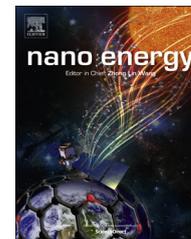


Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/nanoenergy

RAPID COMMUNICATION

Few-layered graphene quantum dots as efficient hole-extraction layer for high-performance polymer solar cells

Zicheng Ding^a, Zhen Hao^a, Bin Meng^a, Zhiyuan Xie^a, Jun Liu^{a,*},
 Q1 Liming Dai^{b,*}

^aState Key Laboratory of Polymer Physics and Chemistry, Changchun Institute of Applied Chemistry, Chinese Academy of Sciences, Changchun 130022, PR China

^bDepartment of Macromolecular Science and Engineering, Case School of Engineering, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, OH 44106, USA

Received 2 April 2015; received in revised form 22 April 2015; accepted 22 April 2015

KEYWORDS

Graphene quantum dots;
 Graphene oxide;
 Work function;
 Hole-extraction layer;
 Polymer solar cell

Abstract

In this study, we demonstrate that few-layered graphene quantum dots (F-GQDs) can be used as hole-extraction layer (HEL) for high efficiency polymer solar cells (PSCs). As a new class of HEL material, graphene oxide (GO) is not suitable for polymer solar cells (PSCs) based on highly efficient donor polymers due to the relatively low work function and the poor film-forming property of GO. To circumvent these two problems, we develop F-GQDs with a small size of about 4 nm and high content of periphery COOH groups. The small size of F-GQD ensures an excellent film-forming capability and the abundant COOH groups increase the work function of F-GQD to 5.26 eV from 5.01 eV of GO. As the result, when used as HEL in high efficiency PSC devices with PTB7:PC₇₁BM or PCDTBT:PC₇₁BM as the active layer, F-GQDs outperforms GO and the state-of-the-art HEL, PEDOT:PSS. These results demonstrate the great potential of F-GQD as efficient HELs to achieve high-performance PSCs.

© 2015 Published by Elsevier Ltd.

Introduction

Owing to their low cost, light weight, flexibility, and ever-increasing efficiency, polymer solar cells (PSC) have attracted great attention in the past two decades [1-5]. To improve power conversion efficiency (PCE) of PSCs, it is critical to facilitate charge extraction and prevent charge

*Corresponding authors.

E-mail addresses: liujun@ciac.ac.cn (J. Liu),
liming.dai@case.edu (L. Dai).

<http://dx.doi.org/10.1016/j.nanoen.2015.04.019>
 2211-2855/© 2015 Published by Elsevier Ltd.

recombination at the interfaces between the active layer and the cathode/anode electrodes. Therefore, a hole-extraction layer (HEL) between the anode and active layer and/or an electron-extraction layer (EEL) between the cathode and active layer are often required for high-performance PSCs [6-8]. However, the state-of-the-art HEL, poly(3,4-ethylenedioxythiophene) doped with poly(styrene sulfonate) (PEDOT:PSS), is still suffering from strong acidity and hygroscopicity to cause the device instability [9]. In order to maximize the PCE without the detrimental effect on device stability, several inorganic semiconductors, such as MoO_3 , V_2O_5 , NiO , WO_3 and RuO_2 , have been used as the HEL in high-performance PSCs [10-14]. However, the use of these inorganic semiconductors increases the manufacturing cost as they need to be vacuum deposited. Recently, graphene oxide (GO) and its derivatives have emerged as a promising class of HEL materials with advantages of solution processability and low cost [15-24].

GO, a derivative of the one-atom-thick graphene with hydroxyl (OH) and epoxy groups on its basal plane and carboxyl groups (COOH) at the edge (see Scheme 1), often has a lateral size larger than several hundred nanometers and the work function of 4.7-5.0 eV [25,26]. Since the work function of GO matches well with the highest occupied molecule orbital (HOMO) level of the prototype donor polymer poly(3-hexylthiophene) (P3HT, HOMO: -4.9 eV) [20] for hole extraction, GO has been used as HEL in PSCs by several groups including our own one [15-19]. Due to the poor film-forming property intrinsically associated with the difficulties for large flakes of GO to uniformly cover the rough surface of indium-tin oxide (ITO) anode [16], the device performance of GO HEL cannot surpass that of PEDOT:PSS. Moreover, GO is not suitable for PSCs based on highly efficient donor polymers with deep HOMO levels (< -5.1 eV) [15,19]. The relatively low work function of GO induces an energy barrier for hole extraction and greatly decreases the PSC device efficiency. Therefore, solution-processable graphene materials with high work function and excellent film-forming property should be developed for high-efficiency PSC devices [21-24].

In this manuscript, we report the use of few-layered graphene quantum dots (F-GQD) with a small size of about 4 nm and high content of periphery COOH groups (see, Scheme 1) as excellent HEL in PSCs based on a highly efficient donor polymer, poly[[4,8-bis[(2-ethylhexyl)oxy]benzo[1,2-b:4,5-b']dithiophene-2,6-diyl][3-fluoro-2-[(2-ethylhexyl) carbonyl]thieno[3,4-b]thiophenediyl]] (PTB7). The small size of F-GQD ensures an excellent film-forming capability [27,28] while the abundant COOH groups increase the work function

of F-GQD to 5.26 eV [29] from 5.01 eV of GO. The PSC device with PTB7 and [6,6]-phenyl-C71-butyric acid methyl ester (PC_{71}BM) as the active layer and F-GQD as the HEL is demonstrated to exhibit a PCE of 7.91%, outperforming its counterparts based on the GO (6.33%) and PEDOT:PSS (7.46%) HEL. To our best knowledge, the PCE thus achieved among the highest values reported for PSCs containing graphene materials [30-32].

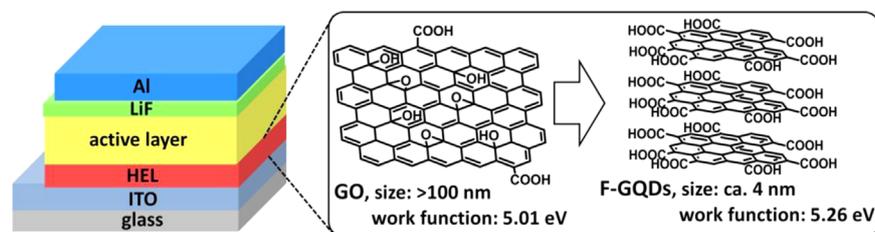
Experimental section

Synthesis of GO

A mixture of graphite powder (1.00 g, 325 mesh), concentrated H_2SO_4 (25 mL), sodium nitrate (0.50 g) was stirred for 30 min in an ice-water bath and was slowly added KMnO_4 (4.50 g) under vigorously stirring, followed by stirring at 35°C for 30 min and at 90°C for another two hours. After cooled down, the mixture was slowly added into de-ionized water (100 mL) and H_2O_2 (30 mL). Centrifugation was carried out to precipitate the solid, which was washed with 1 M hydrochloric acid for three times and de-ionized water for another three times. The resultant solid was then dispersed in water by ultrasonication for 30 min, followed by centrifugation at 6000 rpm for 30 min. The supernatant was collected and purified through dialysis to afford aqueous GO solution (ca. 200 mL). To determine the concentration, 20 mL of the GO solution was filtered with a $0.22\text{-}\mu\text{m}$ membrane and then the dried in vacuum to give a solid content of 0.09 g. Hence, the concentration of the GO solution was 4.5 mg/mL and the yield of the reaction was 90%.

Synthesis of F-GQD

Vulcan VXC-72 carbon black (5.00 g, purchased from Cabot Corporation) was added into a mixture of concentrated H_2SO_4 (200 mL) and concentrated HNO_3 (100 mL). The mixture was stirred and refluxed for 24 h. After cooled down to room temperature, the mixture was at first neutralized with Na_2CO_3 powder and then acidified with hydrochloric acid to give $\text{pH}=1$. The resulting mixture was added into acetone (300 mL), followed by filtration to remove the precipitate. The filtrate was collected and the solvent was removed by rotary evaporation. The resulting deep yellow solid was dried in vacuum to afford F-GQD. Yield: 1.90 g, 38%.



Scheme 1 (a) Device structure of the PSC. (b) Schematic structures of GO and F-GQD. Note the size and work function of GO and F-GQD underneath of the schematic structures.

Download English Version:

<https://daneshyari.com/en/article/1557380>

Download Persian Version:

<https://daneshyari.com/article/1557380>

[Daneshyari.com](https://daneshyari.com)