

Low band-gap polymeric photovoltaic devices

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Abstract. We present results on photovoltaic devices based on novel thiophene-isothianaphthene copolymers (PDTI) with π - π^* band-gaps ranging from 1.2 eV to 1.8 eV. Single-layer photovoltaic devices were fabricated from films of PDTI doped with a soluble fullerene derivative [6,6]-phenyl-C₆₁-butyric-acid-methyl-ester (PCBM) as the electron acceptor and blended into poly(methyl methacrylate) to enhance the film quality. These devices exhibit spectral response extending into the infrared and are better matched to the solar spectrum as compared to standard PPV based ones. Such low band-gap materials also make possible the construction of dye-sensitized photovoltaic devices that take advantage of energy transfer from high energy absorbing dyes to the host polymer.

Keywords: Solar Cells, Poly (thiophene-isothianaphthene) copolymers, Fullerenes and Derivatives, Low Bandgap Polymers, Sensitization, Organic Semiconductors

1. Introduction

The discovery of ultrafast, photoinduced charge transfer from conjugated polymers to C₆₀ (buckminsterfullerene) has brought emphasis on applied semiconducting-polymer research for photovoltaic devices [1]. Thus far, the efficiency of these devices under AM1.5 illumination has been increased to > 2.5 % [2], utilizing a soluble poly (phenylene vinylene) derivative as hole conductor and a methanofullerene as electron conductor. Although 2.5 % is a very promising value for an all organic system, one of the deficiencies of these systems is the rather poor match of the absorption spectrum of the polymer with the solar spectrum.

The utilization of small organic dye molecules for photovoltaic devices has been investigated during the last couple of decades (for a summary of the early reports see for example [3,4]). Different classes of organic dyes, including merocyanine, doped metallo-phtalocyanine or charge transfer systems have been studied as promising

materials. The advantage of these low molecular weight systems for photovoltaics is their high absorption coefficient with a good overlap with the solar spectrum, while their transport properties are strongly correlated with their macroscopic order/crystallinity.

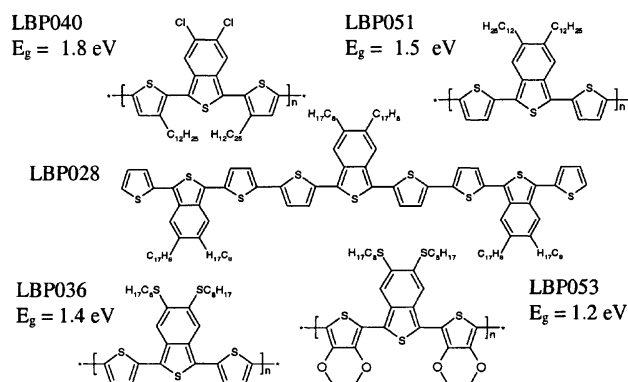


Figure 1: Chemical structure and the electronic bandgap of the different PDTI low bandgap polymers.

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In this work we suggest an alternative access to extend the photoactive spectral region of conjugated polymer based plastic solar cells by low band gap polymers. A series of differently substituted poly (thiophene-isothianaphthene) copolymers (PDTI) with bandgaps ranging from 1.8 eV to 1.2 eV (as determined by electrochemistry and absorption spectroscopy in the solution) was synthesized for this purpose (Fig. 1).

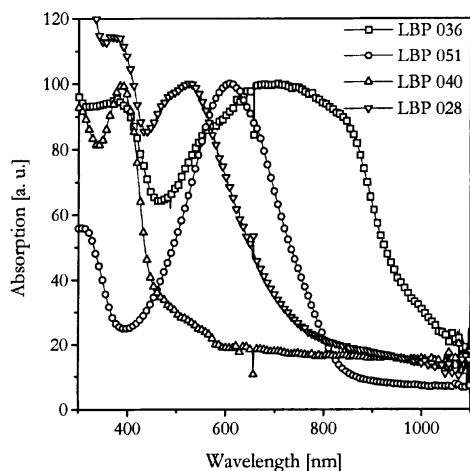


Figure 2: Absorption spectra of the different low bandgap polymers. Spectra were normalized to their peak absorption value in the visible.

2. Experimental

For the solar cells reported here PMMA was used as host matrix since the molar mass of the PDTIs was too low to form homogenous pinhole free thin films by solution casting (average weight molar mass M_w of 6000 – 8000 g). The weight ratio of the devices was PMMA : PDTI : PCBM = 1 : 2 : 6. Devices were spin cast from toluene with an average film thickness of ~ 80 nm as determined by alpha – stepper measurements. I/V characteristics were measured under AM 1.5 simulated irradiation with 80 mW/cm^2 from a Steuernagel solar simulator. The spectral photocurrent was detected by a Lock In amplifier while the sample was excited with monochromatic light with $\sim 200 \text{ } \mu\text{W/cm}^2$ and a FWHM of ~ 4 nm.

3. Results

Figure 2 shows the absorption spectrum of dorp cast films from the polymers. The lowest bandgap was observed for the polymers LBP 036 and LBP 051, however, the extension of the spectrum of LBP 036 to the infrared might indicate some residual doping.

While the absorption spectra already indicate the proper spectral region, spectral photocurrent spectra are taken to demonstrate the charge generation in these regions (Figure 3). The absorption of the spin cast PMMA : PDTI : PCBM films were an superposition of the individual component's

absorption spectra. The peak optical density of the spin cast films was in the range of 0.1. From this we estimate that the devices absorb less than 20 % of the incident light at their maxima.

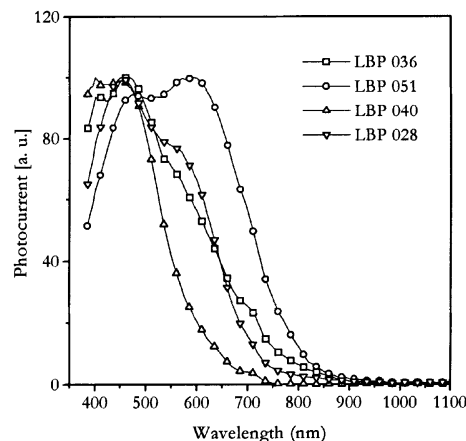


Figure 3: Spectrally resolved photocurrent of the single devices. Spectra were normalized to their peak in the visible.

The spectral photocurrent, except for LBP 036, coincide quite good with their absorption spectra and indeed prove the low bandgap of these polymers Their device characteristics under AM1.5 is listed in table 1.

Table 1:
PV parameters for the single polymers

PDTI	V_{oc} [mV]	I_{sc} [mA/cm ²]	FF	η [%]
LBP 036	280	0.6	0.24	0.04
LBP 051	260	1.6	0.37	0.15
LBP 040	840	1.2	0.23	0.21
LBP 028	260	0.5	0.27	0.4

4. Conclusion

The series of PDTI are indeed very promising for photovoltaic devices as well as photodiodes with an extended spectrally range to the infrared. The I_{sc} of the diodes are rather high with respect to their low absorption, but overall efficiencies suffer from the rather poor diode behavior. Higher efficiencies due to enhanced absorption and better diode behavior are expected for higher molecular weight polymers with improved processability.

References & Acknowledgement

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