Electronic Supplementary Information

Organic Field-Effect Transistors with a Low Driving Voltage Using Albumin as the Dielectric Layer

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Materials and characterization

Egg white albumin (≥99%, purchased from Shanghai Yuanye Bio-technology Co.) was dissolved in deionized water (150 mg/mL) and stored at 8 °C. Before depositing the dielectric layer, this solution was filtered through a nylon syringe filter with a pore size of 0.22 μm. So homogeneous protein solution can be obtained after albumin dissolved in deionized water, and the spin-coated dielectric layer was uniform and flat. The roughness was only 0.273–0.438 nm in 5 μm × 5 μm scan area (see Fig. 2). In contrast, directly spin-coating egg white (from the fresh egg) on ITO cannot give a very good film due to impurities contained in egg white. Octadecyltrimethoxysilane (OTMOS) (Sigma-Aldrich) was prepared in its trichloroethylene solution (3 mM), and P3HT (Rieke Metals Inc.) was dissolved in chlorobenzene with the concentration of 10 mg/mL.

The cross section image of the albumin dielectric layer was measured by scanning electron microscope (SEM) on heavily-doped silicon wafer instead of ITO glass due to its better electrical conductivity. Film thicknesses under different RHs on ITO glass substrates were measured by an Ambios Technology XP-2 profilometer. The surface morphology of the albumin dielectric films at different RH was investigated via a Veeco DI Dimension V atomic force microscope (AFM) operating in the tapping mode.

Fabrication and characterization of OFET devices

OFETs with the structure of a bottom-gate top-contact configuration were fabricated, as shown in Figure S1. The prepared albumin solution was spin-coated onto the ITO glass substrate, which was hydrophilic treated according to the standard

RCA procedure,[S1] at a speed of 600 rpm for 60 s. To remove the solvent and promote a crosslinking reaction in the albumin film, the baking process was 100 °C for 10 min, 120 °C for 10 min, and 140 °C for 10 min. To improve the contact at dielectric/organic semiconductor interface,[S2,S3] self-assembly monolayer (SAM) modification on the albumin film with OTMOS was performed by fast spin-coating and subsequently rinsing similar as the modification process of OTMOS on SiO_2 surface.[S4] P3HT was spin-coated on top of the dielectric layer to form a film with ca. 30 nm. Finally, gold source and drain electrodes (50 nm in thickness) were vacuum-deposited through a shadow mask with channel lengths (L = 80 μm) and channel width (W = 8800 μm) dimensions under a pressure of ca. 4.5×10^{-6} Torr and a rate of 1 Å s^{-1}.

All the devices tested were exposed to different ambient environments at room temperature in a home-built container for wet air flow. Compressed air was humidified by bubbling through a water reservoir and the relative humidity could be modulated by controlling the bubbling rate. By using this method, a maximum RH value of 70%–80% can be achieved. When a low RH level was needed, the container was filled with dry compressed air slowly so that the RH decreased. The RH in the container was real-time monitored by an electronic hygrometer. Before electrical testing, under each RH condition the devices were kept for 3 hours in the container for stabilization. It should be noted that all the moisture treatments of OFETs under various RH conditions were performed after finishing fabrication of devices. In addition, the device performances are all measured shortly after the moisture treatment to avoid desorption of water molecules in protein dielectrics. In the case of absence of humidity, the devices were placed in the glove box (H_2O < 0.1 ppm, O_2 < 0.1 ppm) for three days, and then the performances in dry nitrogen atmosphere were tested. The capacitance per area (C_i) of albumin dielectrics and the electrical performances of OFETs were evaluated by the Agilent 4294A precision impedance analyzer and the Keithley 4200-SCS semiconductor characterization system, respectively.

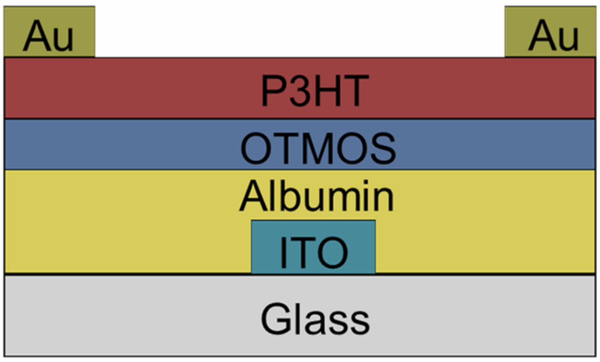

Fig. S1 Structure of P3HT OFET with OTMOS-treated albumin as the gate dielectrics.

Device performances under low humidity with higher voltages

When the relative humidity was 20%, we increased V_{DS} and V_{GS} to −9 V. The result was that the source-drain current (I_{DS}) increased with the increase of voltage, but no remarkable saturation regime appeared yet (see Fig. S2). In addition, under 0 V gate voltage, when V_{DS} was scanned from −5 to 5 V, the source-drain current I_{DS} change with V_{DS} almost linearly (Fig. S3). This indicates that P3HT was doped to behave like conducing polymers. Without applying gate voltage, the source-drain current I_{DS} under low humidity was higher than that under high humidity.

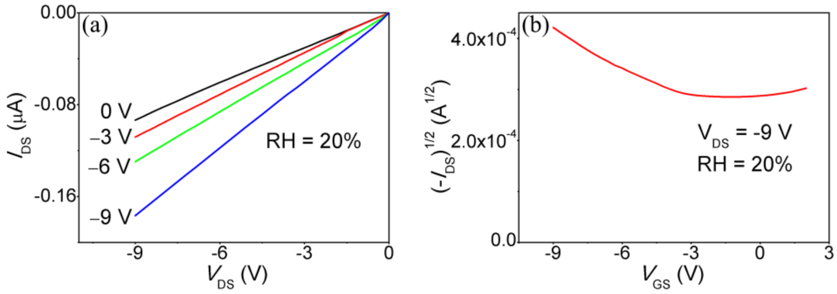

Fig. S2 (a) Output curve and (b) transfer curve with increasing V_{DS} and V_{GS} to −9 V under RH=20% condition.

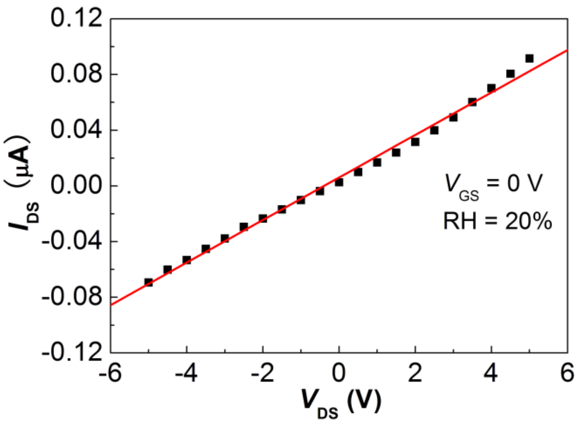

Fig. S3 The source-drain current (I_{DS}) versus V_{DS} (from −5 V to 5 V) curve at V_{GS} = 0 V and RH = 20%.

References

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