Thin-Film Device Laboratory
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 (FY2020) and plan (until Mar. 2025)

Activity 1: Development of flexible and highly efficient photo-charging system.

Flexible energy harvesting and energy storage integrated devices are expected as a technology for providing power to next-generation wearable electronic devices or biomedical devices. However, current flexible integrated devices have low total energy conversion and large device thickness, which hinders their application to efficient and stable self-powered systems.

Here we have realized a highly efficient and ultra-thin optical charging device with a total thickness of less than 50 μm and a total efficiency of 5.9%.an ultra-thin organic solar cell with a thickness of 3 μm and a supercapacitor with a thickness of 40 μm are integrated to achieve the photo-charging system. This flexible photo-charging capacitor delivers much higher performance compared with previous reports by tuning the electrochemical properties of the composite electrodes, which reduce the device thickness to 1/8 while improving the total efficiency by 15%. The devices also exhibit a superior operational stability (over 96% efficiency retention after 100 charge/discharge cycles for one week) and mechanical robustness (94.7% efficiency retention after 5000 times bending at a radius of around 2 mm. This integrated system is expected to be used as a long-term power supply reduction for flexible and wearable electronic devices.

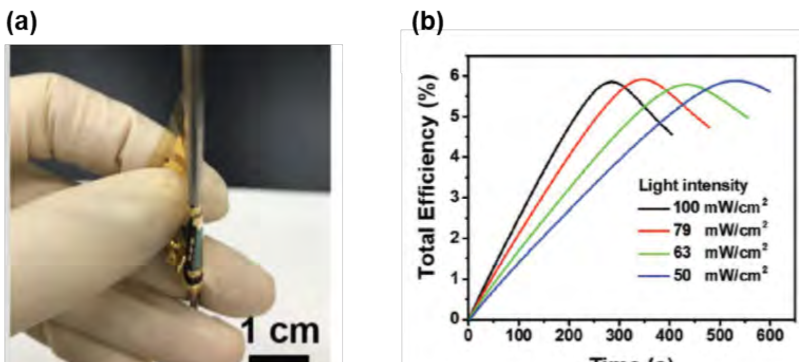

Fig. 1 (a) A Photo of ultra-flexible optical charging system. The total film thickness is 50 μm or less, and it can be driven without breaking even if it is wound around a thin rod. (b) Calculated result of the total energy conversion and storage efficiency profiles for device under four different light intensities.

Activity 2: New electron transport layer for ultra-flexible organic solar cells

The energy conversion efficiency of organic solar cells has been dramatically improved, exceeding 18% on glass substrates. However, it is still difficult to achieve high power conversion efficiency and excellent mechanical robustness for ultra-flexible organic solar cells. Since conventional oxide-based carrier injection layers are brittle, it is necessary to realize an injection layer that is highly flexible and has excellent compatibility with various active layers and electrodes.

Here We have newly developed an electron transport material of Zn^{2+}-chelated polyethyleneimine (denoted as PEI-Zn). With combining this electron transport layer with non-fullerene acceptor active layer, high energy conversion efficiency can be achieved by using an active layer using a non-fullerene acceptor. On 1.3 μm polyethylene naphthalate substrates, ultraflexible non-fullerene solar cells with the PEI-Zn interlayer display a power conversion efficiency of 12.3% on PEDOT:PSS electrodes and 15.0% on AgNWs electrodes. Furthermore, the ultraflexible cells show nearly unchanged power conversion efficiency during 100 continuous compression-release deformation cycles with a compression ratio of 45%. PEI-Zn has been shown to be a promising material with compatibility with a wide range of materials. It is expected to be used as a standard electron transport material for flexible and printed organic solar cells.

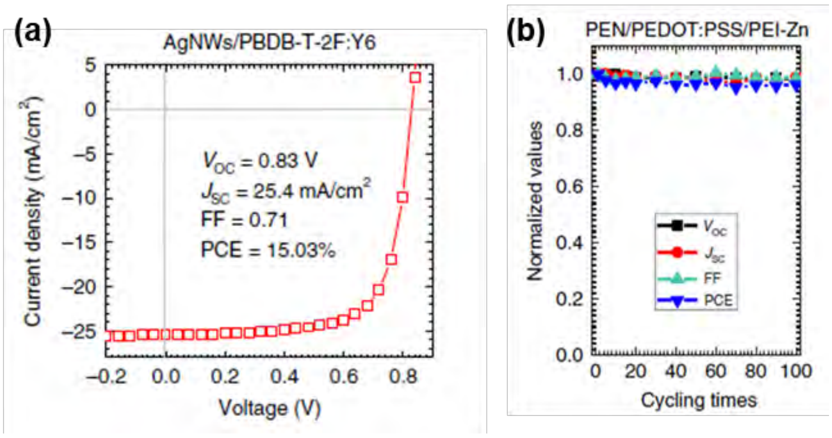

Fig. 2 (a) J-V characteristics of the ultrathin devices with Ag nanowires as the transparent electrode and PBDB-T-2F:Y6 as the active layer. (b) Evolution of photovoltaic parameters after different compressed-release cycles of ultraflexible of cells with PEN/PEDOT:PSS/PEI-Zn.

Plan

The results have led to further improvements in the efficiency of ultra-thin organic solar cells. In the future, we will develop fully-solution processes to fabricate ultra-thin organic solar cells and aiming to achieve high performance and stability. In addition, by establishing integration technology, we will promote system-level integration research in which all devices, from power supply to sensor, maintain their good flexibility. Through these efforts, we aim to contribute to fields such as soft robotics and biological sensors.

(3) Members as of March, 2021

(Chief Scientist)
Takao Someya

(Senior Research Scientist)
Kenjiro Fukuda

(Postdoctral Researcher)
Steven Rich

(Student Trainee)
Jiabin Wang

(4) Representative research achievements

1. Ruiyuan Liu, Masahito Takakuwa, Ailong Li, Daishi Inoue, Daisuke Hashizume, Kilho Yu, Shinjiro Umezu, Kenjiro Fukuda, Takao Someya, "An Efficient Ultra‐Flexible Photo‐Charging System Integrating Organic Photovoltaics and Supercapacitors", *Advanced Energy Materials*, **10**, 2000523 (2020).
2. Kenjiro Fukuda, Kilho Yu, Takao Someya, "The Future of Flexible Organic Solar Cells", *Advanced Energy Materials*, **10,** 2000765 (2020).
3. Yan Wang, Sunghoon Lee, Tomoyuki Yokota, Haoyang Wang, Zhi Jiang, Jiabin Wang, Mari Koizumi, Takao Someya, "A durable nanomesh on-skin strain gauge for natural skin motion monitoring with minimum mechanical constraints", *Science Advances*, **6**, eabb7043 (2020).
4. Fei Qin , Wen Wang, Lulu Sun, Xueshi Jiang, Lin Hu, Sixing Xiong, Tiefeng Liu, Xinyun Dong, Jing Li, Youyu Jiang, Jianhui Hou, Kenjiro Fukuda, Takao Someya, and Yinhua Zhou, "Robust metal ion-chelated polymer interfacial layer for ultraflexible non-fullerene organic solar cells", *Nature Communications*, **11**, 4508 (2020).
5. Zhi Jiang, Kilho Yu, Haoyang Wang, Steven Rich, Tomoyuki Yokota, Kenjiro Fukuda, Takao Someya, "Ultraflexible Integrated Organic Electronics for Ultrasensitive Photodetection", *Advanced Materials Technologies*, **6**, 2000956 (2021).

Laboratory Homepage
https://www.riken.jp/en/research/labs/chief/thin_film_device/index.html
http://rikensomeya.riken.jp/index_en.html