Ultra-Flexible Organic Light Emitting Diodes for Bio-medical Application

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ABSTRACT

We developed an ultrathin, flexible, OLED device and demonstrated the activations of the neurons in animals. Optical stimulation from the OLED attached to nerve fibers evoked contractions in the innervated muscles. Mechanical damage to the tissues was significantly reduced because of the flexibility. Owing to the MRI compatibility, neuronal activities evoked by direct optical stimulation of the brain were visualized using MRI.

1. Introduction

Applications of organic electronic devices are rapidly extending from consumer devices, such as display and lighting, to wearable and biomedical applications [1, 2]. A variety of organic electronic devices can be fabricated on polymer films under room-temperature solution processes, and this has led to the realization of lightweight, thin, flexible, and large-area devices. The flexibility of organic light-emitting diodes (OLEDs) is considerable advantages in potential applications, particularly in optogenetics, as OLEDs have a high affinity for the target tissue [3, 4]. For such applications, however, the OLED should be improved to achieve an emission intensity sufficient for activating light-gated ion channels.

In this study, we developed an ultra-flexible OLED for optogenetics, and stimulated the brain and peripheral motor and sensory neurons of the W-TChR2V4 transgenic rat which expresses channelrhodopsin-2 (ChR2), one of light-gated cation channels, in these neurons [5, 6]. The maximum light power density of 0.48 mW/mm^2 was enough high to drive the OLED over the animal's relatively low threshold of approximately 0.3 mW/mm^2 for nerve excitation. Using the OLED device, we stimulated motor and sensory neurons by virtue of stable and conformal contact to the body.

2. Experiment

The blue color OLEDs were manufactured on 1-μm-thick parylene substrate. The surface of the parylene was modified by 500-nm thick polyimide layer as a planarization layer. The 70-nm thick indium-tin-oxide (ITO) layer was formed by sputter process as a transparent electrode. To reduce heat damage to the ultra-flexible substrate, the ITO layer was formed without substrate heating. Thanks to a reduction of the device thickness (3 μm) and placement of the active layer in the neutral strain

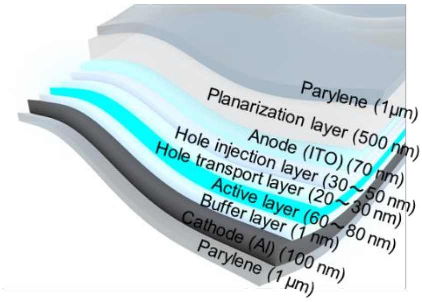

Figure 1. Structure of the ultra-flexible OLED

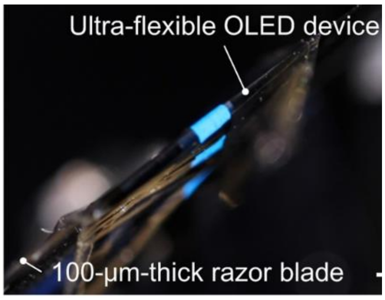

Figure 2. Picture of the ultra-flexible OLED

position, our ultra-flexible OLEDs show the good mechanically durability (Fig. 1). The ultra-flexible OLEDs wasn't broken even when bent with a bending radius of 100 μm on the tip of a razor (Fig. 2).

To demonstrate the muscle contractions, the OLED was attached to both muscle belly and nerve fiber. To stimulate the motor nerve terminals expressing ChR219, we surgically exposed the gracilis muscle (GRM) of rat hindlimb and attached the OLED device to the GRM's nerve (Fig. 3). The nerve terminals on the muscle belly were identified using fiber-guided laser stimulation with an emitting tip diameter of 250 μm scanned on the muscle.

3. Result

The emission spectrum demonstrates that the peak intensity of the OLED occurs at a wavelength of around 455 nm (Fig. 4). The emission characteristic covering a wavelength of 470 nm is appropriate to activate ChR2 expressed in neurons [7]. The luminance of the OLED is 4.3×10^4 cd/m^2 at 10 V (Fig. 4). The optical power density measured by facing a photodiode was 0.48 mW/mm^2.

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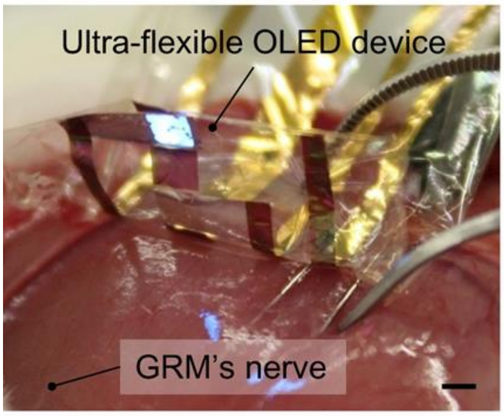

Figure 3. The OLED stimulator was attached to a surface of gracilis muscle (GRM) with high conformity, even during hindlimb movement.

The J-V characteristics of the OLED did not vary before and after the attachment to the muscle. This indicates that the leak current flowing from the OLED to the body was negligibly small because of durable encapsulation. The myoelectric potential was measured using paired needle electrodes inserted into the GRM. An optical stimulation of GRM induced a tensional response after 4 ms (Fig. 4a). During optical stimulation with repetition rates ranging from 2–40 Hz, hindlimb movement was induced in synchronization with optical pulses (Fig. 4b). At frequencies of 20 Hz and 40 Hz, the contraction diminished because of desensitization [8]. Even during the contraction, the ultra-flexible OLED delivered stable optical stimulations because of the high conformity to the muscle surface.

4. Conclusion

In this study, we succeed to develop the ultra-flexible blue color OLED. The OLED shows the good mechanically durability and high electrical characteristics. Using the ultra-flexible OLED, we demonstrated the activations of the neurons of rats by directly attached the OLED to the surface of gracilis muscle.

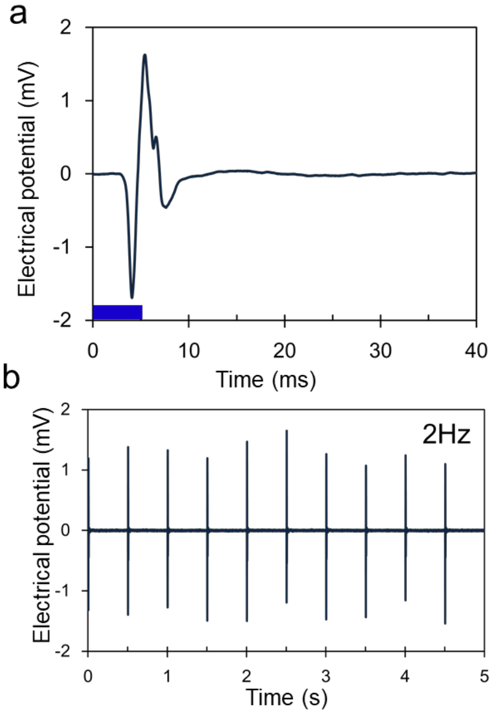

Figure 4. Stimulation of neuromuscular system. a, The evoked electrical potential at the GRM. The stimulation frequency was 10 Hz. The blue bar indicates the optical stimulation with a duration of 5 ms. b, The evoked electrical potential at the GRM stimulated at 2 Hz

References

[1] D. Khodagholy, T. Doublet, P. Quilichini, M. Gurfinkel, P. Leleux, A. Ghestem, E. Ismailova, T. Hervé, S. Sanaur, C. Bernard, G. G. Malliaras, "In vivo recordings of brain activity using organic transistors" Nature Commun. 4, 1575 (2013).

[2] P. Leleux, J. Rivnay, T. Lonjaret, J. M. Badier, C. Bénar, T. Hervé, P. Chauvel, G. G. Malliaras, "Organic electrochemical transistors for clinical applications" Adv. Healthc. Mater. 4, 142-147 (2015).

[3] J. T. Smith, B. O'Brien, Y. K. Lee, E. J. Bawolek, J. B. Christen, "Application of flexible OLED display technology for electro-optical stimulation and/or silencing of neural activity" J. Display Technol. 10, 514-520 (2014).

[4] H. Uoyama, K. Goushi, K. Shizu, H. Nomura, C. Adachi, "Highly efficient organic light-emitting diodes from delayed fluorescence" Nature 492, 234-238 (2012).

[5] T. Honjoh, Z. G. Ji, Y. Yokoyama, A. Sumiyoshi, Y. Shibuya, Y. Matsuzaka, R. Kawashima, H. Mushiake, T. Ishizuka, H. Yawo, "Optogenetic patterning of whisker-barrel cortical system in transgenic rat expressing channelrhodopsin-2" PLoS One 9, e93706 (2014).

[6] H. Tomita, E. Sugano, Y. Fukazawa, H. Isago, Y. Sugiyama, T. Hiroi, T. Ishizuka, H. Mushiake, M. Kato, M. Hirabayashi, R. Shigemoto, H. Yawo, M. Tamai, "Visual properties of transgenic rats harboring the channelrhodopsin-2 gene regulated by the Thy-1.2 promoter" PLoS One 4, e7679 (2009).

[7] G. Nagel, T. Szellas, W. Huhn, S. Kateriya, N. Adeishvili, P. Berthold, D. Ollig, P. Hegemann, E. Bamberg, "Channelrhodopsin-2, a directly light-gated cation-selective membrane channel" Proc. Natl. Acad. Sci. USA 100, 13940-13945 (2003).

[8] C. Towne, K. L. Montgomery, S. M. Iyer, K. Deisseroth, S. L. Delp, "Optogenetic control of targeted peripheral axons in freely moving animals" PLoS One 8, e72691 (2013).