Science Bulletin 65 (2020) 1141–1143

Contents lists available at ScienceDirect

Science Bulletin

journal homepage: www.elsevier.com/locate/scib

Science Bulletin
www.scibull.com

Research Highlight

Polymer-based bioelectronics go self-powered

Peiyun Li [a], Ting Lei [a,*], Liming Ding [b,*]

[a] Key Laboratory of Polymer Chemistry and Physics (MOE), Department of Materials Science and Engineering, Peking University, Beijing 100871, China
[b] Center for Excellence in Nanoscience (CAS), Key Laboratory of Nanosystem and Hierarchical Fabrication (CAS), National Center for Nanoscience and Technology, Beijing 100190, China

Bioelectronic devices work at the interfaces of biology and electronics. One of the most important targets of bioelectronics is to real-time monitor electrophysiological signals and metabolite of biofluids, including sweat, tear, saliva, interstitial fluid, etc. [1]. These biosensors have contributed to a large part of the market in healthcare industry and their value is estimated to be US$13 billion annually [2]. Driven by the promise of the huge market, researchers specially concentrate on noninvasive metabolite monitoring devices, which can constantly monitor users' metabolic status and provide an important basis for the prevention and treatment of certain diseases, such as diabetes, without any injury to human body.

The flourishment of bioelectronics also brings many challenges, among which the issue of energy supply is particularly critical. An integrated bioelectronic device contains at least a biosensor, a power source, and a signal transmission unit. The existence of the power source, usually a commercial battery, enlarges the volume of the device, limits mechanical flexibility and increases difficulty of encapsulation. Moreover, limited energy supply means a trade-off between energy consumption and data quality, and the device should maintain at low power consumption during continuous, prolonged monitoring [1]. Especially for implantable electronic devices that require long-term operation, the extra power source greatly limits comfort of users and service life of devices, and multiple surgeries are even required to replace the battery. Therefore, the power supply issue hinders the practical application of bioelectronic devices significantly.

The past two decades have witnessed the tremendous advances in conjugated polymers. Their good solution processability and high mechanical flexibility endow them with unique features in various optoelectronic applications, such as organic field-effect transistors (OFETs) [3] and organic photovoltaics (OPVs) [4]. Besides, the instinct characteristics of polymers, including soft, stretchable, and mechanically comfortable, make them proper candidates for bioelectronic devices [5]. Recently, a new feature of conjugated polymers–mixed ionic-electronic conducting, is attracting increasing attentions, since this feature enables conjugated polymers with new applications, including low-amplitude electrophysiological signal amplification, energy conversion/storage, and neuromorphic computing [6]. Organic electrochemical transistor (OECT) is an electronic device that takes the advantage of the mixed ionic–electronic conducting property of conjugated polymers. An OECT is similar to an OFET in device structure, but it utilizes the ionic signals as the gate input to modulate the conductance of the conjugated polymer in the channel. OECTs can be operated in aqueous environment and have exhibited superior performances over other types of materials (e.g., graphene) in the amplification of biologically related weak signals [7]. Several types of materials for OECTs were developed, including p-type and n-type polymers [8,9]. Some p-type polymers based on polythiophene exhibited better performance than the conventional OECT material poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS). N-type OECT polymers based on naphthalene diimide (NDI) were also developed, though their device performances still need further improvement. The prosperous OECT materials provide enormous possibilities for applications in bioelectronics.

Recently, a biofuel powered glucose sensor based on an n-type conjugated polymer was developed by Inal and co-workers [2]. The channel and gate electrode of the glucose sensor (based on OECT) (Fig. 1b) and the anode of the enzymatic biofuel cell (EFC) all comprise the n-type polymer, namely NDI-T2 (P-90) (Fig. 1a). P-90 is a typical donor–acceptor polymer, consisting of an alternating NDI acceptor, bithiophene (T2) donor, and randomly distributed branched alkyl and linear ethylene glycol side chains. The ratio of ethylene glycol to alkyl side chains in the polymer was optimized to 90:10 in their previous study [10], which enables adequate swelling of the polymer and optimal ionic and electron transport properties in aqueous environment. With only glucose oxidase (Gox) coupled on the NDI-T2 (P-90) and no other mediators, the miniaturized glucose sensor showed a reversible detection range of six orders of magnitude (10 nmol L^{-1}–20 mmol L^{-1}). Composed of a Gox coated NDI-T2 (P-90) anode and a polymeric cathode, the biofuel cell can convert the chemical energy of glucose and oxygen into electrical power. Both glucose and oxygen are readily available endogenous substances in biological fluids and can be continuously renewed through metabolism (Fig. 1c). The all-polymer biofuel cell showed stability over 30 days at physiologically relevant glucose concentrations. Furthermore, after assembled into a battery array, the EFC can generate enough power to operate an OECT from bodily fluids, e.g., saliva.

* Corresponding authors.
E-mail addresses: tinglei@pku.edu.cn (T. Lei), ding@nanoctr.cn (L. Ding).

https://doi.org/10.1016/j.scib.2020.03.038

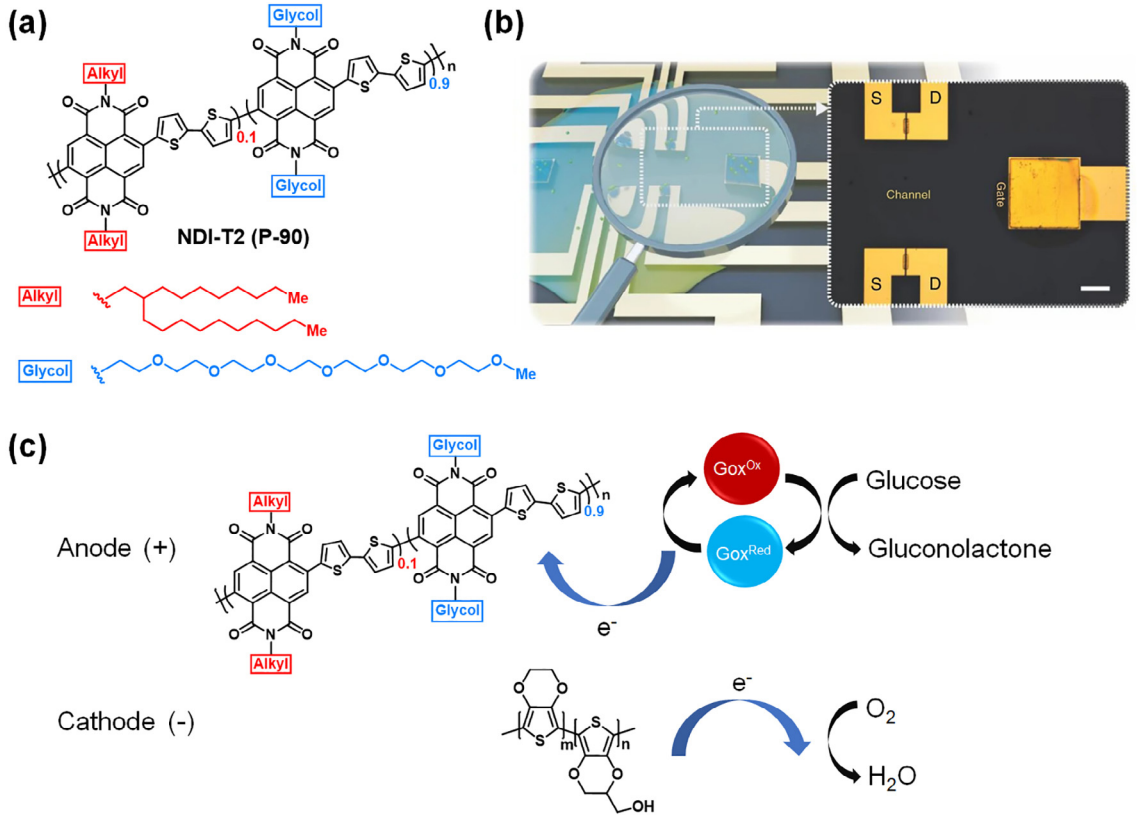

Fig. 1. Self-powered glucose sensor with an n-type semiconducting polymer. (a) Chemical structure of the n-type copolymer NDI-T2 (P-90); (b) schematic illustration for the sensor; (c) reactions that occur during the operation of the EFC. (b) was reprinted with permission from Ref. [2]. Copyright 2019, Springer Nature.

Unfortunately, this work, while achieving the basic functionality, did not combine the EFC with the glucose sensor to form an integrated self-powered bioelectronic device, and the performances in terms of the glucose sensor and EFC need further improvement for practical use. But in many aspects, the achievements of this work are far-reaching and enlightening, since the combination of EFCs with biosensors provides a potential approach to realize self-powered biosensors, which can provide convenience and more possibilities for noninvasive biotesting. We believe the ease of chemical modification of conjugated polymers could allow further improvement of the device performance and exploration of the plenty room of self-powered devices. In the future, this self-powered technology might be applied to actuators of any integrated bioelectronic systems which run on metabolites produced in living body [2]. By that time, many bioelectronic devices could use the same energy supply mode as human tissues or organs.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

This work was supported by the Key-Area Research and Development Program of Guangdong Province (2019B010934001) and the Beijing Natural Science Foundation (2192020). L. Ding thanks the National Key Research and Development Program of China (2017YFA0206600) and the National Natural Science Foundation of China (51773045, 21772030, 51922032, and 21961160720) for financial support.

References

[1] Kim J, Campbell AS, de Avila BE, et al. Wearable biosensors for healthcare monitoring. Nat Biotechnol 2019;37:389–406.
[2] Ohayon D, Nikiforidis G, Savva A, et al. Biofuel powered glucose detection in bodily fluids with an n-type conjugated polymer. Nat Mater 2019. https://doi.org/10.1038/s41563-019-0556-4.
[3] Jia H, Lei T. Emerging research directions for n-type conjugated polymers. J Mater Chem C 2019;7:12809–21.
[4] Liu Q, Jiang Y, Jin K, et al. 18% efficiency organic solar cells. Sci Bull 2020;65:272–5.
[5] Someya T, Bao Z, Malliaras GG. The rise of plastic bioelectronics. Nature 2016;540:379–85.
[6] Paulsen BD, Tybrandt K, Stavrinidou E, et al. Organic mixed ionic-electronic conductors. Nat Mater 2020;19:13–26.
[7] Khodagholy D, Rivnay J, Sessolo M, et al. High transconductance organic electrochemical transistors. Nat Commun 2013;4:2133.
[8] Inal S, Rivnay J, Suiu AO, et al. Conjugated polymers in bioelectronics. Acc Chem Res 2018;51:1368–76.
[9] Rivnay J, Inal S, Salleo A, et al. Organic electrochemical transistors. Nat Rev Mater 2018;3:17086.
[10] Giovannitti A, Maria IP, Hanifi D, et al. The role of the side chain on the performance of n-type conjugated polymers in aqueous electrolytes. Chem Mater 2018;30:2945–53.

Peiyun Li obtained her B.E. degree in Materials Science from Huazhong University of Science and Technology in 2019. She is currently pursuing her Ph.D. degree at Peking University. Her research focuses on organic electrochemical transistors and their applications in flexible electronics, neuromorphic computing and bioelectronics.

Ting Lei is an Assistant Professor in Department of Materials Science & Engineering, Peking University. He received his B.S. and Ph.D. degrees from Peking University in 2008 and 2013. After a postdoc training in Stanford, he joined Peking University in 2018. His current researches focus on organic/polymer functional materials, organic electronics, carbon-based electronics, and bioelectronics.

Liming Ding got his Ph.D. degree from University of Science and Technology of China (was a joint student at Changchun Institute of Applied Chemistry, CAS). He started his research on OSCs and PLEDs in Olle Inganäs Lab in 1998. Later on, he worked with Frank Karasz and Tom Russell at PSE, UMASS Amherst. He joined Konarka as a Senior Scientist in 2008. In 2010, he joined National Center for Nanoscience and Technology as a Full Professor. His research interests include optoelectronic materials, perovskite solar cells, organic solar cells, photodetectors and LEDs.