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Enhancing the performance of organic thin-film transistors using an organic-doped inorganic buffer layer

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ABSTRACT

Organic thin-film transistors (OTFTs) with various buffer layers between the active layer and source/drain electrodes were investigated. The structure was polyethylene terephthalate/indium-tin oxide/poly(methyl methacrylate) (PMMA)/pentacene/buffer layer/Au (source/drain). V_2O_5, 4,4′,4″-tris{N,(3-methylpheny)-N-phenylamino}-triphenylamine (m-MTDATA) and m-MTDATA-doped V_2O_5 films were utilized as buffer layers. The electrical performances of OTFTs in terms of drain current, threshold voltage, mobility and on/off current ratio have been determined. As a result, the saturation current of −40 μA is achieved in OTFTs with a 10% m-MTDATA-doped V_2O_5 buffer layer at a V_{GS} of −60 V. The on/off current ratio reaches 2×10^5, which is approximately double of the device without a buffer layer. The energy band diagrams of the electrode/buffer layer/pentacene were measured using ultra-violet photoelectron spectroscopy. The improvement in electrical characteristics of the OTFTs is attributable to the weakening of the interface dipole and the lowering of the barrier to enhance holes transportation from the source electrode to the active layer.

1. Introduction

Organic thin film transistors (OTFTs) have attracted much attention in the development of commercial electronic devices including smart cards, sensors, radio-frequency identification tags, electronic paper, and flat panel displays [1–4], because of their low manufacturing cost, low processing temperature, the usefulness in the driving circuits of display pixels, and reducing optical energy loss [5,6]. In the past several years, evidence that the mobility of OTFTs is almost equal to, or even greater than that in amorphous silicon thin-film transistors has been obtained [7]. Nevertheless, the device performance of pentacene-based OTFTs still need further enhancement to meet with the requirement of commercial applications. Three issues are mostly addressed: (a) choosing a metal material for source/drain electrodes having an optimum work function to tally with energy band of the organic active layer, (b) utilizing film engineering on optimizing organic active layer to enhance its mobility, and (c) inserting an interlayer or buffer layer between the organic active layer and source/drain electrodes to reduce its contact resistance. First, metals with a high work function, such as Au, were widely adopted in p-type OTFT devices to reduce the height of the barrier between the source/drain electrode and pentacene [8]. However even using the high work function metals as source/drain electrode, the interface still exist interface dipole which will enlarge the energy barrier [9,10]. Secondly, a highly crystalline organic material, such as pentacene, is used as an active layer material to increase its carrier mobility [11,12].

Besides, the performance of OTFT devices is influenced drastically by parasitic resistance at the interface between the active layer and the source/drain electrode. A buffer layer is commonly utilized to modify the interface and reduce its contact resistance. Lots of published works adopt inorganic materials, such as MoO_3 and $FeCl_3$, or organic materials, copper phthalocyanine (CuPc) and tetrafluorotetracyanoquinodimethane (F_4-TCNQ) to form the buffer layer. Chu et al. inserted MoO_3 as a buffer layer, improving electrical property by reducing the contact resistance [13]. Schroeder et al. replaced the metal insulator-type buffer layer with a metal semiconductor of $FeCl_3$ [14]. Chen et al. used CuPc as a buffer layer and the mobility of OTFTs was improved from 0.11 to 0.21 cm^2/Vs after the modification. Vanoni et al. [15] found that F_4-TCNQ can reduce the contact resistance by more than a factor of 20. 4,4′,4″-Tris{N,(3-methylpheny)-N-phenylamino}-triphenylamine) (m-MTDATA), as a famous starburst glassy molecule in the field of organic optoelectronic, processes a dense film structure and favorable hole transport capability. Hu et al. applied m-MTDATA to enhance charge-injection [16,17], which is similar to that of the hole injection layer in an organic light-emitting diode [18]. V_2O_5 was used as a buffer layer to construct an organic solar cell in our previous work and had been demonstrated to effectively increase the mounts of hole transporting from active layer to anode [19]. The studies referred above used single inorganic or organic material to form the buffer layer. Recently, Li et al. reported the use of an organic-inorganic hybrid interlayer as a buffer layer and obtained the mobility of 0.87 cm^2/Vs and on/off current ratio of 1.7×10^6 in an OTFT

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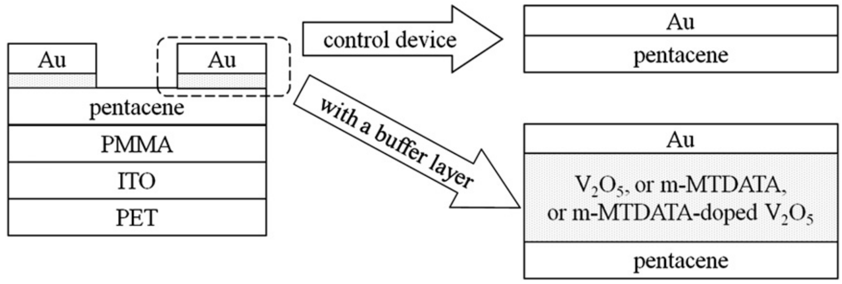

Fig. 1. Schematic architectures of the OTFT with a buffer layer between pentacene and Au electrodes.

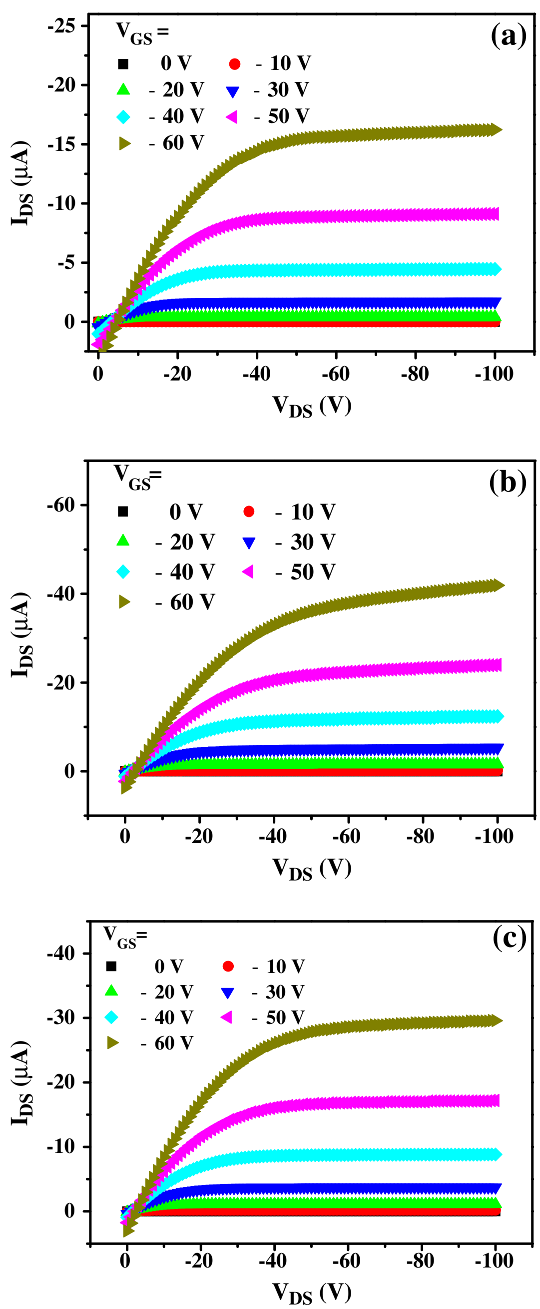

Fig. 2. The output characteristics of I_{DS} versus V_{DS} of OTFTs (a) without a buffer layer and with a buffer layer of (b) V_2O_5 and (c) m-MTDATA, respectively.

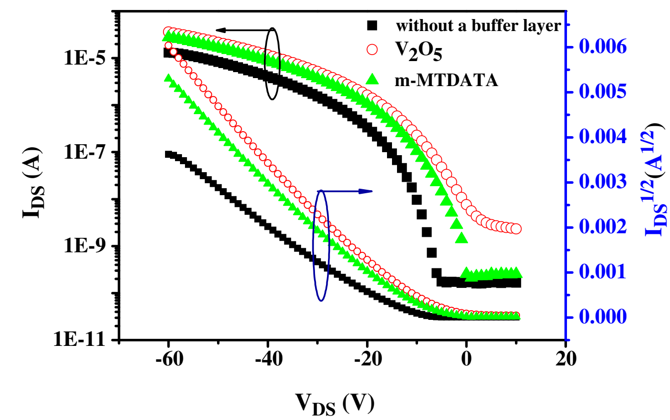

Fig. 3. The transfer characteristics of I_{DS} versus V_{GS} and the square root of the I_{DS} versus V_{GS} curve.

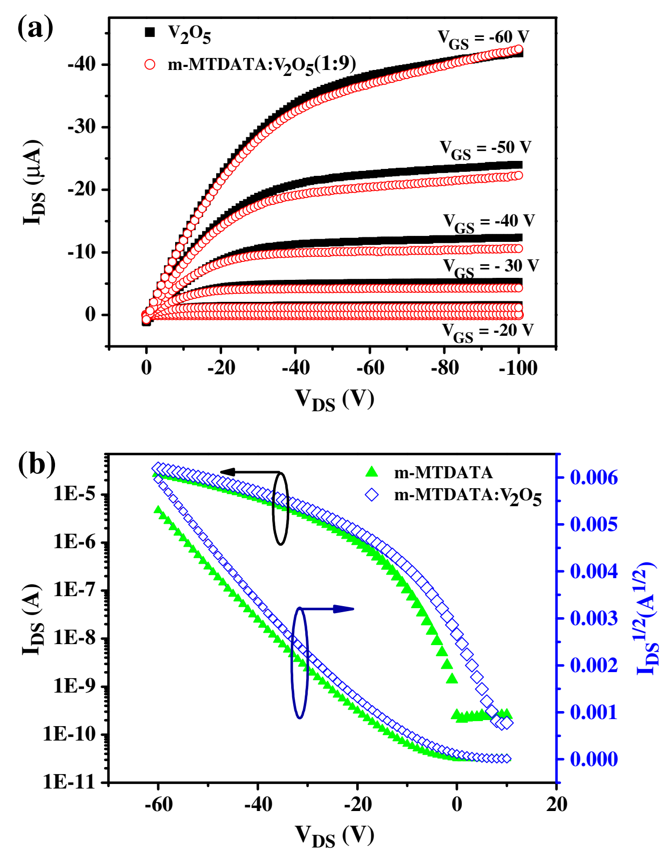

Fig. 4. (a) The output characteristics of I_{DS} versus V_{DS} of OTFTs with a V_2O_5 or m-MTDATA-doped V_2O_5 buffer layer. (b) The transfer characteristics of I_{DS} versus V_{GS} and the square root of the I_{DS} versus V_{GS} curve of OTFTs with a m-MTDATA or m-MTDATA-doped V_2O_5 buffer layer.