Thin-Film Device Laboratory (2022)
Chief Scientist: Takao Someya (Ph.D.)

(0) Research field

CPR Subcommittee**:** Engineering

Keywords: Organic Electronics, Organic solar cells, Flexible electronics, Printing technology, stretchable conductors

(1) Long-term goal of laboratory and research background

Our laboratory is aiming to develop novel applications of thin-film devices such as organic electronics as well as to explore their fundamental study. More specifically, electronic and/or photonic devices are integrated on the ultra-thin films or rubber sheets to produce next-generation information devices having excellent mechanical flexibility. These flexible devices are cooperatively linked with state-of-the-art silicon technologies such as ultralow power wireless chips and applied to flexible systems. Moreover, by utilizing the biocompatible electronics such as flexible devices, emerging region that fuses the machine and the biological will be investigated to advance unique bio-medical and robotics applications. Furthermore, the rapid prototyping with the technique of digital fabrication will be utilized to establish various kinds of new systems and services that support humans and consequently the new manufacturing parading that can respond to rapid changes of society and meet their needs will be realized.

(2) Current research activities (FY2022) and plan

(A-1) Rechargeable Cyborg Insects using ultrathin organic solar cells

Cyborg insects are intriguing robots capable of long-term activity in environments that are difficult for humans to reach, such as in urban search and rescue missions. To control the movement of cyborg insects wirelessly for extended periods and to collect environmental data, an environmental power generation device such as a solar cell, capable of generating more than 10 milliwatts (mW), is necessary. However, no technology existed to implement such high-power generating devices without hindering the movement of the insects.

This time, we successfully developed rechargeable and wireless-communicating cyborg insects by attaching a flexible, ultra-thin organic solar cell, with a thickness of 4 μm, to the dorsal abdomen of insects using a "stepping stone structure" that alternates adhesive and non-adhesive areas. By adhering films thinner than 5 μm in a stepping stone structure, we quantitatively demonstrated that the basic movements of the insects are not impaired. The 4 μm-thick organic solar cell module, mounted on the abdomen of a living insect, achieved an output of 17.2 mW under simulated sunlight. Using this organic solar cell module, we were able to recharge a lithium polymer battery installed in the cyborg insect and operate a wireless movement control module. This breakthrough allows for long-term and long-distance activity as long as the insect's lifespan, without the concern of battery depletion, potentially expanding the applications of cyborg insects.

Future plan, 1) Reduce the invasiveness of stimulation electrodes by using film-type electrodes. 2) Manufacture large-area, high-efficiency ultra-thin solar cells to improve the charging speed of the battery.

Figure 1. Rechargeable Cyborg Insects using ultrathin organic solar cells

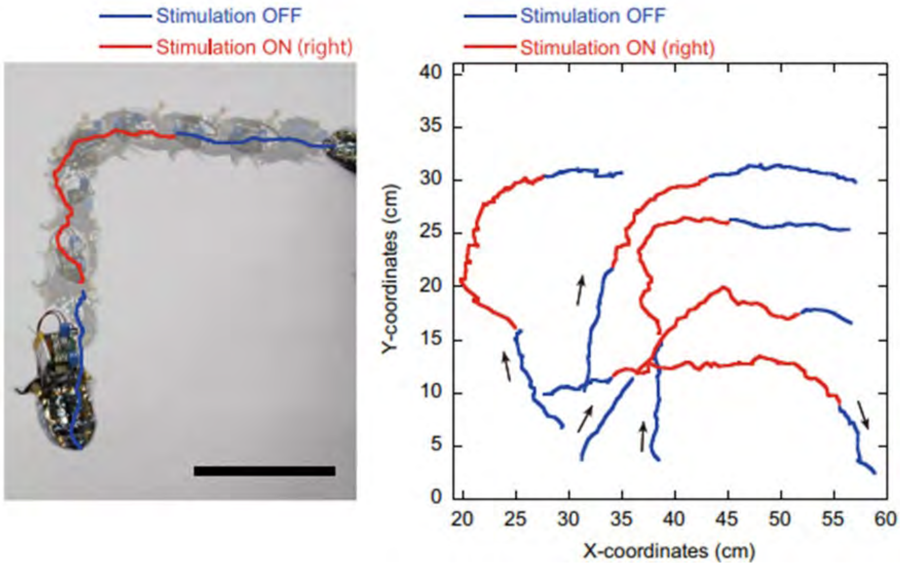

Figure 2. Wireless locomotion control with recharged battery. (Left) Multiple exposures and corresponding trajectories of locomotion. The blue and red lines represent off and on stimulation, respectively. Scale bar, 100 mm. (Right) Trajectory of five locomotion control attempts.

(B-1) Ultra-Thin Stretchable Conductors for On-Skin and Implanted Sensors

To achieve the ultimate goal of wearable and implantable devices, which is to provide necessary health measurements and treatments over long periods, ultra-thin and stretchable sensors are required. A crucial component for such sensors is an ultra-thin, stretchable conductor. These conductors need to maintain stable conductivity while providing stretchability of over 100% tensile strain, a feat that has been difficult to achieve until now.

We have developed a method to deposit a gold layer approximately 50 nm thick onto a silicone rubber (PDMS) substrate approximately 1.2 µm thick, forming a microcrack structure. By using a 100 µm thick PDMS support layer, sufficient thermal deformation occurs in the thin PDMS substrate, successfully forming the gold microcrack structure. This ultra-thin stretchable conductor achieved up to 300% tensile strain without losing conductivity. Combining it with an adhesive ion-conductive polymer layer significantly improved adhesion to the skin. This enabled continuous and stable recording of ECG signals even after intense activities such as running and swimming. It was also demonstrated to be usable as a neural interface implantable in rats, confirming that the ultra-thin stretchable conductor requires a low current value necessary for muscle activation through composite nerve action potentials.

Future plan, 1) Further improve the reliability and low-wearing burden of on-skin sensors. 2) Establish new demonstrations through actual wearable sensor applications.

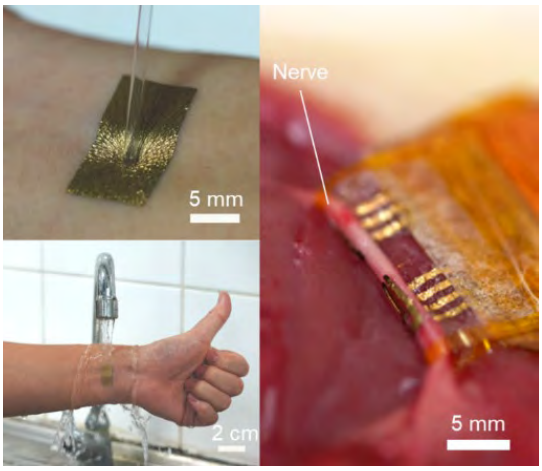

Figure 3. Ultra-thin stretchable conductor attached to human skin (Left) and rat nerve (Right)

(3) Members

(Chief Scientist)
Takao Someya

(Senior Research Scientist)
Kenjiro Fukuda

(Postdoctoral Researcher)
Lulu Sun

(4) Representative research achievements

1. Y. Kakei, S. Katayama, S. Lee, M. Takakuwa, K. Furusawa, S. Umezu, H. Sato, K. Fukuda, and T. Someya, “Integration of body-mounted ultrasoft organic solar cell on cyborg insects with intact mobility”, **npj Flex. Electron.**, 6, 78 (2022).
2. S. Cheng, Z. Lou, L. Zhang, H. Guo, Z. Wang, C. Guo, K. Fukuda, S. Ma, G. Wang, T. Someya, H. M. Cheng, X. Xu, “Ultrathin Hydrogel Films toward Breathable Skin-Integrated Electronics”, **Adv. Mater.**, 35, 2206793 (2022).
3. Z. Jiang, N. Chen, Z. Yi, J. Zhong, F. Zhang, S. Ji, R. Liao, Y. Wang, H. Li, Z. Liu, Y. Wang, T. Yokota, X. Liu, K. Fukuda, X. Chen & T. Someya, “A 1.3-micrometre-thick elastic conductor for seamless on-skin and implantable sensors”, **Nat. Electron.**, 5, 784-793 (2022)).
4. S. I. Rich, M. Takakuwa, K. Fukuda, and T. Someya, "Simple Method for Creating Hydrophobic Ultraflexible Photovoltaics", **ACS Appl. Mater. Interfaces**, 15, 12495-12501 (2023).
5. B. Du, K. Fukuda, T. Yokota, D. Inoue, D. Hashizume, S. Xiong, S. Lee, M. Takakuwa, L. Sun, J. Wang, and T. Someya, "Surface-Energy-Mediated Interfacial Adhesion for Mechanically Robust Ultraflexible Organic Photovoltaics", **ACS Appl. Mater. Interfaces**, 15, 14624-14633 (2023).

Laboratory Homepage

https://rikensomeya.riken.jp/index.html
https://rikensomeya.riken.jp/index_en.html