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Organic tandem solar cells—modelling and predictions

Nils-Krister Persson*, Olle Inganäs

Department of Physics and Measurement Technology, Biomolecular and Organic Electronics, Center of Organic Electronics, Linköpings Universitet, SE-581 83, Linköping, Sweden

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Abstract

Tandem combinations of organic photovoltaic devices are studied from an optical point of view. We unify coherent (wave-based) as well as incoherent (irradiance-based) light addition in our treatment of the incoming and reflected electromagnetic waves, and calculate the spatially resolved absorption profile in the cells. The model allows for any number and any order of thin and thick layers to be analysed. Irradiation is monochromatic or polychromatic, AM 1.5 or AM 1.0, and therefore applicable for solar cell simulation. The optical modelling is unified with electrical models of charge generation and transport in the solar cells. Through this, de-coupling of optical and electrical processes is possible. Moreover, the model allows identification of limiting processes in the devices. The model is applied to a tandem cell with copolymers of polyfluorene combined in bulk heterojunctions with fullerene acceptors, one device for high energy absorption and one for lower, where anodes and cathodes for the cells are semi-transparent metallic polymer layers. It is concluded that these materials do not at present have an electrical performance, which can be enhanced by the tandem cell combination.

Keywords: Solar cell; Optical modeling; Tandem; PDMS; Ellipsometry

1. Introduction

Better use of the available energy in the solar spectrum is necessary for the development of polymer-based photovoltaic devices (PPVDs). Low band gap materials are continuously

*Corresponding author.
E-mail address: nilpe@ifm.liu.se (N.-K. Persson).

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being developed [1,2]. Arrangements for enhancing the photon path way to increase optical absorption include; the dual use of the back contact as an electrode and a mirror, minimization of the reflectance, and diffuse interfaces [3]. The standard geometry of PPVDs is a multilayered thin film stack on a stiff substrate, such as glass or quartz. One layer in the stack, the active one, is responsible for the absorption of photons, which later will generate charge carriers. Normally only one quantum event of charge carrier photogeneration is used; it may, however, be more attractive with multiple band gap materials/devices for enhanced energy conversion.

There might hide latent possibilities if this one-stack geometry is extended to two or several stacks, each with its own active layer where the band gaps are different. This tandem geometry is a well-known concept for inorganic photovoltaic devices [4]. In a tandem, each stack can be designed for absorbing part of the incoming light. Even if parallel arrangements are conceivable, the serial geometry is the most common. The foremost cell then absorbs in the blue, whereas the second absorbs the low energy part of the solar spectrum. This gives in principle two cells (the four electrode case) which, however, may also be combined in a assembly with only two electrodes and a recombination layer, where charges from one device are recombining with the opposite charge from the second device. In this case the two cells may be put in electrical series, if the photocurrents from the two devices are exactly equal. With four electrodes, the electrical output may be combined in serial or parallel fashion in many ways.

Tandem is also an alternative to incorporating several materials with different band gaps in a common device by blending [5] different polymers in one active layer, a procedure that may lead to better optical absorption but will also generate a lower photovoltage.

Taking the laboratory PPVDs to commercialisation requires new fabrication methods such as silk screen printing [6] or ink jet printing [7]. Spin coating of organic layers is suitable for small areas only, waste precious material that is centrifuged away and often needs solvents that sometimes are hazardous to environment as well as humans. Spin coating also limits the possibility to build multilayer devices, because the risk of dissolving the layer beneath when spinning the next layer. It may be possible to find routes for layer deposition from solution, using solvents that are incompatible to each other. Different lamination techniques have been suggested as another alternative. Parts of the complete device are then manufactured separately, for example as an anode side and a cathode side, that are assembled to form a complete device [8,9]. This route could also be relevant in the assembly of tandem cells. Present lamination technology for large-scale production (calendaring, simple pressing, etc.) demands a carrier that contains a macroscopically thick layer that can stand the mechanical strain, but also a working temperature somewhere between the glass transition temperature and the melting temperature. For laboratory purposes different lamination procedures have been tried; low temperature (60 °C) and low pressure [9] for high surface area interfaces, or room temperature and low pressure [10] or even room temperature and no pressure [11], often making use of elastomeric substrates [12].

The earliest studies of organic laminated solar cells were done by Granström et al. [13] (polymers) and Petritsch [8] (dyes). Tandem organic photovoltaic devices also exist and are typically built from small molecular materials rather than polymers, as these can be deposited from vacuum either with homogenous layered devices [14–19] or with Grätzel cell structures [20].