**Two different types of S-Shaped J-V characteristics**

**in organic solar cells**

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In this paper S-shaped characteristics of organic solar cells are analyzed by a drift-diffusion model which includes surface processes on the anode and cathode through boundary conditions. The model is described in [1] and it is extended by the transfer matrix calculation of interference effects [2], the Scharfetter and Gummel discretization [3], and the boundary conditions that take into account the finite surface recombination velocities and thermally activated charge carrier densities at contacts [4]. The surface recombination velocities for electrons and holes on both contacts have been varied as well as the injection barriers for both types of carriers.

By reviewing the literature [4, 5], two different types of S-shaped J-V characteristics in organic solar cells can be distinguished. The first type of the S-shaped J-V characteristic that is more often seen in literature, manifests S-shape bending in the vicinity of the voltage axis, after which it rises almost exponentially [4, 5]. The other type of S-shaped J-V characteristic proceeds to grow monotonically after bending and it has only one saddle point [5]. According to our analysis, the first type of S-shaped J-V curve is associated with the surface recombination rate and it can be reproduced by our model if surface recombination velocity for any type of carrier on any contact is assumed to be comparable or smaller than its average diffusion velocity. The other type of S-shaped J-V curve seems to be a consequence of the injection barrier for electrons. When the injection barrier for electrons is lower than 0.2eV, the calculated J-V characteristics don’t have the S-shape. For the electron barrier heights around 0.2eV, the S-shape bending of the J-V curve is observed and it occurs for all larger barrier heights. According to our simulations, the barrier height for holes is not responsible for the S-shape, but together with the electron barrier height affects the organic solar cell open circuit voltage (Voc).

The validity of our model is confirmed by comparing the simulated J-V curves with the experimentally obtained data. The model has been applied to the ITO/PEDOT:PSS/P3HT:PCBM/Al and ITO/PEDOT:PSS/P3HT:ICBA/Al solar cells. For the P3HT:PCBM based solar cells regular J-shaped J-V curves were measured, while for the P3HT:ICBA solar cells the J-V characteristics with anomalous S-shape behavior were recorded. All experimentally obtained J-V curves were reproduced very well with our model. It seems that the ITO/PEDOT:PSS/P3HT:ICBA/Al solar cell S-shaped J-V curve originates from the electron barrier height on the cathode contact, rather than from the low surface recombination velocities on the electrodes.

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