Intrinsically Stretchable Electronic Materials for Body-Area Sensor Networks

Naoji Matsuhisa[1,2]

naoji@keio.jp
[1]Department of Electronics and Electrical Engineering, Keio University, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama, Kanagawa 223-8522, Japan
[2]JST PRESTO, 4-1-8 Honcho, Kawaguchi, Saitama 332-0012, Japan
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ABSTRACT

I introduce the next-generation wearable devices (power source, sensor, and display) which can be attached on skin. The devices consist of rubber-like, stretchable electronic materials. The mechanical properties similar to our skin enable long-term monitoring and display of our vital data without intimate engagement of doctors.

1 Introduction

Wearable devices are great tools to enable long-term monitoring or display of the wears' vital data. Most of the commercially available wearable devices have a small and rigid form factor, such as a watch, wristband, ring, and glasses, which can minimize the discomfort caused by wearing. Still, their minimal contact to our body surface limits the types of measurable information (e.g. electrocardiogram (ECG), Photoplethysmogram (PPG)), the sensing area in our body, and the signal integrity. As the next-generation wearable devices, soft and ultrathin electronic devices are highly desirable because the sheet-type electronic devices can have a conformal contact to any skin surface of our body.[1], [2] However, the mechanical properties of conventional electronic materials are very rigid and brittle, and soft materials tend to have very poor electrical properties. In order to realize softness or stretchability in electronic devices, there have been developed a structural design approach of flexible/rigid electronic materials, and a materials approach to realize intrinsically stretchable electronic materials.[3] The latter has shown high robustness of fabricated device compared with the structural approach. Here we describe various types of intrinsically stretchable electronic materials that can realize a stretchable power source, sensor, human-computer interface, and display. Furthermore, we introduce a novel wireless communication of such intrinsically stretchable devices.

2 Intrinsically stretchable electronic materials and devices

2.1 Stretchable batteries

We realized a stretchable lithium-ion battery by the development of stretchable solid-state lithium-ion conducting polymer and highly conductive, chemically stable current collectors.[4] The current collectors are made of a microcracked gold thin film.[5] The gold thin film is fabricated simply by the thermal deposition of gold on elastomer substrates. The microcracked morphology ideal to realize a high stretchability of gold was obtained by very high deposition rate (3.2 nm/s). The stretchable gold conductor showed remarkably low sheet resistance of 30 Ω/Sq. even under 100% tensile strain. The fabricated stretchable lithium-ion battery could successfully turn on a light emitting diode under extreme deformations including 70% strain and twisting. Our soft batteries could power sensors and displays introduced in the followings.

2.2 Stretchable sensors

We fabricated a stretchable and transparent strain and touch sensor which can cover a back of our hand. For the realization, we developed a stretchable and transparent conducting polymer which can be patterned in a resolution of less than 100 μm. The material is prepared by modifying Poly(2,3-dihydrothieno-1,4-dioxin)-poly(styrenesulfonate) (PEDOT:PSS) by lithium salt which can effectively increase the conductivity and stretchability of PEDOT:PSS. The careful design of chemical structure of a lithium salt enabled a conductivity higher than 100 S/cm and crack-free stretchability of 150%.

Capacitive strain sensors were made of a stretchable dielectric sandwiched by our stretchable conducting polymer layers. Strain increases the size of capacitor electrodes and decreases the thickness of dielectric, resulting in the increase of capacitance. Our highly-sensitive soft strain sensor successfully detected a weak pulse wave signals on a wrist.

Touch sensors are made of row and column lines of stretchable electrodes. Our fingers disrupts the electrical field induced between the electrodes, which can be sensed as touches. Our stretchable and transparent touch sensors successfully detected multitouch even under strain.

2.3 Stretchable displays

The developed transparent and stretchable conducting polymer based on PEDOT:PSS is also useful for the stretchable display. The display is based on an electrochromism,[6] and fabricated by sandwiching a solid electrolyte layer with two sheets of the stretchable PEDOT:PSS (**Fig. 1**). The display showed a clear color contrast at a low voltage of less than 2 V, and a stretchability of 50%. Additionally, the display was able to operate at a frequency higher than 10 Hz. The stretchable display is useful to show information obtained by sensors.

2.4 Wireless communications of intrinsically stretchable electronic devices

Finally, we show a body-area stretchable sensor network (BodyNET) realized by a newly designed radio frequency identification (RFID) for stretchable electronic devices.[7] Unlike conventional stretchable wireless sensor systems, the sensor tag attached to the skin is free from any rigid components including batteries and microprocessors. Our wireless sensor consists of a carbon nanotubes-based strain sensor, and an antenna/capacitor made of an Ag-flakes based stretchable conductors. The sensor showed a robust communication even under a strain of 50%. The soft wireless sensor is conformably attached to the skin and enables wireless readout of weak pulse signals (**Fig. 2**). Furthermore, these sensors were attached to the wrists, the abdomen, and the knees to form a BodyNET. The decrease of pulse rate, and breeze rate was successfully recorded during a deep sleep. Additionally, their increase was observed during sports.

3 Conclusions

The electrical performance of intrinsically stretchable electronic materials has been approaching to that of flexible/rigid electronic materials. As a result, the soft materials have realized wearable devices that obtain high-integrity vital data for long term without interfering our daily lives. Furthermore, their application is not limited to healthcare. They will realize novel types of human-computer interface for VR/AR, and electronic skins for soft robots.

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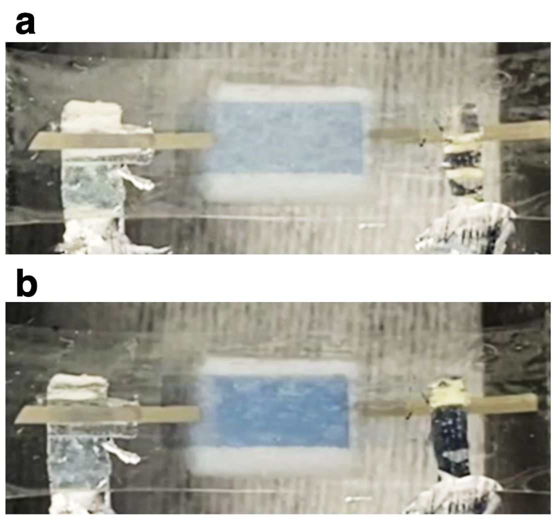

Fig. 1 A stretchable electrochromic display under 50% strain. (a) Turn-off state (0 V), (b) Turn-on state (2 V).

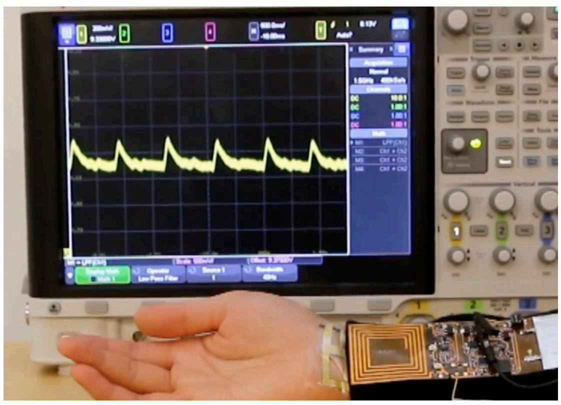

Fig. 2 Monitoring of pulse wave signals on a wrist by a wireless, stretchable sensor system based on a modified RFID.