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Interface Engineering of Semiconductor/Dielectric Heterojunctions toward Functional Organic Thin-Film Transistors

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Supporting Information

ABSTRACT: Interface modification is an effective and promising route for developing functional organic field-effect transistors (OFETs). In this context, however, researchers have not created a reliable method of functionalizing the interfaces existing in OFETs, although this has been crucial for the technological development of highperformance CMOS circuits. Here, we demonstrate a novel approach that enables us to reversibly photocontrol the carrier density at the interface by using photochromic spiropyran (SP) self-assembled monolayers (SAMs) sandwiched between active semiconductors and gate insulators. Reversible changes in dipole moment of SPs in SAMs triggered by lights with different wavelengths produce two distinct built-in electric fields on the OFET that can modulate the channel conductance and consequently threshold voltage values, thus



leading to a low-cost noninvasive memory device. This concept of interface functionalization offers attractive new prospects for the development of organic electronic devices with tailored electronic and other properties.

KEYWORDS: Interface engineering, organic field-effect transistor, spiropyran, semiconductor/dielectric interface

ver the past decade, great progress has been made in organic field-effect transistors (OFETs) through the development of novel high-performance organic semiconductors and device optimization.^{1,2} The field-effect mobilities of OFETs are already comparable to those of amorphous silicon thin-film transistors and thus OFETs are on the verge of commercialization. On the other hand, to meet satisfactory requirements for different real markets OFETs with specific functionality are also highly desirable. Therefore, functional OFETs, as a new branch of organic electronics, have been attracting much attention in the past several years.^{3,4} Several types of functional OFETs, such as organic phototransistors, organic memory transistors, light-emitting organic transistors, OFET-based sensors and other stimuliresponsive transistors, have been demonstrated (ref 4 and references therein). On the scientific side, these functional OFETs offer grounds for understanding some basic questions in organic electronics.^{5–9} On the technological side, they can mimic the functions of biological systems and conversion of external inputs to useful signals for a wide variety of potential applications such

as light detection,^{10,11} signal storage,^{12,13} laser emission,¹⁴ environmental monitoring,^{15–17} and medical diagnostics,¹⁸ which are all highly important to modern society. However, the development of efficient techniques for installing desired functionalities into OFETs remains a major challenge that needs to be resolved before OFETs can realize their full commercial potential.

In typical OFETs, it is well-known that charge transport occurs through at most the first few layers of molecules at the semiconductor/dielectric interface.^{19–21} Therefore, the property of this interface plays an important role in device characteristics. Any small changes from the interface could cause drastic changes to the electrical properties of OFETs. On the basis of this fact, we propose that rational functionalization of the semiconductor/ dielectric interface may provide an efficient approach to improving

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Figure 1. Schematic representation of the OFET structure and related SP SAMs. Photochromic SPs in SAMs on SiO_2 gate substrates can undergo the photoisomerization between SP-closed and SP-open, leading to a significant change in the molecular dipoles. This change at the semiconductor/ dielectric interface should interfere the device characteristics.

the device performance and/or installing new functionalities. To achieve control of the interfacial properties, we investigated the use of functional self-assembled monolayers (SAMs). In fact, formation of SAMs has been often used to modify the morphology of organic semiconductors, 2^{2-24} the dielectric properties of the gate insulator, $7^{,19,25}$ the electronic states at the dielectric interface $2^{21,26-29}$ and the level alignment at the electrode interfaces, 3^{0-37} thus tailoring the charge mobility, the contact resistance and the trap density at the interface. Aiming at reversibly tuning channel conductance or carrier density by an external stimulus without using gate voltage, we intentionally incorporated the typical photochromic molecules, spiropyrans (SPs), into SAMs because SPs can switch between a neutral, colorless form (SP-closed) and a zwitterionic, colored form (SP-open) triggered by lights with different wavelengths, accompanying a significant change in the electric dipole moment (P_{mol}) of SPs as well (6.4 D for SP-closed and 13.9 D for SP-open) (Figure 1).^{38,39} Such unique photoisomerization process in SAMs based on SPs has been exploited for applications, such as the controlled release of amino acid derivatives⁴⁰ and the generation of photoactive membranes showing switchable wettability,⁴¹ and is an interesting platform to study switchable electronic characteristics at the nanoscale.⁴²⁻⁴⁷ In this paper, we demonstrate that by using photosensitive SP SAMs on SiO₂ gate substrates, the electrical characteristics of OFETs can be reversibly and optically controlled for the first time through engineering of the interfacial properties induced by the effect of the molecular dipoles.

As a test bed, OFETs were fabricated in a bottom-gate topcontact configuration using pentacene as the model organic semiconductor on heavily doped p-type silicon wafers with 300 nm insulating layer of thermally grown SiO₂ on the surface (Figure 1). Before semiconductor deposition, SP SAMs were formed on silicon wafer substrates in two steps as described previously.^{39,41} First, the precleaned SiO₂ surface was silanized with APTMS, leaving the surface-bound amino groups available for subsequent reactions. A spiropyran carboxylic acid was then tethered to the modified surface through covalent amide bond formation with the aid of the well-known carbodiimide dehydrating/activating agent DCC. Details of molecule syntheses, device fabrications, and operation conditions can be found in the Supporting Information.

The surface reaction between the carboxyl acids of SPs and the surface-bound amino groups produces the amide linkage, thus imparting significant stability to SAMs. They are able to survive rinsing and even soaking with prolonged sonication in common solvents such as toluene and methylene chloride. After rinsing by copious toluene, the IR spectrum (Figure 2a) shows the loss of the carboxyl acid C=O stretch (1720 cm^{-1}) and appearance of a new carbonyl stretch at 1702 cm^{-1} . This frequency should be assigned to an amide linkage that binds to the surface [typically $1630-1695 \text{ cm}^{-1} \text{ (ref } 48\overline{)}$]. In addition to that, a number of major features related to the structured characteristics of SP were observed. These peculiar bands comprise the typical stretching bands of the aryl nitro groups at 1510 cm^{-1} , the C=C stretching modes of the endocyclic double bond in SP at 1650 cm^{-1} , the relatively weak stretching bands of aryl rings at 1605 cm^{-1} and the alkyl bending vibrations at 1450 cm⁻¹. X-ray photoelectron spectroscopy (XPS) is in agreement with the transmission FTIR analysis indicating the successful immobilization of SPs on the SiO₂ surface. In comparison with the XPS spectrum on bare SiO₂ surface, there is a clear indication of the emergence of the N1s peak after SP grafting (Supporting Information Figure S1). As shown in Figure 2b, the N1s peak consists of three well-separated components centered at 399.6, 401.5, and 405.3 eV, respectively. The main peak at 399.6 eV should be attributed to heterocyclic nitrogen atoms in SP and/or unreacted amines in APTMS during the second step; the other two at 401.5 and 405.3 eV are characteristic of amide linkages formed from surface reactions and $\rm NO_2$ nitrogen atoms in SP, respectively. These results are similar to previous reported observations.^{49,50} The successful immobilization of SPs on the SiO₂ surface sets the foundation for the following device application.

Low-angle X-ray reflectivity was used to determine the thickness of SAMs.⁵¹ Figure 2c shows the X-ray reflectivity for the substrates with and without SP attachment. Compared with the



Figure 2. SP SAM Characterizations. (a) The FT-IR spectrum of a silicon wafer substrate after two-step SP immobilization. (b) High-resolution XPS scans of the N(1s) region for SP SAMs. (c) Low-angle X-ray scattering of SP SAMs. Data, black stars; fit to a three-layer model (red line). Inset shows the light-induced water contact angle changes of SP SAMs. (d) Model with three layers color-coded to the real-space model. More details can be found in the Supporting Information (Figure S2). (e) UV/visible absorption spectra of a SP SAM on a quartz substrate under UV (black) and visible light (red) irradiation.

substrate without SAMs, quicker decays in reflectivity followed by an intensity minimum or a kink were clearly observed for the substrate with SAMs, indicating that a very thin layer was formed on top of the SiO₂ surface. The reflectivity can be fit well by using the Parratt formalism to a box model with three layers: an SP layer, an alkyl layer, and an APTMS layer.⁵² The fit yields a monolayer thickness of \sim 2.2 nm (Figure 2d and Supporting Information Figure S2). Compared with the molecular length (\sim 3.0 nm obtained from its optimized conformation where the SP skeleton is perpendicular to the alkyl chain), defined as the distance between the Si atom at one end and the C atom in methyl group at the other, this suggests that the monolayer is oriented on the SiO₂ surface with the angle of inclination of \sim 47.2°. By using the optical molar extinction coefficient of SP in THF solution (9.4 \times 10³ M⁻¹ cm⁻¹), we estimated its coverage on quartz windows to be \sim 1.8 molecules in a 1 \times 1 nm square. This estimation is in reasonable agreement with the 2.0 molecules per nm^2 estimated for a SP molecule that is tightly packed on the surface with the angle of inclination of \sim 42.8° (Figure S3 in the Supporting Information), implying that a highcoverage SP SAM is indeed formed at the single-layer level.

To explore the photoactivity of SP SAMs, we studied their UV–visible absorption spectra. As shown in Figure 2e, we observed the large characteristic difference in the absorption band with $\lambda_{max} = 563$ nm under UV ($\lambda = 365$ nm) and visible light ($\lambda > 520$ nm) irradiation, proving that SP molecules in SAMs are able to reversibly switch back-and-forth between SP-closed and SP-open.⁵³ The calculated percent conversion (x_e) of SP molecules from SP-closed to SP-open at the photostationary state is ~84.4% (Figure S4 in the Supporting Information). For

macroscopic characterization, the water contact angle was measured by putting 1 μ L of water droplets on the SAM surface. The reversible light-induced water contact angle changes of 12–15° were achieved (Figure 2c, inset),⁵⁴ indicating that the surfaces are more polar under UV irradiation, as would be expected by the opening of SPs, than visible irradiation, where SPs would be in the closed form. This provides additional evidence for successful transformations of SPs between the two distinct states. The reversible photoisomerization of SPs in SAMs demonstrated in both UV–vis and contact angle measurements is a harbinger of the interesting optoelectronic properties described below.^{38,44,46}

After having understood the properties of SP SAMs, we then fabricated 40 nm pentacene thin-film transistors on the monolayer-modified silicon substrates (60 μ m long and 7 mm wide). The average saturation carrier mobility (μ_{max}) of these devices is ~0.03 cm² V⁻¹ · s⁻¹, lower than that of devices on bare silicon substrates (~0.2 cm² V⁻¹ · s⁻¹), and correspondingly the threshold voltages ($V_{\rm Th}$) shifted to more negative values (\sim -50 V). These might be due to the increase of the interface trap density in the presence of SP molecules and unreacted amine groups on the surface,^{21,26–29,46} and/or the formation of relatively small pentacene crystal domains during thermal deposition as demonstrated by atomic force microcopy (AFM) (Supporting Information Figure S5).^{22–24} Note that electrical characterization of SP SAM-SiO₂ hybrid dielectric films by using the sandwich electrode structures with gold pads (0.9 mm²) on their surface did show the negligible changes in capacitance (C_i) before and after UV irradiation.²⁹ To aid in the subsequent analysis of the photoswitching processes, we intend to regulate the intensity of visible light that makes the photocurrents of the devices under visible



Figure 3. Device characteristics and photoresponses of a pentacene device. (a) Transistor output before and after UV irradiation. (b) Transfer characteristics before and after UV irradiation, $V_D = -100$ V. Inset shows one full switching cycle of the time-dependent behavior of the same device, $V_D = -30$ V, $V_G = -15$ V. (c) Time trace of I_D for the same device over a period of ~3 h with the first three cycles expanded for clarity, showing the reversible photoswitching events under irradiation of UV light and visible light. $V_D = -30$ V; $V_G = -15$ V. (d) Responsivity (R) and photosensitivity (P) as a function of V_G with the effective irradiance power of 7.4 μ mW/cm² for the same device, $V_D = -100$ V.

irradiation equivalent to those induced by UV irradiation. By doing this, we can record the device characteristics without obvious current jumps when UV and visible lights are switched. All of the measurements were performed at room temperature and atmospheric pressure.

We found the large and reversible changes in drain current $(I_{\rm D})$ occurred in these SP-functionalized OFETs (~100 devices) upon exposure to UV and visible light stimuli. Figure 3a,b shows such a representative photoswitching effect in a 40 nm pentacene thin film transistor with SP SAM-SiO₂ hybrid dielectrics. Both output and transfer characteristics exhibit classical linear/saturation behaviors. To clearly demonstrate the process and mechanism discussed below, we do not show the slow back-conversion process of the devices in the dark after UV irradiation, which is supposedly because of the slow transformation of SPs from SPopen to SP-closed. Noticeably, after UV irradiation for \sim 1000 s, dramatic increases in drain current $(I_{\rm D})$ occurred, regardless of the gate bias. The reverse process from the high conductance state to the low conductance state was powered by visible light. After \sim 26 min of further visible-light irradiation, the drain current of the device was essentially restored to its original value. We found that the back-and-forth phototswitching effect is rather gradual in time. Figure 3b inset shows the time evolution of the current-voltage curves for one full switching cycle during UVand visible-light illumination, respectively. A sudden current jump (\sim 8% in the total current change) was observed at the moment of turning on UV light, which is generally attributed to the photoexcitation of organic semiconductors, that is, the photogeneration of charge carriers, as proven by control experiments in Supporting Information Figure S6. The kinetics of each

process can be fit with a single exponential. On the basis of the data in Figure 3b inset, the overall rate contants in different parts were calculated, $K_{(UV)} = \sim 3.7 \pm 0.2 \times 10^{-3} \text{ s}^{-1}$, $K_{(\text{visible})} = \sim 2.8 \pm 0.1 \times 10^{-3} \text{ s}^{-1}$ and $K_{(\text{dark})} = \sim 2.0 \pm 0.1 \times 10^{-4} \text{ s}^{-1}$ (data in the dark unshown). These kinetic results for the photoswitching process are very similar to those from our previous work.^{38,44} The similarity between the reversible photoswitching of the electrical conductivity of the functionalized devices and the reversible photoisomerization of SPs in SAMs obtained from UV—visible absorption studies suggests that the photoswitching process of SP molecules is responsible for the changes in device characteristics of pentacene OTFTs.

To rule out potential artifacts, we performed control experiments in which we measured the photoresponse of a pentacene device on APTMS-treated silicon substrates that lacks SP SAMs (Supporting Information Figure S6). During irradiation with either UV or visible light, we consistently observed the slow decrease in drain current probably resulting from problems associated with the device stability. From the trace in Supporting Information Figure S6, the overall rate constants for each part were obtained, $K_{(\rm UV)} \approx K_{(\rm visible)} = \sim 6.6 \pm 0.1 \times 10^{-4} \text{ s}^{-1}$. In comparison with those in functionalized devices, two significant differences should be pointed out. One is that the rate constants of the device in Figure 3 under UV and visible light irradiation are 1 order of magnitude larger than those obtained from the control device (Supporting Information Figure S6) under the same conditions. The other significant difference is that the photoswitching effect under UV illumination in functionalized devices is opposite to that in control devices. Therefore, in conjunction with the similar photoswitching phenomena between functionalized



Figure 4. Memory effects of a pentacene device. (a) and (b) The gradual conversion of the transfer curves when the curves were taken every 110 s for UV illumination and every 3 min for visible light illumination, $V_D = -100$ V. (c) The representative 5 switching cycles of V_G for the same device. (d) Reversible shifts in V_G of the same device for programming and erasing processes, $V_D = -100$ V.

devices and SP SAMs described above, these results clearly prove that the photoisomerization of SP molecules in SAMs is responsible for the switching effect in device characteristics. On the basis of the kinetic data achieved from Figure 3b, the percent conversion (x_e) of SPs from SP-closed to SP-open at the photostationary state in devices was calculated, ~55.3%, smaller than that obtained from UV—visible absorption studies, which might be due to the larger steric hindrance effect in SP SAMs that are covered by a thick pentacene layer.

To demonstrate the reversibility of the switching, we used shorter irradiation times. We found that these devices consistently showed long-term operational stability in a perfectly reversible manner. Figure 3c demonstrates the switching cycles of the drain current as a function of time of the same device with the first three cycles expanded for clarity. After the measurements over a period of \sim 3 h and \sim 200 cycles, the devices still show the good switching effect without obvious degradation operating in ambient atmosphere. To indicate the intrinsic device photosensitivity, we calculated two of the important merits: the responsivities (*R*) expressed in A/W and the current change ratios (*P*), from the changes in current in Figure 3b by using the conventional model for the calculations

$$R = \frac{I_{\text{light}}}{P_{\text{ill}}} = \frac{|I_{\text{l}} - I_{\text{dark}}|}{P_{\text{ill}}} = \frac{|I_{\text{l}} - I_{\text{dark}}|}{I_{\text{ill}}LW};$$
$$P = \frac{\text{signal}}{\text{noise}} = \frac{I_{\text{light}}}{I_{\text{dark}}} = \frac{|I_{\text{l}} - I_{\text{dark}}|}{I_{\text{dark}}}$$

where I_{light} is the light-induced drain current, I_{l} is the drain current under illumination, I_{dark} is the drain current in the dark, P_{ill} is the incident illumination power on the channel of the

device, $I_{\rm ill}$ is the light power intensity, L is the channel length of the device, and W is the channel width of the device. Interestingly, the device photoresponsivity is bias-dependent. Figure 3d shows the responsivity data of the device at various gate biases and a fixed source-drain bias. The best data achieved for the SP-functionalized device are $R = \sim 400 \text{ A/W}$ and $P = \sim 450$, when $V_{\rm G}$ scans from 10 to -100 V under UV irradiation, considering a very low effective light power density of 7.4 μ W/cm^{2.55} These values are larger than those obtained from most of organic phototransistors⁴ and comparable to those of amorphous silicon (R = 300 A/W and P = 1000).⁵⁶ We infer that the high device photoresponsivity is attributed to the synergistic combination of the photoexcitation of organic semiconductors (only \sim 8% contribution) and the photoisomerization of SPs in SAMs. This is significant, considering that the photoresponsivity in our functional transistors mainly results from a single 2.2 nm thick monolayer (>90% contribution).

In addition to the conductance switching, remarkably, reversible shifts in the threshold voltages, defined as the cross point of the linear fit (dashed lines) with the horizontal axis in Figure 4d where the drain current (I_D) is plotted in a square root scale against the gate voltage (V_G) , were observed, demonstrating a low-cost organic memory device. Figure 4a,b show shifts in the transfer curve for our OFET memory device after sequentially applying UV and visible light illumination. The entire transfer curve was gradually and substantially shifted in the positive direction when UV light was applied for ~15 min, and it was then steadily sustained at the shifted position for at least 20 min even during continuous V_G sweeps. Significantly, the optical modulation process was found to be reversible, which is in full agreement with the conductance switching described above.



Figure 5. A proposed model for the band bending diagrams at the semiconductor/insulator interfaces. Before UV irradiation, the initial dipole field of SP SAMs produces a built-in electric field in OFETs, which leads to a shift of the surface potential (left).²⁸ After UV irradiation, the increase in dipole field of SAMs induced by SP photo-isomerization could result in the increase in local built-in electric field and therefore an increased band bending (right).

After visible light irradiation for \sim 25 min, the shifted transfer curves gradually recovered their original position. As shown in Figure 4c, up to five reversible cycles were carried out without obvious lost in efficiency of the switch. that is, fatigue. On the basis of these results, therefore, our unoptimized OFET memory devices show the reversible switching behavior of $V_{\rm G}$ in a series of information processing: programming with UV light, reading electrically and erasing with visible light (Figure 4d). Because both programming and erasing processes use convenient lights as a noninvasive tool, which does not disturb the $V_{\rm G}$ state detection in the electrical manner, these devices could be indeed utilized as a nondestructive OFET memory.^{12,13,26,35} In principle, by decreasing the thickness of the insulating SiO_2 layer⁷ or using a highdielectric constant (high-k) layer,⁵⁷ in combination of the significant positive shifts in $V_{\rm G}$, the high operating voltage needed for programming and erasing can be dramatically reduced. However, the ability to realize nonvolatile memory effects is hampered by the thermal back-conversion process of SPs. Improvement of the device thermal stability at the more positive $V_{\rm G}$ state and increase of the switching process are challenges for future studies to overcome.

To understand the interesting properties, we then turned our attention to studying the switching mechanism. A number of previous reports have demonstrated that the dipole alignment of SAM molecules play the key role in modulation of the electronic states at the dielectric interface^{21,26–29} and the electrode work function.³⁰⁻³⁷ In the present case with photoswitchable SP SAMs, we anticipated that reversible changes in dipole moment (P_{mol}) of SP molecules accompanying their photoisomerizations produce the different built-in electric fields in OFETs, which are superimposed to the externally applied gate field (Figure 5). The increase in local electric field induced by UV irradiation could result in an increased band bending (and therefore in an increased hole density in the channel), thus leading to the $V_{\rm G}$ shift in our devices observed experimentally above. To obtain a more precise insight onto these experimental results, we have calculated the expected electric field inside SAM layers using the form $E_{\rm in} = N(\mu_{\rm mol}/\varepsilon d_{\rm mol})^{32,58}$ where N and $d_{\rm mol}$ are the areal density and height of SP-SAM molecules, respectively, and ε is the effective dielectric constant inside the SP-SAM molecules. For the SP-SAMs investigated, we assumed N is \sim 1.8 \times $10^{14}~{\rm cm}^{-2}$ (see the Supporting Information) and ϵ is between 2 and 3. 58 Using the $\mu_{\rm mol}$ values in refs 38 and 46 (6.4 D for SPclosed and 13.9 D for SP-open) and $d_{\rm mol}$ (~2.2 nm) achieved from X-ray reflection experiments, we obtained the difference in the net voltage between SP-open SAMs and SP-closed SAMs as

1.1–1.7 V, corresponding to the internal field $E_{\rm in}$ of 5.2– 7.9 MV cm⁻¹. By taking the thickness of the SiO₂ gate insulator (300 nm) into account, this values lead to the difference in the external gate voltage of 156-237 V, which is 7-10 times larger than the results obtained experimentally ($\Delta V_{\rm G}$ = \sim 22 V on average). The reason for this difference at the moment is complex. One possibility is the inaccuracy in the density and the tilted angle of SAM dipoles, and in the crystallinity of SP SAMs. Actually, we have determined the thickness and coverage of SAMs, but we do not take the imperfect alignment of SAM molecules into account. The second possibility is the possible charge transfer between organic layers and the photogenerated phenoxide ion groups in SP-open forms. In p-type semiconductors, possible charge transfer between conducting layers and electrondonating molecules can quench the p-type carriers in the device, thus resulting in the shift of $V_{\rm G}$ in the negative direction.^{21,44} The third possibility results from the model itself. It is not necessarily clear that whether the local field produced by SP SAMs can be simply added to the external field.

Another two possibilities for the switching mechanism are the variations in capacitance of SP SAM-SiO₂ hybrid dielectrics or surface morphology of pentacene thin films. The first is unlikely as proved by capacitance measurements mentioned above, where we found that the capacitance of hybrid gate dielectrics nearly kept constant under UV and visible light irradiation. To preclude the possibility of the variation in film morphology, we performed the morphological characterization by AFM. We did not observe the obvious morphological changes of 40 nm pentacene thin films before and after UV irradiation (AFM images unshown). However, these experiments do not allow us to in situ clarify the morphological structures of pentacene thin films at the semiconductor/insulator interface. The final possibility for the switching mechanism is the direct charge transfer between organic layers and the phenoxide ion group in SP-open forms. As described above, the photogenerated phenoxide ion can behave like a charge trap and thus lead to the decrease of carrier mobility and the $V_{\rm G}$ shift in the negative direction, which is opposite to that described above. To further rule out this possibility, we carried out control experiments where we built pentacene thin film transistors on SP SAMs that were covered by a 20 nm thin film of polymethyl methacrylate (PMMA) (Supporting Information Figure S7 and S8). In this case, SP SAMs were separated from pentacene layers by PMMA thin films, thus eliminating the SP/ pentacene interface. Remarkably, all the devices did show the reproducible and similar photoswitching properties under the same operation conditions as described above. What is left unclear is why the n-type semiconductors (F_{16} CuPc and N,Ndihexylperylene diimide) with the same device geometry did not work and if it was due to the damage of well-aligned SP-open in SAMs by the positive electrical field applied.

In conclusion, we detailed a unique approach of realizing reversible photocontrol of the interfacial carrier density in OFETs using functional SAMs sandwiched between the organic layers and the gate insulators for the first time. From the viewpoint of interface engineering, the present study has revealed a novel insight for installing desired functionalities into organic electronic devices, which is difficult and rare so far, except for a few examples.^{26,35} The photochemical bistable SAMs triggered by SP photoisomerizations produce two distinct built-in electric fields on the OFET that can reversibly modulate the channel conductance and consequently $V_{\rm Th}$ values, thus leading to a bifunctional OFET and a low-cost noninvasive memory device.

This is significant, considering that these functionalities in our transistors mainly result from a single 2.2 nm-thick monolayer. On the other hand, integrating molecular functionalities into OFETs suggests a new and sensitive methodology for amplifying molecular conformation information into the detectable electrical signals and exploring fundamental properties of molecular conformation dynamics. We expect that these results provide the deeper understanding of interfacial phenomena and offer new attractive route for building future practical/multifunctional molecular devices through interface modification.⁵

ASSOCIATED CONTENT

Supporting Information. Molecular synthesis, device fabrication, XPS spectra, the chemical structure of SP SAMs, UV–vis spectroscopy, calculation method for the percent conversion of SP molecules, AFM images, and data for control experiments. This material is available free of charge via the Internet at http://pubs.acs.org.

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