Nanostructured Electrodes and Photoactive Layers for Efficient, Stable and Flexible Organic Photovoltaic Devices

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Solar energy is an abundant and clean resource, but cost of solar panels prohibits economical generation of electricity from this resource. In this regard, organic photovoltaic (OPV) devices are attractive due to their potential for low cost roll-to-roll manufacturing on flexible substrates and the expanded range of applications of flexible solar cells (1-4). However, the efficiency and stability of the OPV devices have been increasing slowly in the past decade and they are yet below the desirable efficiency levels offered by silicon technology (1-6). The efficiency of the OPV devices is dependent on the type of acceptor and donor polymers used, effective formation of nanoscale morphology for donor-acceptor bulk heterojunction (BHJ) and the effectiveness of electrodes for extraction of photo-generated carriers. These morphological attributes and their evolution during operation also impact the stability of the OPV devices (5-6).

This work presents our latest results for conventional and inverted OPV devices (5) based on polymers such as poly(3-hexylthiophene) (P3HT) and poly[*N*-9"-hepta-decanyl-2,7-carbazole-alt-5,5-(4',7'-di-2-thienyl-2',1',3'-benzothiadiazole) (PCDTBT) and fullerene derivatives such as derivative [6,6]-phenyl C_{71}-butyric acid methyl ester ($PC_{71}BM$). It is observed that by controlling the morphology of acceptor and donor domains in the BHJ photoactive films higher power conversion efficiency (PCE) and performance for OPV devices can be achieved, with the best efficiencies demonstrated for the PCDTBT: $PC_{71}BM$ devices exceeding 7%. Here, the interplay between fabrication processes and the performance of the devices is investigated to achieve optimum PCE, short-circuit current and open-circuit voltage for the OPV devices. In addition to choice of polymers, different techniques can be used to enhance the nanoscale morphology such as post annealing and solvent-vapour annealing after deposition of the BHJ films.

In addition to the properties of BHJ layer, nanoscale morphology of the electrode and contact layers play a critical role in determining the performance of OPV devices. While usage of electron selective nanostructured electrodes such as ZnO nanorods is found to facilitate extraction of electrons, the length and distribution of nanorods must be optimized for efficient interactions with the BHJ layer and suppressing the series resistance arising from long nanorods. Issues related to the fabrication of the hole selective layers such as poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS) and their stability during operation of the OPV devices are discussed. Nano-engineering of contact layers is critical for achieving high efficiency and stability in relation with the desired morphology of a specific BHJ layer.

In addition to contact and BHJ films, a flexible solar cell requires a flexible transparent conductor (TC). We present our recent results for conductive electrospun nanofiber based TCs and graphene as replacements for the brittle indium tin oxide (ITO) used for solar cells on glass substrates. These novel nanofiber TC web and their associated flexible substrates act as new platforms for fabrication of low cost, flexible solar cells. Performance of the TC is compared to other novel TCs (7-9) in terms of transparency, sheet resistance and flexibility. The performance of nanofiber TC webs and graphene TC is manifested in OPV devices that employ these TCs instead of ITO as the transparent electrode and demonstrate comparable performance to the devices using ITO electrodes. This work demonstrates the significance of the novel materials and deposition technologies for enabling efficient and stable OPV devices for roll-to-roll manufacturing on flexible substrates.

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