Realisation of Polymer-Fullerene Solar Cells without Charge Transport Limitations

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Easily processable conjugated polymers for optoelectronics, in general, and for photovoltaic energy conversion, in particular, is an attractive research field, in which the combined efforts of material science, device engineers, and spectroscopists are welcomed. To improve the efficiency of polymer solar cells, currently within the range of 2.5 and 3.5%, it is vital to understand which mechanisms control the current-voltage characteristics of a given device. Temperature and light intensity dependence of the main solar cell parameters is very informative for analysing the power efficiency losses. The strong temperature dependence of the J_{SC} (Fig. 1a) reflects the transport losses due to trapping and recombination of charge carriers. Such behaviour was established recently for bulk-heterojunction devices based on absorber materials with low charge carrier mobility, polyparaphenylene-vinylene derivative, OC1C10-PPV blended with the fullerene PCBM, [1]. In contrast, in solar cells based on higher mobility polymers, poly (3-hexylthiophene 2.5-diyl) (P3HT) blended with PCBM, the J_{SC}, being thermally activated at low temperatures, saturates and becomes nearly temperature independent at elevated temperatures (Fig. 1b), clearly indicating that the charge carriers traverse the active layer without significant losses [2,3].

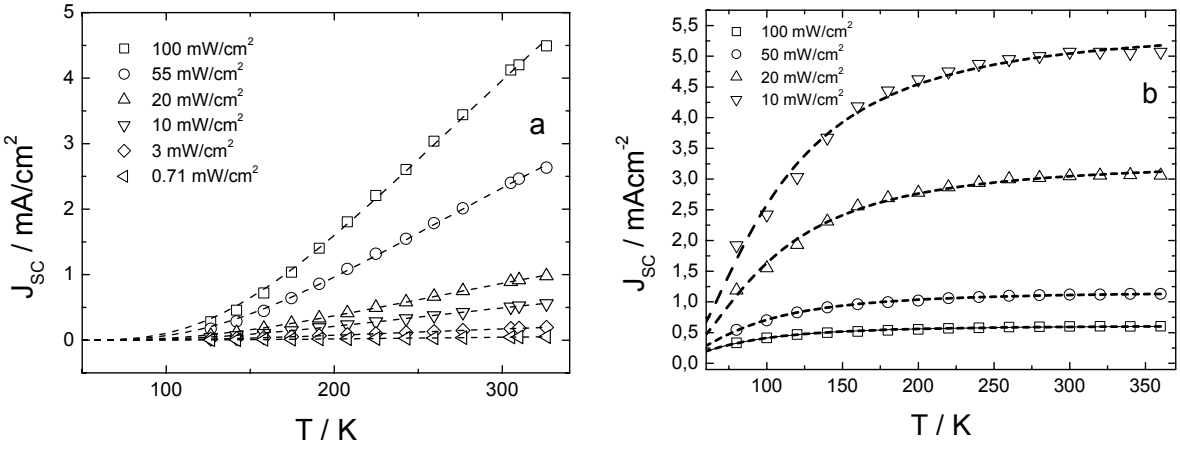

Figure 1. Short circuit current density J_{SC} as a function of temperature and light intensity for ITO/PEDOT:PSS/PPV:PCBM/Al **(a)** and for ITO/PEDOT:PSS/P3HT:PCBM/Al **(b)** solar cells.

The second important aspect is the manner in which electrical contact to the polymer or fullerene is created. We studied the temperature dependent current – voltage characteristics of regioregular P3HT thin films sandwiched between indium tin oxide (ITO) and aluminium (Al) electrodes (ITO/P3HT/Al devices), with the aim of determining the current limiting mechanism(s) in these devices, and the temperature and/or applied electric field range(s) in which these mechanisms are valid. The current-voltage characteristics of the ITO/P3HT/Al devices showed that current flow across the device is limited by hole injection at the Al/P3HT interfaces at temperatures below 240 K, when the device is biased with high potential on Al. Above this temperature, the bulk transport properties control the characteristics. For the

reverse bias, the ITO/P3HT contact does not limit the current; instead it is controlled by a space charge that accumulates due to the low charge carrier mobility in the polymer. An expression that provides a criterion to determine the validity of applying either the Richardson-Schottky thermionic emission model or the Fowler-Nordheim field emission model was deduced. It can be employed to determine the electrical field at which the transition from charge injection by thermionic emission to that by field emission for a given temperature and interface potential barrier height takes place (Fig. 2a). Our experimental data (Fig. 2b) fit to the deduced expression.

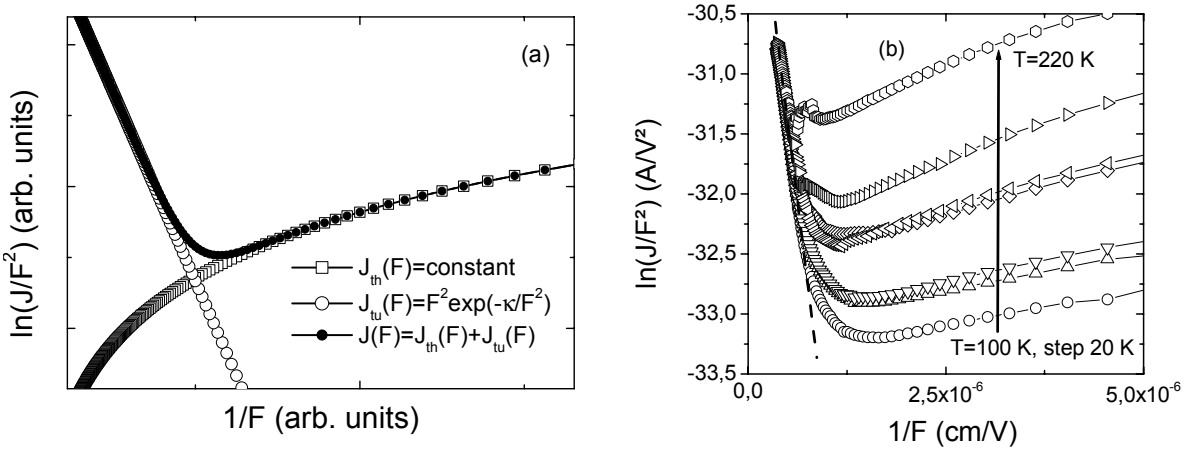

Figure 2. (a) The superposition of contributions of thermionic $J_{th}(F)$ (open squares) and tunnelling $J_{tu}(F)$ (open circles) in total current density $J(F)$ (closed circles). In the thermionic term, the potential barrier is considered as field-independent. (b) Fowler-Nordheim plots for the tunnelling of holes from Al into P3HT Dotted line indicates the linear parts of the curves.

Theoretical limits of the model are also discussed. By considering the regions of the current-voltage curves where field emission or thermionic emission was applicable, the interface potential barriers were estimated, respectively. Hence, conclusions on whether the current-voltage behavior of the devices was contact limited or bulk limited could be drawn [4].

References:

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