Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp623-624

# Turn-on voltage engineering of monolithically-stacked organic photodiode-blocking diode toward low power organic imager

Yi-Lin Wu[1,2], Naoji Matsuhisa[1], Peter Zalar[1], Kenjiro Fukuda[2,3], Tomoyuki Yokota[1], Takao Someya[1,2,3]

[1] Electrical and Electronic Engineering and Information System, The University of Tokyo
7-3-1 Bunkyo-ku, Tokyo 113-8656, Japan
Phone: +81-3-5841-6709 E-mail: yi-lin.wu@ntech.t.u-tokyo.ac.jp
[2]Center for Emergent Matter Science, RIKEN
2-1 Hirosawa, Wako, Saitama 351-0198, Japan
[3]Thin-Film Device Laboratory, RIKEN
2-1 Hirosawa, Wako, Saitama 351-0198, Japan

**Abstract**

**We have successfully demonstrated a method to engineer the turn-on voltage of monolithically stacked organic photodiode-blocking diode devices, which is self-contained as a light sensing pixel in an organic image sensor. By engineering the work function of the top electrode of the monolithically-stacked photodiode-blocking diode device, the turn-on voltage could be adjusted. This led to the capability to turn device off at 0 V. The mechanism was explained by individual diodes with different top contact. This result is expected to deliver organic photodiode-blocking diode contact. Our result could pave the way for low standby power image sensor for low power imaging system.**

## 1. Introduction

Due to the high sensitivity, large-area processability, and mechanical flexibility, organic photodiodes have the potential in realizing novel wearable optical imaging applications such as blood vessels monitoring and retina reconstruction.[1] Multiplexing signal readout from image sensors based on organic photodiode matrix has been commonly realized by the integration of photodiode with 3-terminal transistors as the switch.[2,3] In the sense of simplifying fabrication and reducing number of wires, using 2-terminal blocking diodes as the switches in imagers should be more beneficial than 3-terminal transistors. Recently, by simple monolithic stacking of organic blocking diodes on organic photodiodes, world's highest pixel density (224 ppi) flexible organic imagers has been demonstrated, and paved the way for high resolution flexible imaging applications.[4]

However, organic imagers utilizing blocking diode as switches have always required higher standby power and more complicated read-out circuit because of the need of additional voltage to switch off unselected lines and pixels. For example, in the recent report of high resolution organic imager based on monolithically stacked organic photodiode and blocking diode, it required additional voltage of 0.5 V to turn off unselected lines.[4] To achieve low standby power, it is desirable for the devices could be switched off at 0 V.

We have successfully demonstrated a method to modify the turn-on voltage of monolithically stacked organic photodiode-blocking diode devices to turn it off at 0 V. This was achieved by modifying the work function of electrodes for blocking diodes to adjust the turn-on voltage. The mechanism is explained by the characterization of turn-on voltage of single organic diode device with different top contact.

## 2. Experiments, results, and discussion

We fabricated monolithically stacked organic photodiode-block diode devices (Figure 1a). The structure is indium tin oxide (ITO)/polyethylenimine ethoxylated solution-(PEIE)[5]/poly(3-hexylthiophene-2,5-diyl) (P3HT): [6,6]-phenyl $C_{61}$ butyric acid methyl ester (PCBM)/poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS)/P3HT/top electrode. This can be considered as a back-to-back connection of an organic photodiode (ITO/PEIE/P3HT:PCBM/PEDOT:PSS) and an organic blocking diode (PEDOT:PSS/P3HT/top electrode). For the top electrode, we chose Al (4.2 eV) and NaF/Al (3.1 eV)[6] for the study.

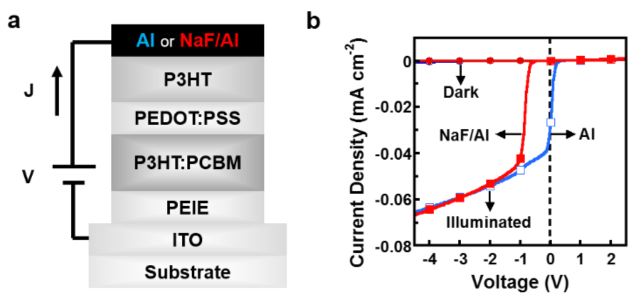


**Figure 1**. Monolithic stacked organic photodiode-blocking diode. (a) Device schematic. (b) Characteristics.

The monolithically-stacked organic photodiode-blocking diode could be switched off at zero voltage (which is commonly known as normally-off) using NaF/Al top electrode (Figure 1b). At dark condition, both the devices with Al and NaF/Al top electrode exhibited nearly zero current regardless of the direction of voltage bias. The zero current at negative bias was due to the zero photocurrent for the photodiode under dark condition. On the other hand, the zero current at positive bias was due to the rectifying effect by the blocking diode part. Importantly, under illumination, the current at 0 V of the device with NaF/Al top electrode was 3 orders of magnitude lower than that with Al top electrode. The device with Al top electrode showed a positive turn-on voltage of +0.20 V, and the device with NaF/Al top electrode showed a negative turn-on voltage of −0.63 V. Furthermore, the photocurrent at negative bias for both devices were almost identical.

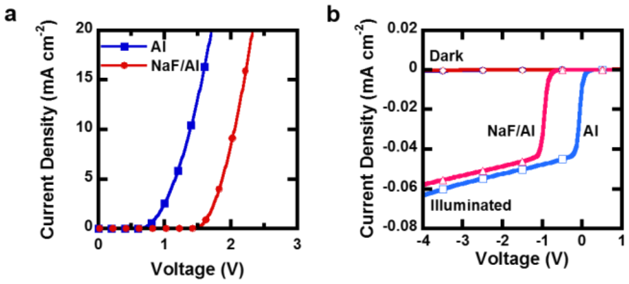


**Figure 2**. Current-voltage characteristics of (a) organic diodes with Al and NaF/Al top contacts and (b) externally connected organic photodiode and organic diodes.

The turn-on voltage difference between the monolithically-stacked organic photodiode-blocking diode device with different top electrode could be attributed to the turn-on voltage of organic blocking diode (Figure 2a). Individual organic blocking diodes were fabricated and characterized. Their structures are ITO/PEDOT:PSS/P3HT/Top electrode. Al and NaF/Al were chosen as the electrode. From the current-voltage characteristics, it is found that the turn-on voltage of the blocking diode with NaF/Al is about 0.8 V larger than that with Al top electrode. This could be attributed to the built-in voltage difference of the diodes caused by the work function difference between two electrodes. Therefore, when connecting larger turn-on voltage diodes with organic photodiode, we could shift the turn-on voltage of organic photodiode-blocking diode stack toward negative, and make the device able to be switched off at 0 V (Figure 2b).

## 3. Conclusions

We demonstrated the method to engineer the turn-on voltage of the light-sensitive rectifiable pixel with monolithically stacked organic photodiode-blocking diode device. This is achieved by turn-on voltage engineering to reduce the current at 0 V without changing the photosensitive characteristics. The turn-on voltage was engineered by modifying the work function of electrodes on the blocking diode side. The mechanism was explained through individual organic diode components. In the future, we will demonstrate low standby power organic imager based on the matrix of normally-off monolithically stacked organic photodiode-blocking diode pixels. Our achievement could pave the way for low power imaging suitable for wearable applications.


## Acknowledgements

This work was financially supported by Japan Science and Technology Agency ACCEL Grant Number JPMJMI17F1, Japan. Yi-Lin Wu was supported by Doctoral Student Special Incentives Program (SEUT-RA) from The University of Tokyo, and Junior Research Associate (JRA) program from RIKEN.


## References


[1] T. Yokota, P. Zalar, M. Kaltenbrunner, H. Jinno, N. Matsuhisa, H. Kitanosako, Y. Tachibana, W. Yukita, M. Koizumi, and T. Someya, Science Advances **2**, e1501856 (2016).

[2] D. Baierl, L. Pancheri, M. Schmidt, D. Stoppa, G.-F.D. Betta, G. Scarpa, and P. Lugli, Nature Communications **3**, 1175 (2012).

[3] G.H. Gelinck, A. Kumar, D. Moet, J.-L. van der Steen, U. Shafique, P.E. Malinowski, K. Myny, B.P. Rand, M. Simon, W. Rütten, A. Douglas, J. Jorritsma, P. Heremans, and R. Andriessen, Organic Electronics **14**, 2602 (2013).

[4] P. Zalar, N. Matsuhisa, T. Suzuki, S. Enomoto, M. Koizumi, T. Yokota, M. Sekino, and T. Someya, Advanced Electronic Materials **0**, 1700601 (2018).

[5] Y. Zhou, C. Fuentes-Hernandez, J. Shim, J. Meyer, A.J. Giordano, H. Li, P. Winget, T. Papadopoulos, H. Cheun, J. Kim, M. Fenoll, A. Dindar, W. Haske, E. Najafabadi, T.M. Khan, H. Sojoudi, S. Barlow, S. Graham, J.-L. Brédas, S.R. Marder, A. Kahn, and B. Kippelen, Science **336**, 327 (2012).

[6] J. Lee, Y. Park, D.Y. Kim, H.Y. Chu, H. Lee, and L.M. Do, Appl. Phys. Lett. **82**, 173 (2003).