



Letter

Novel organic-perovskite hybrid structure forward photo field effect transistor

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ABSTRACT

To enhance photosensitive performances for an organic thin film transistor, we fabricated a hybrid structured transistor with C8BTBT film as organic active layer, onto which, a $\text{CH}_3\text{NH}_3\text{PbI}_3$ layer was formed through the vacuum deposition. The phototransistor showed the best photo responsivity as high as 33 A/W, much higher than most other organic based thin film transistors, in addition to keeping fast response time and well gate tunable ability. The working mechanism were further investigated with the temperature dependence measurement. The organic-perovskite hybrid transistor may open up a path way for the optimization of organic photo sensitive transistors.

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Organic thin film transistor (OTFT), as a fundamental device of organic semiconductor materials, is an important component in various applications, including organic logic circuits, OLED driving units, and memory devices [1–5]. Among OTFT-based functional devices, photo-sensitive transistors, which can be applied in light-induced switches, photo-sensitive skins, and light detection circuits, have not yet to be investigated as extensively as their inorganic counterparts [6,7]. Although the energy structures of organic semiconductors provide adequate possibility for the generation of electron–hole pairs through light excitation, the relatively low drift velocity of carriers and high density of localized states cannot guarantee an effective extraction of photo-generated carriers within their short life time. Therefore, the formation of photocurrent is usually of low efficiency. Other detrimental factors included high bonding energies of excitons and high recombination rates of electrons with holes. As such, these drawbacks have been addressed through significant efforts, including optimizing device structures by shortening their channels and adopting a vertical

layout [8,9], employing single-crystal phase organic active layers [10], and coupling organic active layers with other photo-sensitive materials to form heterojunctions [11]. With heterojunction structures, the performance of organic photovoltaic and light-sensing devices can be enhanced and thus can be used as a benchmark for the improvement of organic photosensitive transistors.

Perovskite materials containing methylammonium lead halide ($\text{CH}_3\text{NH}_3\text{PbX}_3$, X = Cl, Br, I) exhibit an ultra-ideal optical–electrical response because of their direct band gap and large absorption coefficient, as well as long life span of photocarriers; thus, these materials have been widely employed in photovoltaic devices [12–15]. In perovskite synthesis, spin coating techniques or other solution methods can provide facile and low-cost routes to form thin films with high power conversion performances [16,17]. While vacuum thermal evaporation method also allows the solvent-free formation of perovskite layers whose growth can be further well controlled [18,19], showing potentials for application in accurate controlled fabrication of large area organic flexible electronics. Perovskite layers fabricated through this method can be utilized for heterojunction devices with extremely low interface trap states. More importantly, the absence of solvents is also beneficial for the maintenance of high-quality molecular stacking in organic active

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layers.

In our research, an organic thin film transistor hybrid with a perovskite layer was fabricated for aiming to obtain excellent photoelectrical characteristics. Dioctylbenzothieno[2,3-*b*]benzothiophene (C8BTBT), which is a small organic semiconducting molecular material that exhibits high hole mobility [20,21], was selected as an active layer. A $\text{CH}_3\text{NH}_3\text{PbI}_3$ layer was formed on the interface of C8BTBT film through the vacuum co-evaporation of $\text{CH}_3\text{NH}_3\text{I}$ and PbI_2 . The fabricated hybrid device shows high performance with an enhanced photoresponsivity, fast response time, and sensitive and well gate-tunable photodetection. In order to reveal the reason of enhanced photo electrical characters, temperature-dependent measurement was further conducted to investigate the distribution of photo-generated carriers among layers and the charge transport mechanism of the photocurrent.

Heavily n-doped silicon wafers with a thermally grown oxidized layer (300 nm) were used as substrates/gate electrodes to fabricate FET devices. A toluene solution containing polystyrene (PS) with a mass ratio of 0.5% was spin-coated onto the substrate as a modified layer. Afterward, 40 nm C8BTBT film was accurately deposited through vacuum thermal deposition (Auto-306, Edwards Co.) at a pressure of 2×10^{-7} mbar. The deposition rate was calibrated and monitored by using a quartz oscillator. Source and drain electrodes were formed by depositing 50 nm gold films via a shadow mask with a channel length and width of 100 and 800 μm , respectively.

Traditionally, $\text{CH}_3\text{NH}_3\text{PbI}_3$ films are formed using solution methods which are not feasible for application on an organic layer. In our research, in order to prevent the solution from damaging small molecular arrangements, a solvent-free vacuum deposition was employed by co-evaporating $\text{CH}_3\text{NH}_3\text{I}$ and PbI_2 at a deposition rate of 1:3. The two materials chemically reacted to form $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite material with a final thickness of 20 nm.

The morphological characteristics of the C8BTBT film and the perovskite film on the organic layers were determined using an atomic force microscope (AFM, Veeco Co.) with a tapping mode. The formation and crystallinity of the perovskite film were evaluated using an X-ray diffraction (XRD) system with 2θ ranging from 10° to 60° . The stacked heterostructure of C8BTBT and perovskite was characterized by the scanning electron microscope (SEM) (Zeiss Merlin).

The electrical and optical–electrical properties of the devices were characterized using a Keithley 4200 semiconductor analyzer in a TTP4 probe station (Lake Shore) under vacuum with a pressure of 1×10^{-5} mbar and a temperature range of 300–140 K. Lasers with a wavelength of 473 nm were used as a light source to examine the optical response properties of the devices.

Fig. 1a shows the schematic of the device structure used in our research. The upper perovskite layer acts as main source of photo generated carriers. Holes and electrons could be separated efficiently at the C8BTBT-Perovskite interface under the electric field of

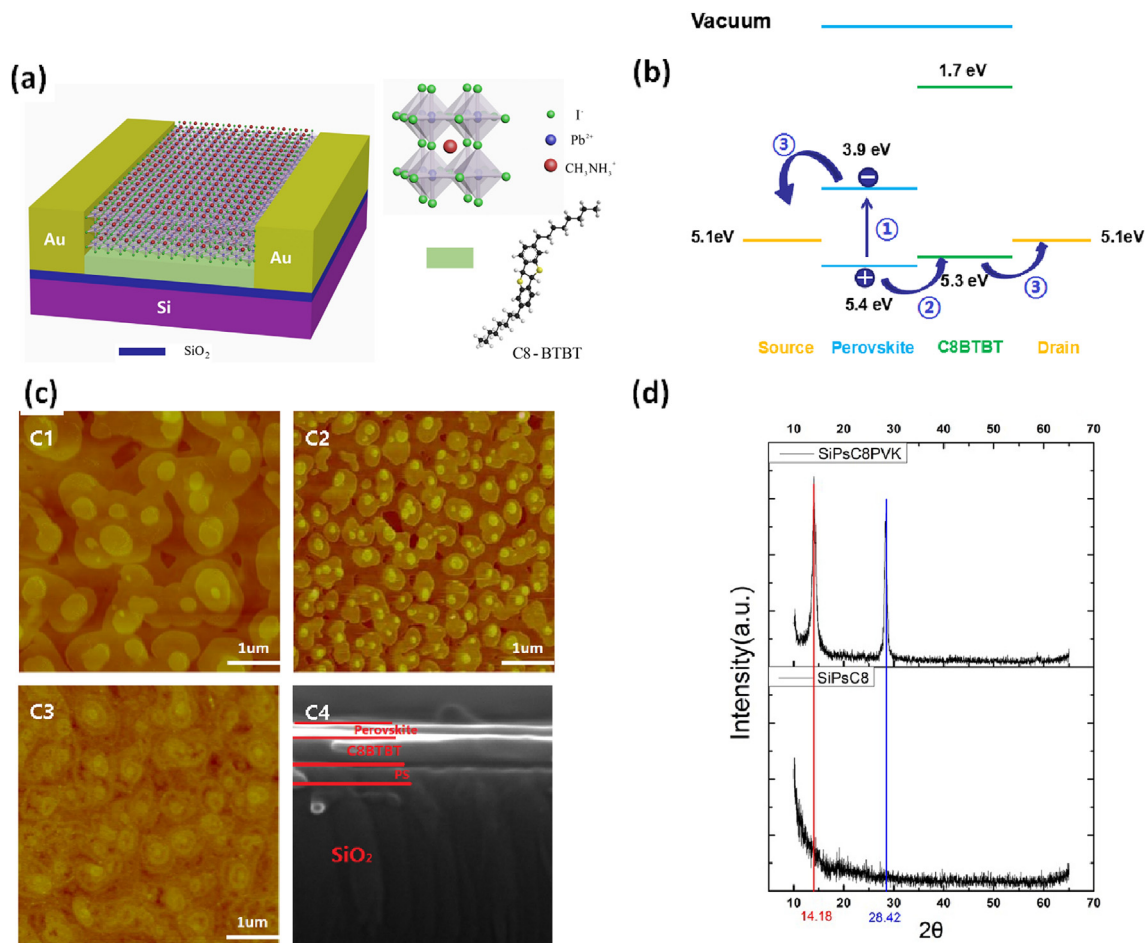


Fig. 1. (a) Schematic diagram of the device of the perovskite–C8BTBT hybrid photo transistor; (b) Simplified picture of the optoelectric process of the phototransistor (c) Atomic force microscope (AFM) images of C8BTBT film deposited on polystyrene with different deposition rates $R = 0.02$ nm/s (c1) and 0.5 nm/s (c2); AFM image of perovskite layer deposited on C8BTBT film (c3); SEM cross-section picture of the layer structure (c4); and (d) X-ray diffraction (XRD) spectra of the $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite on SiO_2 -Ps-C8BTBT (SiPsC8PVK), and SiO_2 -Ps-C8BTBT structure without perovskite (SiPsC8).

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