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Effects of processing additive on bipolar field-effect transistors based on blends of poly(3-hexylthiophene) and fullerene bearing long alkyl tails

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ABSTRACT

Bipolar FETs (BiFETs) based on the bulk heterojunction system comprised of various ratios of P3HT and soluble fullerene derivatives are demonstrated. We studied the effect of addition of small concentrations of the processing additive, 1,8-octanedithiol (ODT), on gate-induced transport properties. The control blend system consisting of poly (3-hexylthiophene) (P3HT) and phenyl-C61-butyric acid methyl ester (PCBM) showed enhanced hole transport properties with the addition of the ODT additive. However, electron transport properties were diminished in the presence of ODT additive because of the relatively isolated PCBM phase between the large-scale segregation of the P3HT amorphous phase. The BHJ BiFET based on P3HT and soluble fullerene derivatives bearing long alkyl tails (FP-Ph-OC10) showed enhanced performance in both hole and electron transport when the ODT additive was applied. We attribute the enhancement of hole mobility to well-formed P3HT fibrilla structures of P3HT caused by the alkyl–alkyl interaction assisted by both the ODT additive and alkyl side chain in FP-Ph-OC10. As the P3HT forms fibrilla structures, connection to the isolated FP-Ph-OC10 phase be formed, resulting in a continuous electron pathway, thereby improving electron mobility. This suggests that not only the selective solubility, but also the alkyl-alkyl interaction between the side-chain and ODT additive may affect the phase segregation of BHJ mixtures.

1. Introduction

Polymer-based bipolar field-effect transistors (BiFETs), which integrate both p-channel and n-channel transistors in one device, are particularly attractive for use in low-cost, flexible, and portable electronic applications, allowing for simplified circuit design and fabrication processes [1–4]. Since the typical conjugated polymers show either high hole mobility or high electron mobility, scientists have attempted to realize ambipolar FETs via the use of blending systems consisting of hole-transporting and electron-transporting materials as an active layer [5–7]. Although recent studies have examined ambipolar FETs derived from single-component materials [4,8,9], the blend-type active layer is still a primary strategy in the fabrication of BiFETs.

Among the parameters that can be optimized to achieve high-performance BiFETs, good charge transport properties in both holes and electrons are the most important factors. Procuring good hole and electron transport in polymer bulk heterojunction (BHJ) blends requires

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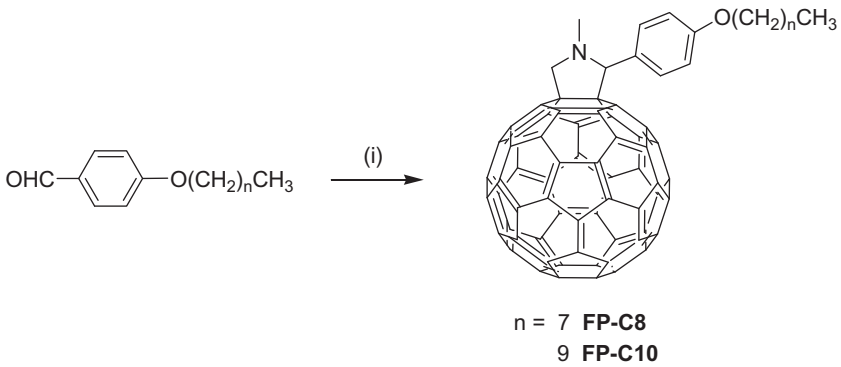

Scheme 1. Conditions and reagents: (i) C_{60}, sarcosine, toluene, reflux.

the assembly of a bicontinuous network of holes and electrons, which is more critically important than the use of materials with intrinsic high mobilities [10]. Processing additives, such as 1,8-octanedithiol (ODT) and 1,8-diiodooctane (DIO), have been utilized in BHJ blends as a means to optimize the phase-separated morphology of BHJ films [7,11–13].

The operation mechanism of processing additives, such as ODT and DIO, has been well established and used for selective solubility [14]. These early processing additives initially lead to the aggregation of the 'polymer' part in the solution, which results in an increase in the size of the BHJ domains in the film. Although hole transport properties can be efficiently improved by adding such processing additive, electron transport properties are often suppressed because phenyl-C61-butyric acid methyl ester (PCBM), which is commonly used as an electron transport material in BHJ BiFETs, can be isolated within the large polymer phase [15].

In this work, we used a soluble fullerene derivative bearing long alkyl tails (FP-Ph-OC10) [16] as an electron transport material to maintain the continuous network of electron transport in BHJ BiFETs. The control blend system consisting of poly (3-hexylthiophene) (P3HT) and PCBM showed enhanced hole transport properties with ODT additive, while the electron transport properties were diminished with ODT additive. The BHJ BiFET based on P3HT and FP-Ph-OC10, however, showed enhanced performance in both hole and electron transport when the ODT additive was applied.

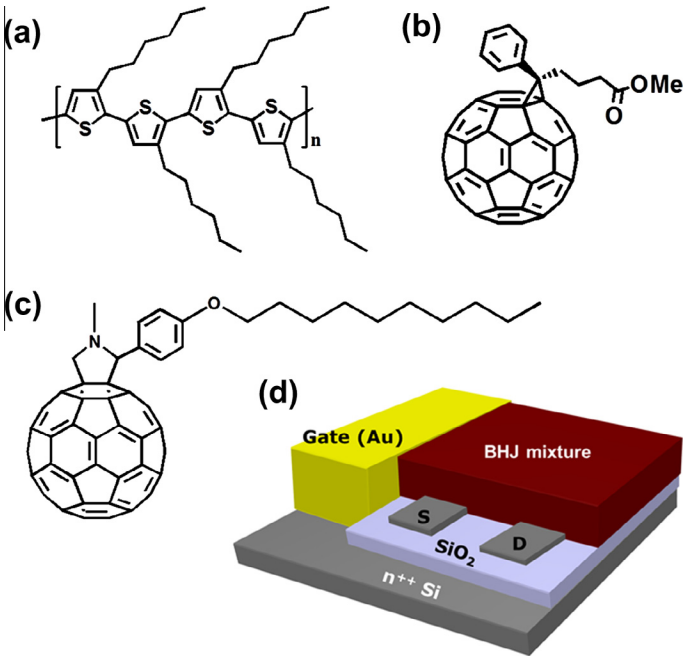

Fig. 1. Molecular structures of (a) P3HT, (b) PCBM, and the fullerene derivative, (c) FP-Ph-OC10. (d) Schematic diagram of a bottom-contact bipolar field-effect transistor.