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 (FY2021) and plan (until Mar. 2025)

Activity 1: Direct gold bonding for flexible integrated electronics.

As electronic devices get smaller and smaller, and the desire to have bendable, wearable, and on-skin electronics increases, conventional methods of constructing these devices have become impractical. One of the biggest problems is how to connect and integrate multiple devices or pieces of a device that each reside on separate ultra-thin polymer films. Conventional methods that use layers of adhesive to stick electrodes together reduce flexibility and require temperature and pressure that are damaging to super-thin electronics.

Here, we present a new method for achieving direct bonding of gold electrodes deposited on ultra-flexible substrates, referring a water vapor plasma-assisted bonding (WVPAB).This bonding process is completed at room temperature and with no additional pressure; hence, there are no restrictions on the polymer material that can be used. Furthermore, high flexibility and high resolution of the bonded area are simultaneously achieved because there are no additional layers. The bond can withstand at least 10^4 bending cycles. It possesses excellent damp heat stability for more than 500 h, confirming the compatibility of the process to a wide range of flexible electronics applications. To demonstrate the feasibility of this bonding technology, high-performance integrated systems of ultra-thin organic light-emitting diodes (OLEDs) and organic photovoltaic (OPV) modules fabricated on separate flexible substrates were connected, showing no degraded performance.

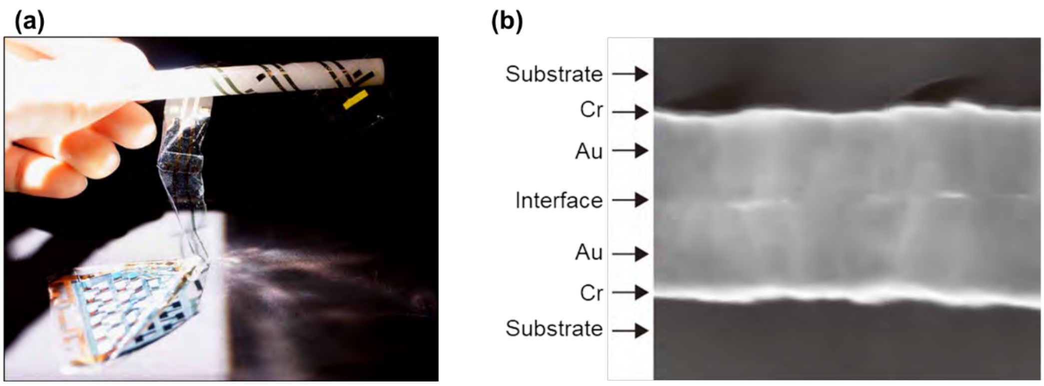

Fig. 1 (a) An integrated device of composed of two ultra-thin electronic devices interconnected by WVPAB using ultra-thin wiring films. (b) High-resolution cross-sectional image using STEM of the interface of the rough Au films bonded using WVPAB.

Activity 2: Highly efficient and highly stable ultra-thin organic solar cell with new electron transport material.

A recent development of photoactive layer has increased the power conversion efficiency (PCE) of organic solar cells dramatically. However, highly efficient ultrathin organic solar cells (PCE > 15%) that can simultaneously achieve sufficient long-term thermal (over 85 °C) and operational stabilities (under 1 sun) in air, have not been reported. Generally, preventing environmental effects is challenging for flexible OPVs, owing to the insufficient barrier of the flexible plastic substrate.

By combining the new electronic transport layer PEI-Zn and the state-of-the-art power generation material PM6: Y6, we have achieved the world's highest PCE of 15.8% for ultra-thin organic solar cells. The solar cells maintain 89.6% of the initial efficiency for 1574 h of storage in air under dark conditions at room temperature, and 92.4% of the initial efficiency after 172 h annealing at 85 °C in air under dark conditions. Under continuous operation under simulated sunlight, T80 (time at PCE/PCE0 = 0.8) was about 1100 h. This is more than 7 times improved compared to the conventional ZnO as electron transport layer. using dynamic secondary-ion mass spectrometry (D-SIMS), the diffusion of zinc from the electron transporting layer (ZnO) into the interface of active layer was identified as the source of performance deterioration for the first time. An ion-chelating interface layer suppressing the zinc diffusion simultaneously enhances the performance and stability.

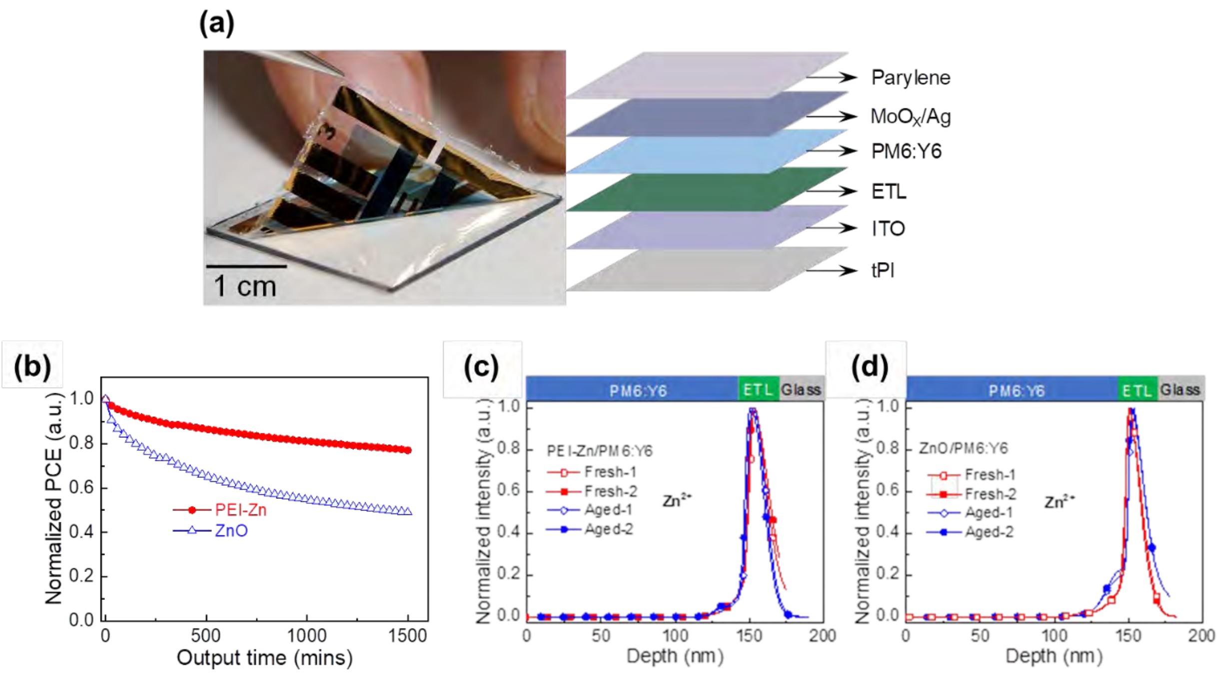

Fig. 2 (a) Photograph and structure of the ultraflexible organic solar cells. (b) Continuous operation stability under the simulated sunlight. D-SIMS results before and after heating the device using (c) PEI-Zn and (d) ZnO.

Plan

In addition to achievements in improving the efficiency and stability of ultra-thin organic solar cells, the integratoin technologies of multiple flexible devices has been achieved in this fiscal year. We plan to promote research activities that focus more on issues related to the fabrication of integrated devices rather than improvement of individual device performance. We aim to contribute to fields such as soft robots and wearable biosensors by promoting system-level integration research in which all devices, from power supplies to sensors, maintain flexibility.

(3) Members as of March, 2022

(Chief Scientist)
Takao Someya

(Senior Research Scientist)
Kenjiro Fukuda

(Postdoctral Researcher)
Steven Rich, Lulu Sun

(Student Trainee)

(4) Representative research achievements

1. Jiachen Wang, Kenjiro Fukuda, Daishi Inoue, Daisuke Hashizume, Lulu Sun, Sixing Xiong, Tomoyuki Yokota, and Takao Someya, "Solution-Processed Electron-Transport Layer-free Organic Photovoltaics with Liquid Metal Cathodes", *ACS Applied Materials & Interfaces*, **14**, 14165–14173 (2022).
2. Sixing Xiong, Kenjiro Fukuda, Shinyoung Lee, Kyohei Nakano,Xinyun Dong,Tomoyuki Yokota,Keisuke Tajima, Yinhua Zhou, Takao Someya, "Ultrathin and Efficient Organic Photovoltaics with Enhanced Air Stability by Suppression of Zinc Element Diffusion", *Advanced Science*, **9**, 2105288 (2022).
3. Masahito Takakuwa, Kenjiro Fukuda, Tomoyuki Yokota, Daishi Inoue, Daisuke Hashizume, Shinjiro Umezu, Takao Someya, "Direct gold bonding for flexible integrated electronics", *Science Advances*, **7**, eabl6228 (2021).
4. Junwen Zhong, Zhaoyang Li, Masahito Takakuwa, Daishi Inoue, Daisuke Hashizume, Zhi Jiang, Yujun Shi, Lexiang Ou, Md Osman Goni Nayeem, Shinjiro Umezu, Kenjiro Fukuda, Takao Someya, "Smart Face Mask Based on an Ultrathin Pressure Sensor for Wireless Monitoring of Breath Conditions", *Advanced Materials*, **34**, 2107758 (2022).
5. Steven I. Rich, Shinyoung Lee, Kenjiro Fukuda,Takao Someya,"Developing the Nondevelopable: Creating Curved-Surface Electronics from Nonstretchable Devices", *Advanced Materials*, **34**, 2106683 (2022).

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