Efficient Bulk Heterojunction Solar Cells from Conjugated Polymer / Fullerene Blends

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Bulk heterojunction solar cells from conjugated polymer / fullerene blends follow in many ways the concepts for inorganic solar cells. Generally, the operation of a photovoltaic device may be visualized as taking place in three consecutive fundamental steps: (1) absorption of light, (2) creation of separate charges at the donor — acceptor interfaces, and (3) selective transport of the charges through the bulk of the device to the appropriate collecting electrodes. A prerequisite for high efficiency for the conversion of photons into electrical current is that the holes and electrons do not recombine before being swept out of the device to the external circuit. Therefore, a metastable photoinduced charge-separated state and high charge carrier mobilities are important factors. A conjugated polymer — methanofullerene blend can provide both of these characteristics [1]. Time-resolved measurements [2] have shown that the initial photoinduced electron transfer from a conjugated polymer to a soluble methanofullerene occurs on the timescale of 50 fs, whereas the timescale for back transfer to the neutral state is very long and extends into the milliseconds range. Once this metastable charge-separated state is formed, the free charges are transported through the device through diffusion and drift processes. The latter is induced by using top and bottom layer electrodes that have different work-functions, thus providing a built-in electric field over the active layer. In the active layer of the device, holes are transported through the conjugated polymer matrix, and electrons are transported by hopping between fullerene molecules. Importantly, these two different charge transport processes do not interfere with each other which has been proved by recent mobility measurements.

The overall efficiency η_{eff} of a solar cells is calculated by the following formula:

$$\eta_{eff} = V_{oc} * I_{sc} * FF / I_{light}$$

where Voc is the open circuit voltage, Isc the short circuit current in A/m^2, FF the fill factor and I_{light} the incident solar radiation in W/m^2. Also the new generation of plastic solar cells with efficiencies over 2.5% as published recently [3] have intrinsic loss mechanisms. In this contribution further possible strategies to improve the overall efficiency of plastic solar cells based upon bulk heterojunctions are discussed.

(a) The Open Circuit Voltage

A highly interesting phenomenon in the Plastic Solar Cells (PSC) is the observation of unusual high open circuit voltages. Typically, a V_{oc} of ~ 800 mV is observed for PSC, quite independent of the metal top electrode used. This insensitivity of the open circuit voltage to the negative electrode work function is interpreted by a pinning mechanism of the top metal electrode to the quasi Fermi level of the fullerenes.

(b) The Short Circuit Current

A key parameter for the efficient charge collection of plastic solar cells is the hole and the electron mobility of the interpenetrating networks. One dimensional simulations of the bulk heterojunction solar cells show a clearly observable peak for the maximum short circuit current versus the device thickness. Depending on the given mobility, the peak shifts to larger values in the device thickness, thereby allowing to absorb more photons and yielding a larger total short circuit current.

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(c) The Fill Factor

In general, a large serial resistance as well as a too small parallel resistance (shunt) tend to reduce the FF. From LEDs, protective interface layers like LiF or SiO_x are well known to reduce the interface barrier for electron injection at the cathode, if they are evaporated between the photoactive material and an Al electrode[4]. Figure 1 shows the enhancement of the diode properties upon insertion of a 6 A LiF layer between the Al electrode and the photoactive MDMO-PPV / PCBM layer under illumination with 80 mW/cm^2 from a solar simulator. While the short circuit current is left almost unchanged and only a small increase in the open circuit voltage is observed (from 780 to 820 mV) due to the interfacial layer, the FF is increased from 0.5 to 0.62.

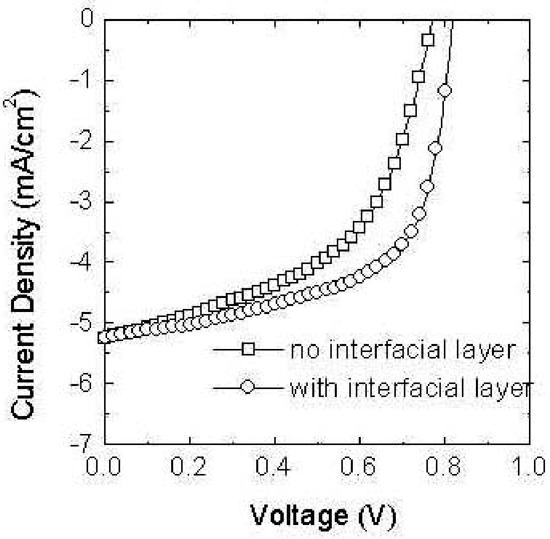

Figure 1: I/V plot of ITO / PEDOT / MDMO-PPV - PCBM /Al solar cells with and without an LiF (6 A) interfacial layer between the Al electrode and the photoactive material.

(d) Spectral Sensitization

One of the limiting parameters in plastic solar cells is their mismatch to the solar spectrum. Typically, conjugated polymers like MDMO-PPV, used for photovoltaics have their peak absorption around 500 nm which is clearly offset to the maximum in the photo flux of the sun, which peaks around 700 nm. The use of low bandgap polymers (E_g <1.8 eV) to expand the spectral region of bulk heterojunction solar cells is demonstrated in this work. These polymers can enhance the spectral range by a direct photoinduced charge transfer to the fullerene like in the case of the wide bandgap polymers.. The charge transport to the electrodes will again occur via the polymer as well as the fullerene.

Conclusion

Bulk heterojunction plastic solar cells with efficiencies > 2.5 % and short circuit current of ~5 mA/cm^2 under AM 1.5 illumination form a solar simulator can be produced routinely by spin casting from solution. While 2.5 % is already a promising value, improvement strategies were suggested for further optimisation of polymeric photovoltaic systems based on the bulk heterojunction principle.

References

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