

CONCEPTS AND STRATEGIES FOR PHOTOVOLTAIC DEVICES WITH FULLERENES

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Abstract

Parameters, which determine the efficiency of organic photovoltaic devices, are short circuit current, open circuit voltage, fill factor and matching with the incident solar light power. Recent concepts and strategies for influencing the parameters are discussed.

INTRODUCTION

Since the discovery of a photoinduced electron transfer between conjugated polymers and fullerenes [1,2] the field of plastic solar cells has gained increasing interest. The most efficient polymeric solar cells fabricated today are so-called bulk heterojunction solar cells, which consist of a p-type conjugated polymer network and, as n-type material, a fullerene derivative mixed into it. Efficiencies up to 3% have been reached with poly-(2-methoxy,5-(3',7'-dimethyl-octyloxy))-p-phenylene-vinylene (MDMO-PPV) as electron donor and (6,6)-phenyl-C₆₁-butyric-acid-methyl-ester (PCBM, a soluble C₆₀ derivative) as electron acceptor [3,4].

The overall efficiency η_{eff} of a solar cell is calculated by the formula $\eta_{\text{eff}} = J_{\text{sc}} * V_{\text{oc}} * \text{FF} / I_{\text{inc}}$, where J_{sc} is the short circuit current, V_{oc} is the open circuit voltage, FF is the fill factor and I_{inc} is the incident solar light power [5]. Recent concepts and strategies for influencing the parameters are discussed.

RESULTS AND DISCUSSION

Influences on the Short Circuit Current

An important parameter for high short circuit currents is the hole and electron mobility of the interpenetrating network. It has been shown that the mobility is effected by the morphology, e.g. phase separation, within the active film. An important increase in efficiency has been reached by improving the morphology by changing the solvent for the preparation of the active layer [3]. The morphology influences both the electron mobility in PCBM and especially the hole mobility of MDMO-PPV, as determined by FET

measurements with the mobility calculated from linear and saturation regime using long integration times. The higher mobilities are probably due to enhanced π -stacking, which leads to better hopping of the charges between the chains [3].

A new synthetic route to MDMO-PPV, the 'sulphinyl' route, is a promising way to obtain the polymeric electron donor with low defect level [4]. In this indirect precursor-route with a non-symmetric monomer, head-to-head and tail-to-tail additions are excluded to a high level. Preliminary results indicate that with the 'sulphinyl' MDMO-PPV:PCBM bulk heterojunction solar cells power conversion efficiencies of nearly 3%, a higher fill factor, a higher incident photon per converted electron (IPCE) value and a higher short circuit current are obtained.

One possibility of circumventing the problem of phase separation is given by the concept of donor-acceptor 'double-cables', where electron accepting and conducting moieties are covalently linked to an electron donating and hole transporting conjugated polymer backbone. The primary structure of such a double-cable forces controlled interactions between the donor and the acceptor moieties and prevents phase separation. Electropolymerized bithiophene fulleropyrrolidine with a flexible spacer yields insoluble polymer films, which were characterized in respect to their electrochemical and photophysical properties [6, 7]. The donor backbone and the acceptor moieties do not interact in the ground state while a photoinduced electron transfer occurs in this double-cable polymer in the excited state, as revealed by photoinduced absorption (PIA) and by light induced electron spin resonance (LESR) measurements. Recently, a soluble double cable polymer was prepared [8]. Photovoltaic devices with this material were fabricated and characterized.

In addition to their application in organic solar cells, double-cable polymers are of high interest for other electronic and optoelectronic devices, due to their potential as intrinsic p-n transporting materials.

Influences on the Open Circuit Voltage

Bulk heterojunction devices show unusually high open circuit voltage values [9]. These values cannot be explained by a metal-insulator-metal (MIM) model that has been often used for describing organic light emitting diodes. In order to investigate the origin of the open circuit voltage in bulk heterojunction plastic solar cells, PPV based devices varying both the nature of the negative metal contact and the nature of the fullerene acceptor have been prepared. Fullerene derivatives with varying acceptor strength (characterized by their reduction potential in electrochemical experiments) were used as electron acceptors in bulk heterojunction plastic solar cells. The open circuit voltage of the devices was found to correlate directly with the acceptor strength of the fullerenes, while it was rather insensitive to variations in the workfunction of the negative electrode metal. These results suggest that the quasi-Fermi level of the fullerene pins the Fermi level of the evaporated negative metal contact [9]. To obtain higher open circuit voltages, the application of fullerenes with lower acceptor strength (more negative reduction potential) would be desirable.

Influences on the Fill Factor, Tuning of the Contacts

The insertion of thin interlayers of LiF under the negative metal electrode Al and Au of bulk heterojunction solar cells significantly enhances the fill factor and stabilizes high open circuit voltages [10]. With Al, the fill factor increases to a value of around 0.6 compared to 0.53 found in devices without LiF. Device performance simulations show, that a lowering of the serial resistivity is responsible for the increase of the fill factor due to formation of a better ohmic contact at the electrode [10]. The formation of a dipole moment across the junction, due to either orientation of the LiF or chemical reactions leading to charge transfer across the interface, is suggested as the mechanism for the enhancement. Compared with devices without the LiF interfacial layer, the white light efficiencies increase to about 3.3%, which is about 20% higher than reference devices fabricated without the layer.

Influences on the Spectral Absorbance, Matching with the Incoming Light Power

One of the limiting parameters in plastic solar cells containing substituted poly-(p-phenylene-vinylene)s and polythiophenes is the mismatch of their absorption to the terrestrial solar spectrum. The optical bandgap of these conjugated polymers (around 2.0 to 2.2 eV) is not optimized with respect to the solar emission, which has the maximum photon flux around 1.8 eV. The use of low bandgap polymers with bandgaps in this region expands the spectral region of bulk heterojunction solar cells and is a viable route to enhance the number of photons absorbed. The photophysics of such low band gap conjugated polymers as well as their excited state interactions with electron acceptors such as fullerenes are of importance when using them in photovoltaic devices. A new soluble low bandgap polymer PTPTB, consisting of alternating electron-rich N-dodecyl-2,5-bis(2'-thienyl)pyrrole (TPT) and electron-deficient 2,1,3-benzothiadiazole (B) has a bandgap of 1.6 eV, as determined by electrochemistry and by optical absorption spectroscopy [11]. Bulk heterojunction PTPTB:PCBM devices show under simulated AM 1.5 illumination a strong photoeffect in the I/V curve. The open circuit voltage of 0.72 V is just 0.1V less than the highest values observed for MDMO-PPV:fullerene devices although the bandgap of PTPTB is reduced by 0.6 eV compared to MDMO-PPV. With short circuit currents of 3 mA/cm² and a fill factor of 0.37 a power conversion efficiency of around 1% under AM1.5 illumination was obtained [12]. The spectral resolved photocurrent (IPCE) of the PTPTB:PCBM device peaks at 600 nm and contributions to the IPCE are observed down to 750 nm, evidencing the low bandgap of PTPTB.

Further strategies to improve the properties of plastic solar cells may be the utilization of this polymer for bulk heterojunction tandem solar cells with either a wide band gap polymer or in conjunction with strongly absorbing small molecular dyes.

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