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# Effect of low concentrations of carbon black in organic solar cells

Xinbo C. Lau, Zhiqian Wang, Somenath Mitra *

*Department of Chemistry and Environmental Science, New Jersey Institute of Technology, Newark, NJ 07102 United States*

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ABSTRACT

We demonstrate for the first time the efficiency improvement of poly(3-hexylthiophene) (P3HT)-fullerene ($C_{60}$) bulk heterojunction photovoltaic cells by the introduction of trace concentrations of carbon black (CB) into the photoactive layer. As compared to control devices with only $C_{60}$, the addition of low concentration (12.5 ppm) of CB resulted in 35% improvement in short circuit current density ($J_{sc}$), and 79% improvement in power conversion efficiency (PCE). CB served the dual function of enhancing electron transport as well as optimizing phase separation leading to high current density and PCE. The results indicate that CB is a promising additive for the performance enhancement of polymer photovoltaic cells and may work with diverse donor–acceptor systems.



## 1. Introduction

Organic photovoltaics (OPVs) are excellent alternatives to conventional silicon and thin film solar cells because they attempt to achieve moderate power conversion efficiencies (PCE) at significantly lower cost. Typical OPVs are based on the creation of bulk heterojunction solar cells consisting of blends of an electron-donating semiconducting polymer and an electron-accepting molecule such as fullerene ($C_{60}$) or its derivative [1–10]. While $C_{60}$ typically has shown low power conversion efficiency, its derivatives such as [6,6]-phenyl C61-butyric acid methyl ester (PCBM) with poly(3-hexylthiophene) (P3HT) bulk heterojunctions have shown PCE that are approaching 5% [11] and the efficiencies of OPVs with low band gap donors that are approaching 10% [12].

Improvement in OPVs can be brought about by addressing some of its limitations, namely, improving absorption of a wide range of the solar radiation spectrum [13,14], and enhancing the electron and hole mobilities [15]. The phase separation in bulk heterojunction solar cells creates percolation pathways for transporting the holes and electrons to their respective electrodes. Therefore, the performance of heterojunction solar cells can also be improved by optimizing phase separation.

Nanocarbons, including carbon black, graphite, carbon nanotubes and nanodiamonds are important for many applications for enhancing electrical properties. They have been used in OPVs, where the introduction of carbon nanotubes and nanodiamonds has been reported to enhance phase separation as well as increase electron mobility [16,15,17–20]. The structure of commercial carbon black (CB) is known to have both crystalline carbon (graphite) and amorphous carbon, where the aggregates tend to form through Van der Waals forces. CB is electrically conductive with conductivities ranging from 0.1 to $10^2$ S/cm at ambient temperature. They impart good conductivity to polymers and have been widely used as fillers in polymers for applications such as conductive packaging for electronics, and as fuel cell electrodes [21]. CB also shows high absorption of the solar spectra [22]. However, the potential drawback of adding a conductive additive to a photoactive layer in a solar cell is that if not properly dispersed, the large agglomerates can lead to extensive charge recombination and even short circuit. The objective of this research is to study the effect of CB as an additive to improve performance of OPVs. It is anticipated that the CB could potentially enhance exciton dissociation, charge transport and improve film morphology. The P3HT/$C_{60}$ system was selected as a model with a particular interest on the effects of CB concentration.

## 2. Experimental

### 2.1. Preparation of different concentrations of $C_{60}$–CB composites

Regioregular P3HT was obtained from Rieke Metals Inc., graphitized mesoporous carbon black was obtained from Sigma-Aldrich Co., and fullerene powder with a purity of 99.98% was obtained from MER Co. This type of CB provides structural homogeneity with significant graphite-like domains, high surface

* Corresponding author. Tel.: +1 973 596 5611.
*E-mail address:* somenath.mitra@njit.edu (S. Mitra).

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area, enhanced conductivity and its approximate diameters are in the range of 20 to 35 nm. The $C_{60}$–CB composites containing ppm levels of CB were prepared according to an experimental procedure previously published by our laboratory [16,23]. First, $C_{60}$ solution was prepared at a concentration of 10 mg/ml. CB powder was sonicated in ODCB (shown in Fig. 1a) for 20 min at seven different concentrations. Then 0.3 ml of different concentrations of CB solutions was mixed separately with 3 ml of $C_{60}$ solution by

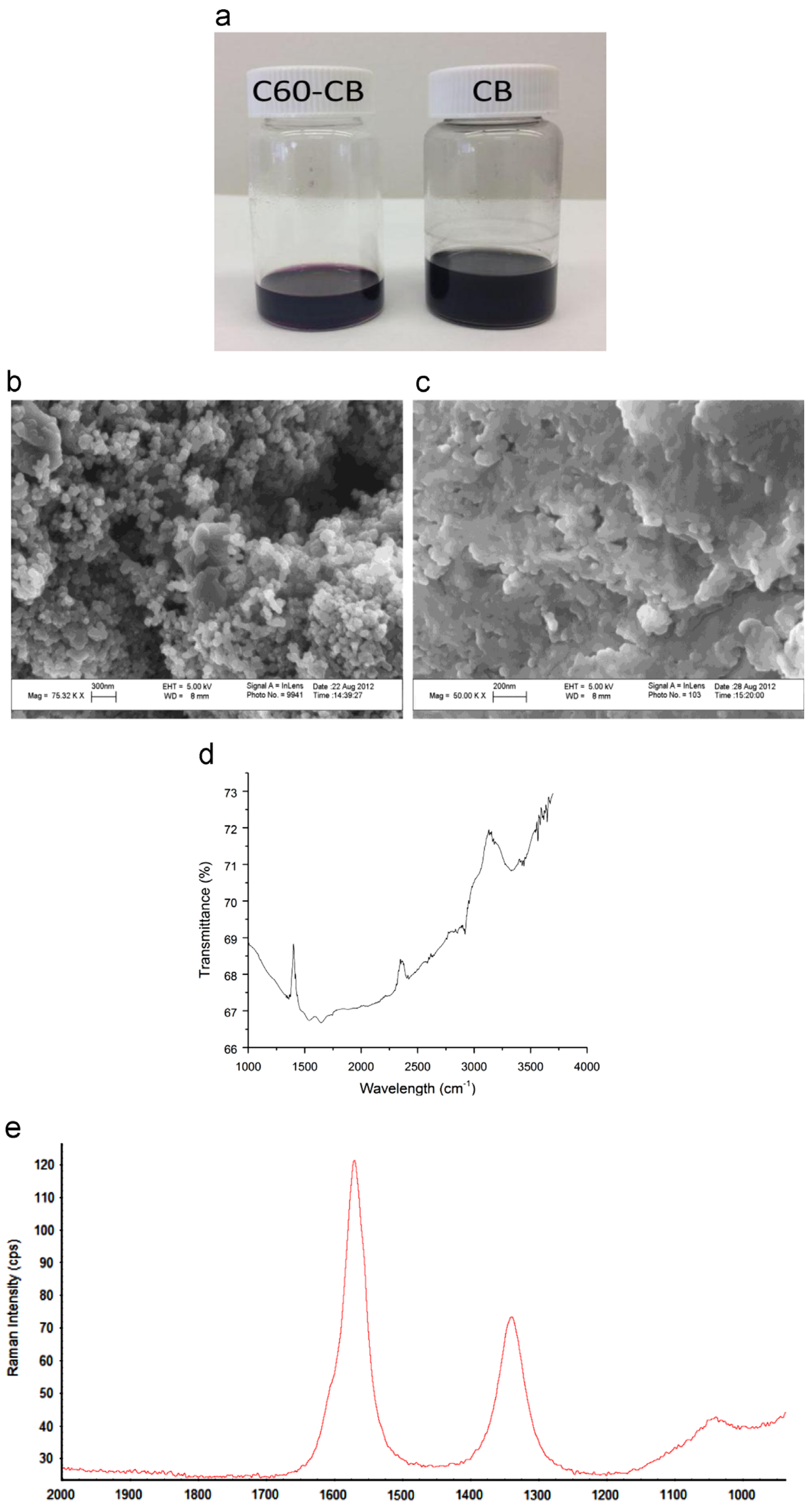


**Fig. 1.** (a) Image of $C_{60}$–CB and CB solutions dissolved in ODCB. (b) SEM image of CB solution and (c) SEM image of $C_{60}$–CB solution. (d) FTIR spectrum of CB powder, and (e) Raman spectrum of CB powder.