

# Semi-transparent polymer solar cells

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**Abstract**—Semi-transparent organic photovoltaic devices have great potential for integrated system applications. In this work we present highly efficient semi-transparent devices comprising a polymer:fullerene blend with absorption extending to the near infrared. We further demonstrate an approach to organic photovoltaic devices featuring a cathode from a transparent and highly conductive polymer.

**Keywords:** Semi-transparent solar cell; conjugated polymer; organic optoelectronic device

## I. INTRODUCTION

Due to the recent reports about organic bulk-heterojunction photovoltaic devices with power conversion efficiencies exceeding 7% [1,2] polymer solar cells made a giant leap towards economically interesting optoelectronic devices. This success of polymer solar cells can be attributed to the development of new co-polymers with an extended absorption to the infrared. Despite the ultra-thin active films in an organic photovoltaic device, these co-polymers act as efficient photon harvesting molecules due to their remarkably high absorption coefficients. Hence this material class offers the potential of a significant material cost reduction in optoelectronic devices. However, in order to dissociate generated excitons in organic photovoltaic devices, the incorporation of strong electron acceptors in the active layer is mandatory. Among these strong acceptors, the fullerene derivatives [6,6]-phenyl C<sub>61</sub> butric acid methyl ester (PC<sub>60</sub>BM) can be considered as standard material that allows for a very efficient electron transfer from the polymer, while also ensuring a good electron transport to the device cathode. By replacing the PC<sub>60</sub>BM with [6,6]-phenyl C<sub>71</sub> butric acid methyl ester (PC<sub>70</sub>BM) the absorption of organic solar cells can be even more enhanced in order to increase the device efficiency.

In contrast to their inorganic counterparts, organic molecules exhibit a band absorption that is limited to a certain wavelength regime, making them a predestined material class for semi-transparent optoelectronic devices. Possible applications for semi-transparent solar cells range from façade integration and window shadowing to integrated power sources for off-grid energy systems. Autonomous signage is a further field of application among many others. Due to the close relation with organic photodetectors, very similar device architectures can be implemented in low-cost lab-on-a-chip systems for integrated light detection. In particular, the combination with low-bandgap, infrared absorbing polymers that let the visible light pass are a promising approach.

In this work we present promising device architectures for highly efficient semi-transparent organic photovoltaic devices incorporating polymer/fullerene bulk-heterojunctions.

## II. RESULTS AND DISCUSSIONS

### A. Semi-transparent solar cells featuring sputtered transparent cathodes.

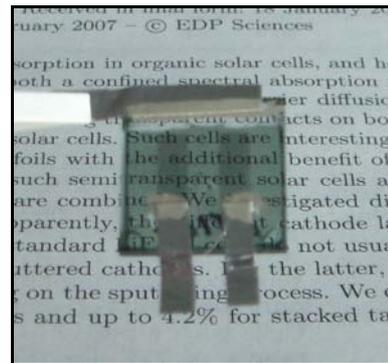


Figure 1: Photo of an organic solar cell comprising a PSBTBT:PC<sub>70</sub>BM absorber layer, a sputtered ZnO cathode and a LiF/Al interlayer.

The polymer poly[(4,4'-bis(2-ethylhexyl)dithieno[3,2-b:2',3'-d]silole)-2,6-diyl-alt-(2,1,3-benzothiadiazole)-4,7-diyl] (PSBTBT) makes up for highly efficient photovoltaic devices when blended with the acceptor PC<sub>70</sub>BM [3]. In order to build a semi-transparent device with two transparent electrodes, we fabricated polymer solar cells following established standard procedures but replaced the opaque metal cathode with a transparent, sputtered zincoxide electrode following the procedure described in [4]. An ohmic contact between the high work function zincoxide and the absorber was established by introducing a combination of ultrathin layers of lithiumcobaltoxide (LiCoO<sub>2</sub>, 0.5 nm) and aluminum (3 nm) below the zincoxide cathode. In the presence of aluminum alkalihalogenides dissociate. While the halogen atom reacts with the aluminum cathode, the alkali (here: lithium) atom migrates into the upper parts of the active layer and subsequently establishes n-doping [5]. The resulting solar cell exhibits a power conversion efficiency of  $\eta \approx 3\%$ . A reference device comprising an opaque aluminum electrode and a LiCoO<sub>2</sub> interlayer, however, exhibits exactly the same electrical properties within the measurement accuracy. Subsequently it can be concluded, that semi-transparent devices can exhibit comparable high efficiencies as non

transparent devices. However, it is important to point out that the vacuum chamber was loaded from ambient atmosphere before cathode deposition. Thus the samples were contaminated with air. Keeping the entire process under inert atmosphere will very likely account for significantly enhanced semi-transparent cell efficiencies, as we were able to fabricate 5.5% efficient solar cells from PSBTBT:PC<sub>70</sub>BM comprising a calcium cathode under nitrogen atmosphere.

### B. Polymeric electrodes for semi-transparent solar cells

One of the expected advantages of organic photovoltaic devices is the potential for significant fabrication cost reduction through printing processes. Subsequently, it is favorable to use printable, i.e. solution processable, functional layers instead of vacuum deposited films. The transparent anode can easily be replaced by the highly conductive polymer system poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) [6-8]. Unfortunately, there is no low work function material system with similar properties that is suitable for the extraction of electrons from the device.

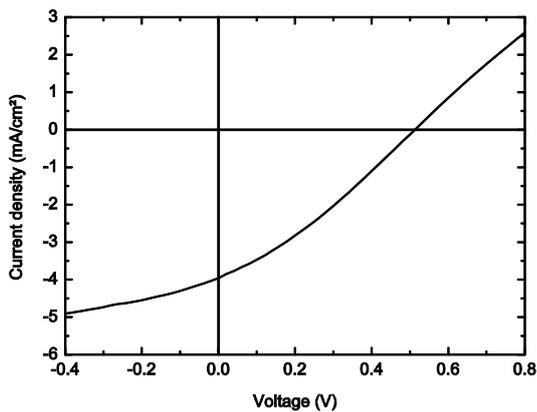


Figure 2: JV curve of a semi-transparent solar cell comprising Indium tin oxide (125nm)/PEDOT:PSS (25nm)/P3HT:PCBM (200nm)/BPhen:Li (20nm)/Gold (3nm)/PEDOT:PSS (50nm).

However, by first establishing an n-doped interlayer below the cathode, conductive polymers with high work functions become interesting materials for cathodes, too [9]. With a polymeric electrode n-doping by LiCoO<sub>2</sub> does not work since a reaction partner for LiCoO<sub>2</sub> is missing in order to create diffusing lithium atoms. Subsequently, intentional n-doping of an additional electron transport layer must be carried out. In this case we decided to co-evaporate a lithium doped bathophenanthroline (BPhen:Li) [10] followed by nominal 3 nm gold on top of a poly-(3-hexylthiophene-2,5-diyl):PC<sub>60</sub>BM bulk heterojunction before cathode deposition. The polymer cathode then was spincast on top of the layer stack. While the BPhen:Li interlayer accounts for an ohmic contact to the PEDOT:PSS cathode, the gold with its high density of states is needed in order to convert the electron current in BPhen:Li to a

hole current within the p-type PEDOT:PSS, i.e. an efficient lossless charge recombination from electrons in BPhen:Li and holes in PEDOT:PSS. This process is well known for tandem solar cells and thus often addressed in literature [11]. Though an ohmic contact is established between BPhen:Li and PEDOT:PSS, the short circuit current density and subsequently the device efficiency ( $\eta \approx 0.6\%$ ) are quite moderate as depicted in figure 2. Partially, this moderate efficiency can be accounted to the considerable serial resistance in the polymer cathode. Further, the recombination at the BPhen:Li/PEDOT:PSS interface needs further investigations in order to improve the lossless conversion between electrons and holes.

### III. CONCLUSION

In conclusion we demonstrated highly efficient semi-transparent polymer solar cells comprising a sputtered ZnO cathode. We further gave evidence that a semi-transparent device can also be formed by utilizing polymer electrodes for electron extraction.

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