (J_{SC}) of 4.25 mA/cm^2, open circuit voltage (V_{OC}) of 0.93V, fill factor (FF) of 45%, yielding the overall PCE of 1.8%. After inserting Ca layer, the device performance was improved greatly, yielding 5.76 mA/cm^2 of J_{SC}, 0.92V of V_{OC}, 54% of FF, and 2.9% of PCE. The performance enhancement of the device with Ca interlayer comes from the increases in both J_{SC} and FF. The V_{OC} *versus* ln (*I*) relationship for the devices without/with Ca is shown in Fig. 2. For the device free of Ca, a strong dependence of V_{OC} on light intensity is observed where the recombination at the open circuit is a combination of monomolecular (slope=2.04kT/e, at low light intensities) and bimolecular processes (slope=1.87kT/e, at high light intensities). After the incorporation of a Ca layer, the slopes were reduced from 2.04 kT/e to 1.34 kT/e at low light intensities and from 1.87 kT/e to 1.11 kT/e at high light intensities, respectively. This suggests that the use of Ca interlayer significantly suppressed the trap assisted recombination. The J_{SC} can be correlated to illumination intensity (*I*) by the following relationship: $J_{SC} \propto I^{\alpha}$ $(\alpha \leq 1)$. We plotted the curve of J_{SC} *versus I* for both the devices in Fig. 2(b). For device free of Ca, the fitting of the data yield α=0.938, which can be attributed to the bimolecular recombination. After Ca deposition, α is 0.990, which implies that bimolecular recombination is close to minimum. In conclusion, the Ca interlayer between ITO and BCP significantly improves the performance of OSC with inverted structure. This improvement is attributed to the suppression of trap-assisted recombination as well as the bimolecular recombination.

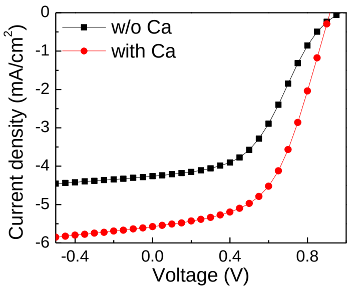

Fig. 1 *J-V* characteristics of OSCs w/o and with Ca interlayer.

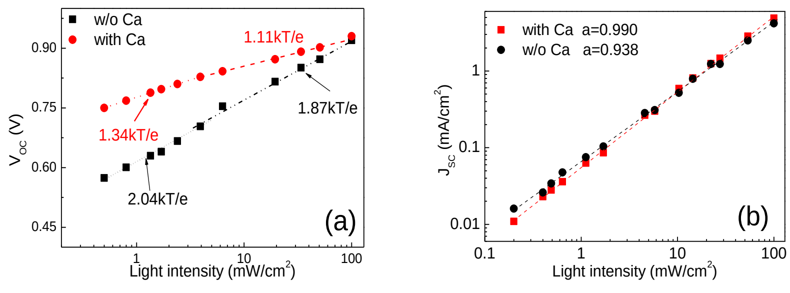

Fig. 2 (a) V_{OC} as a function of light intensity and (b) J_{SC} plotted against light intensity on the logarithmic scale for the devices w/o and with Ca.

References

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