



Airstable near-infrared sensitive organic field-effect transistors utilizing erbium phthalocyanine as photosensitive layer



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ABSTRACT

Near-infrared photosensitive organic field-effect transistors (PhOFETs) based on pentacene/erbium phthalocyanine (ErPc₂) and copper phthalocyanine (CuPc)/ErPc₂ heterojunction, as well as ErPc₂ single-layer PhOFETs, were fabricated and characterized. The results showed that the heterojunction PhOFETs exhibit higher mobility, maximum photoresponsivity (R_{max}) and maximum photo/dark current ratio (P_{max}), comparing with the ErPc₂ single-layer ones. Such a better performance of the heterojunction devices can be attributed to the higher mobility channel layer. And the pentacene/ErPc₂ PhOFETs demonstrate an R_{max} of 6498 mA/W, P_{max} of 2.6×10^3 , hole mobility of $1.5 \times 10^{-2} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ and excellent air stability, its R_{max} is 186 times larger than that of the ErPc₂ single-layer PhOFETs. Therefore, ErPc₂ can be used as an excellent NIR photoresponsive layer of heterojunction PhOFETs.

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1. Introduction

Recently, organic electronics involved in thin-film devices like displays [1–3], sensors [4], electronic labels [5,6], ring oscillators [7], and complementary integrated circuits are comprehensively investigated. Among them, the photoresponsive organic field-effect transistors (PhOFETs) have better application prospects because of low noise and high sensitivity compared with photodiodes [8], in which light can play a role of an additional terminal that optically controls device operation with conventional three terminals, source, drain, and gate electrodes. It was reported that, a large number of metal phthalocyanines (Q-band, 600–800 nm) [9] were used as photosensitive layer in organic solar cells (OSCs) and PhOFETs, such as copper phthalocyanine (CuPc) [10,11], lead phthalocyanine (PbPc) [12], and neodymium phthalocyanine (NdPc₂) [13], since they perform high thermal and chemical stability, and considerable photoelectric properties [14,15]. And the near-infrared (NIR) light is intimately linked to industrial applications, such as NIR photodetectors [16,17] and night vision.

Copper phthalocyanine (CuPc), is a planar organic molecule with good thermal stability, which can be easily deposited as thin film by thermal evaporation [18,19]. And it is well known that CuPc is a *p*-type organic semiconductor material [20]. In the past decades, the organic light-emitting diodes (OLEDs) based on CuPc as a buffer layer [21], the OSCs based on CuPc as a donor material [22] and the OFETs based on CuPc as an active layer [23] have been extensively studied due to its interesting photoelectric properties: an optical gap (~ 1.7 eV), very suitable for visible absorption (i.e., usage in photovoltaic devices), and a transport gap (~ 2.3 eV), fit for electronic devices [24]. And the carrier mobility of CuPc OFETs has reached $1.5 \times 10^{-3} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$. Therefore, CuPc can be used as a desirable channel material of OFETs.

Besides, pentacene-channel OFETs have received considerable attention, since they exhibit room-temperature field-effect mobilities on the order of $1 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$, drain current on-off ratios more than $\sim 10^6$, and operating bandwidths ~ 10 MHz [25], sufficient for low-cost electronics and driver circuits for flat panel displays. Pentacene (denoted as PENT) is a typical hole transport material with high mobility, and the hole mobility of single crystal PENT OFET reaching up to $35 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ was reported [26]. Hence, we also chose pentacene as the *p*-type channel layer due to its outstanding hole mobility and excellent air stability [27,28].

In this study, we first utilized a kind of rare earth phthalocyanines, erbium phthalocyanine (ErPc₂), as the photosensitive layer

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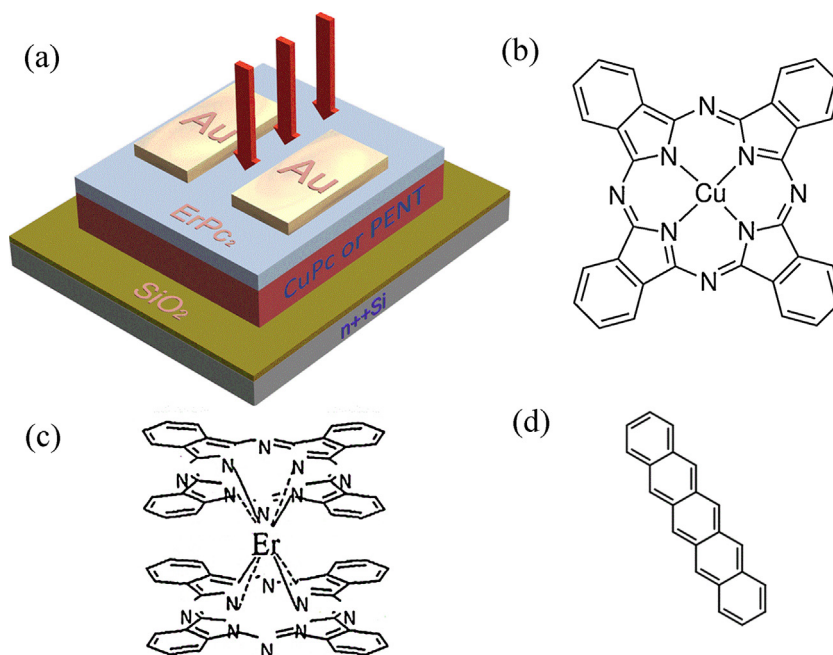


Fig. 1. (a) Structure schematic of PhOFETs. Molecular structure of (b) CuPc, (c) ErPc₂ and (d) pentacene.

of PhOFETs. And because of ErPc₂ molecule consists of a central erbium atom and π -electron system [29] with sandwich structure (see Fig. 1(c)), therefore it can show semiconductor properties. It is clear that, lead phthalocyanine (PbPc) is a good NIR photosensitive material [30], however, after characterization it is found that the NIR absorption coefficient of PbPc film is smaller than that of ErPc₂ (see Fig. 2(b)). It can be also found that an optimal device performance is obtained at $T_{sub}=140^{\circ}\text{C}$ at which the R_{max} (5 mA/W) of PbPc single-layer device reach maximum [31]. As a result, we expect that the NIR photodetection of ErPc₂ as photosensitive material is comparative even superior to that of PbPc mentioned above. Based on excellent photoelectrical

properties, here ErPc₂ is naturally selected for the NIR photosensitive material. However, the mobility and the exciton dissociation efficiency of ErPc₂ single-layer (SL) PhOFETs are proved low, leading to a poor performance of ErPc₂ SL PhOFETs. To address this issue, organic heterojunction was adopted in this study. By this way, the high-mobility organic semiconductor can be introduced and acts as the channel layer of PhOFETs. So far, to the best of our knowledge, the PhOFETs based ErPc₂ have been rarely reported. PENT/ErPc₂ and CuPc/ErPc₂ heterojunction PhOFETs, as well as the ErPc₂ SL ones were fabricated and investigated. The results showed that the heterojunction PhOFETs exhibit superior performance to the ErPc₂ SL ones.

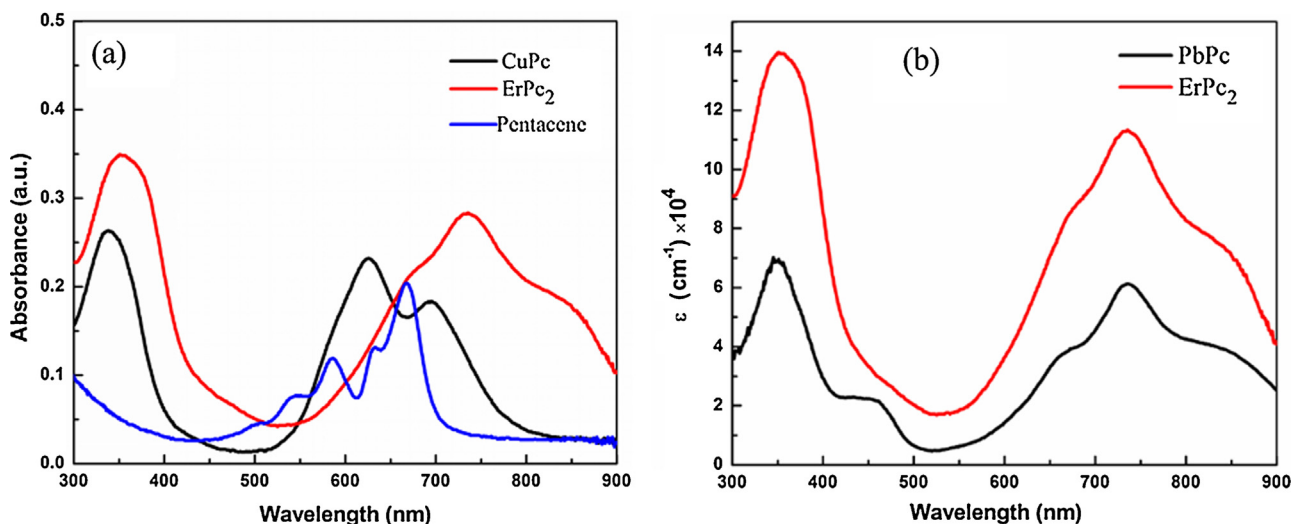


Fig. 2. (a) Optical absorption spectra of the 25-nm-thick ErPc₂, CuPc and pentacene (PENT) films deposited on quartz substrate. (b) The absorption coefficient of 25-nm-thick ErPc₂ and PbPc films.

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