Highly Sensitive Photodetector Based on Inorganic-Organic Heterojunction Phototransistor

Ahasan Ullah,[a] Roshell Lamug,[b] Sanjida Yeasmin,[a] Xueqiao Zhang,[a] Oksana Ostroverkhova [b] and Li-Jing Cheng [*a]

[a] *School of Electrical Engineering and Computer Science, Oregon State University, Corvallis, OR 97331, USA*
[b] *Department of physics, Oregon State University, Corvallis, OR 97331, USA*
[*] *chengli@oregonstate.edu*

Abstract: We propose a high-performance inorganic-organic phototransistor based on planner IGZO-ADT heterojunction. The device exhibits superior photosensitivity to visible light and excellent stability at ambient conditions.

1. Introduction

Transparent indium gallium zinc oxide (IGZO) thin-film transistors (TFTs) are promising devices for application in displays and sensors owing to their high field-effect mobility and low off-current [1,2]. However, the wide band gap (3.5 eV) and optical transparency of IGZO make the devices not responsive to visible light excitation, limiting their application in photodetection. Although IGZO TFTs exhibit high photocurrents in response to UV excitation, their performance is limited by the large density of trap states, resulting in a long decay time in photocurrent called persistent photoconductivity. To solve this problem, we exploited an inorganic-organic hybrid heterojunction (HJ) on an IGZO TFT that utilizes an organic capping layer to absorb visible light and transfer the photogenerated electrons to the IGZO channel for current measurements. Photodetectors with such configuration have been investigated with different light absorber capping layers, such as a polymer semiconductor (PBDTT-DPP: $PC_{61}BM$) [2], perovskite (MaPbI3)[1], and quantum dots [3]. This study reports a phototransistor based on triethylsilylethynyl anthradithiophene TES-ADT/IGZO heterojunction. TES-ADT shows excellent stability and high optical absorption at around 550 nm wavelength. It also forms a type II heterojunction with IGZO. Although TES-ADT offers decent photoresponsivity, it is not a suitable material for use as a phototransistor because of its low carrier mobility and high hole trap states that result in a very long decay time in photocurrent [4]. With the combination of strong visible absorption of TES-ADT and excellent electron mobility of IGZO, the proposed HJ phototransistor shows a high responsivity (R) of 220 mA/W and specific detectivity (D*) of 3.7×10^{12} Jones. Moreover, the TES-ADT capping layer absorbs UV light that prevents the exposure of high-energy excitation to IGZO, suppressing the unwanted persistent photocurrent.

2. Results and Discussions

The schematic in Fig. 1(a) illustrates the structure of the inorganic-organic hybrid heterojunction phototransistor. A heavily doped Si with 300 nm SiO_2 was used as the gate of the TFT. A 25 nm a-IGZO was deposited using RF sputtering on SiO_2 and annealed at 250^{O} C for 1 h in an oxygen ambient. A 50 nm thick aluminum source and drain

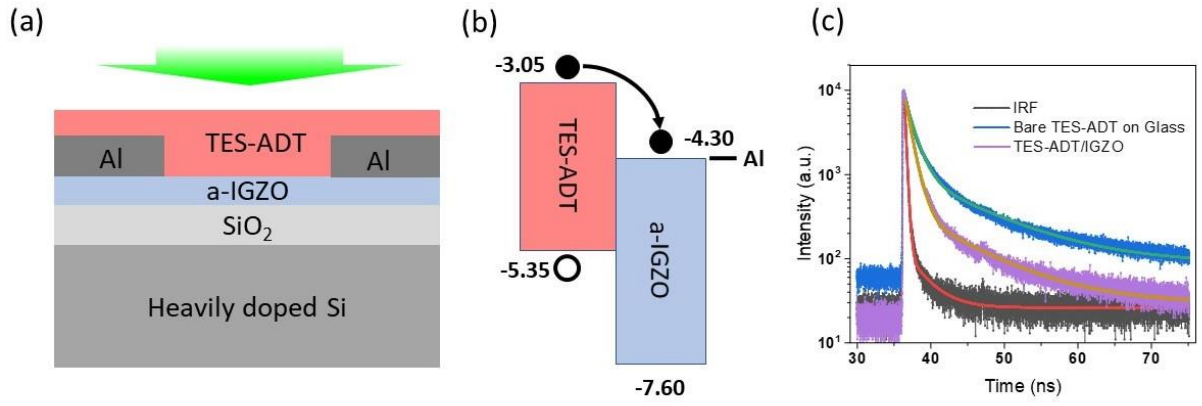

Fig. 1. (a) A schematic of a TES-ADT/IGZO HJ TFT. (b) Energy band diagram of the TES-ADT/IGZO HJ (unit: eV) (c) PL lifetime of bare TES-ADT and TES-ADT/IGZO.

electrodes were deposited using thermal evaporation through a shadow mask which defined the channel length of 100 µm. A 50 nm thin film containing TES-ADT and PMMA was spin-coated on the IGZO TFT to form the planner heterojunction between the IGZO and TES-ADT. The mixture of TES-ADT and PMMA was dissolved in toluene with a proper ratio that enabled an average intermolecular spacing of 1 nm between TES-ADT molecules after forming the solid film.

Fig. 1(b) presents the energy band diagram and charge transfer process at the junction between TES-ADT and IGZO, where TES-ADT and IGZO serve as an electron donor and acceptor, respectively. Optical excitation creates excitons in the TES-ADT layer. The excitons present near the HJ interface dissociate due to the energy difference between the LUMOs of the two materials. Subsequently, the dissociated electrons transfer from ADT to IGZO with a lower conduction band edge. As a result, the excess electrons in IGZO increases the channel conductivity. Fig. 1(c) shows the photon lifetime collected from a TES-ADT/IGZO HJ (3 ns) is much shorter than that from the bare TES-ADT film (5.3 ns). The reduced photon lifetime indicates an efficient charge transfer process from TES-ADT to IGZO.

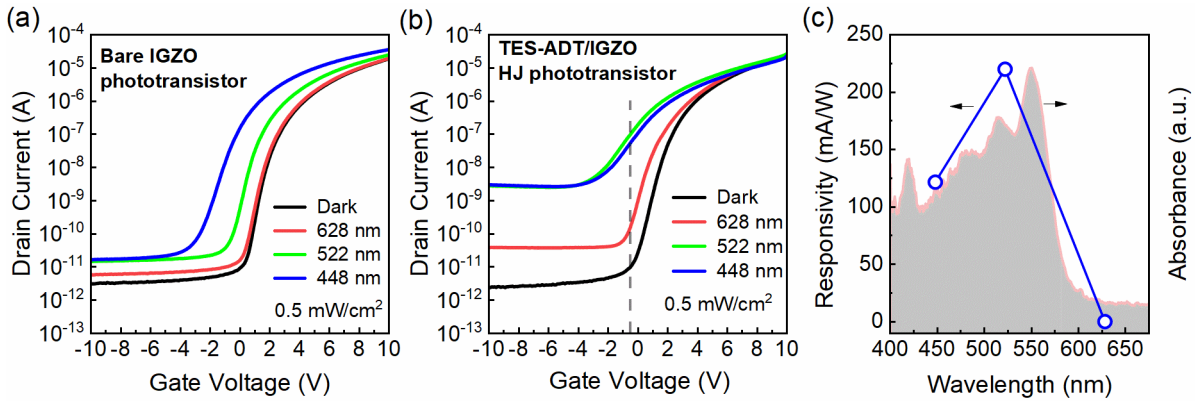

Fig. 2. Transfer characteristics of (a) a bare IGZO phototransistor and (b) an ADT/IGZO HJ phototransistor. (c) Wavelength-dependent responsivity of the HJ phototransistor at $V_G = -0.5\ V$ and $V_{ds} = 5\ V$.

We characterized the performance of the TES-ADT/IGZO phototransistor under narrow-band optical excitation at different wavelengths. The transfer characteristics of both bare TFT and the HJ TFT are presented in Fig. 2(a) and 2(b). The excitation intensity for all different wavelengths was 0.5 mW/cm^2. Both the bare and HJ TFT showed similar characteristics in the dark, indicating that the TES-ADT layer coating did not affect the transistor property. Compared to the bare IGZO TFT, the HJ TFT was very responsive to blue (448 nm) and green (522 nm) light excitations, and the photoresponsivity dropped under red (628 nm) excitation, as shown in Fig. 2(b). At $-0.5\ V$ applied gate voltage, the HJ TFT exhibited an excellent photocurrent-to-dark current ratio (I_{ph}/I_{dark}) of about 10^4 under blue and green excitation. The photoresponsivity (R) of the HJ device was calculated using $R=I_{ph}/P_{in}$, where P_{in} is the incident optical power and is summarized in Fig. 2(c). The photoresponsivity follows the absorption spectrum of the TES-ADT, exhibiting a maximum responsivity of 220 mA/W under green excitation. Our proposed photosensor also shows an excellent specific detectivity (D^*) of 3.7×10^{12} Jones, calculated by $D^* = R\sqrt{\frac{A}{2qI_{dark}}}$ with A and q being the device area and the elementary charge, respectively.

This work was supported by NSF grant DMR-1808258. Thanks to Prof. J. Anthony for TES-ADT.

3. Conclusion

In summary, we demonstrate an inorganic-organic heterojunction phototransistor. The device shows excellent responsivity and detectivity, making the IGZO-based TFTs promising for visible light detection.

4. References

1. X. Xu, L. Yan, T. Zou, R. Qiu, C. Liu, Q. Dai, J. Chen, S. Zhang, and H. Zhou, ACS Appl. Mater. Interfaces **10**, 44144 (2018).
2. Y. S. Rim, Y. (Micheal) Yang, S.-H. Bae, H. Chen, C. Li, M. S. Goorsky, and Y. Yang, Advanced Materials **27**, 6885 (2015).
3. S. W. Shin, K.-H. Lee, J.-S. Park, and S. J. Kang, ACS Appl. Mater. Interfaces **7**, 19666 (2015).
4. B. T. Lim, J. Cho, K. H. Cheon, K. Shin, and D. S. Chung, Organic Electronics **18**, 113 (2015).