Conductive fabric responding to extremely small temperature changes

E. Laukhina\textsuperscript{a, b, *}, V. Laukhin\textsuperscript{b, c}, V. Lebedev\textsuperscript{b}, C. Rovira\textsuperscript{a, b}, and J. Veciana\textsuperscript{a, b}

\textsuperscript{a}CIBER de Bioingeniería, Biomateriales y Nanomedicina (CIBER-BBN), Madrid, Spain
\textsuperscript{b}Institut de Ciencia de Materials de Barcelona (ICMAB-CSIC), Campus UAB, Bellaterra, 08193, Spain
\textsuperscript{c}Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain

Abstract

This paper presents a conductive fabric with temperature sensing capability. A polycarbonate film covered with the thin layer of the molecular semiconductor $\alpha'$(BEDT-TTF)$_2$I$_x$Br$_{3-x}$ was used as a sensing component; the resistance of $\alpha'$(BEDT-TTF)$_2$I$_x$Br$_{3-x}$-based layer changes as 250-300 $\Omega$ /cm\(^2\) per degree; BEDT-TTF=bis(ethylenedithio)tetraphiafulvalene. Due to the low mass of the layer of organic molecular semiconductor and its good thermal conductivity, such temperature sensor reacts quickly towards thermal changes. The film was successfully embedded on the surface of a polyester textile obtaining a conductive fabric that responds fast and in a reversible manner to extremely small temperature changes. Such composite textiles can be easily prepared at low cost and they are compatible with printing techniques. This work strongly contributes on the ongoing research of developing smart textiles for their biomedical applications.

Keywords: smart textile, molecular conductors, temperature sensor, organic electronics

1. Introduction

Particularly interesting is the integration of lightweight conductive sensing materials in human wearable interfaces such as fabrics, since wearable electronics could offer personalized healthcare, security and comfort [1-4]. These

* Corresponding author. Tel.: +34-93-5801853; fax: +34 93 580 5729.
E-mail address: laukhina@icmab.es
Fabrics are able to sense and react to environmental conditions. Such textiles have many different uses and are developed to meet modern needs. Textile to behave smartly must have a sensor, an actuator and a controlling unit. Many sensors and actuators have been developed, which are imparted to the fabric during finishing. [1-4] Locher et al. [5] reported hybrid temperature sensing fabric with measurement accuracy of 0.5 degree over a temperature range of 10°C to 60°C; this measurement accuracy was comparable to commercial thermistors. As measured elements they utilized thin copper wires being embedded in a fabric. In context of fabric deformation some doubts are cast upon the involvement of copper wires in textile: the electrical resistance of the wires also responds to any textile deformation.

The goal of this research is to develop the all-organic temperature sensing fabric that permits to achieve a measurement accuracy being significantly higher than commercial thermistors demonstrate. Here we present the all-organic film-like sensor that provides fabric with “nerve system” to detect small temperature changes.

Our approach supports the idea of a combination of organic electronics and clothing. One of the novel approaches to engineering lightweight all-organic sensors is the covering polymeric films with organic BEDT-TTF-based conductors [6]. Recently, we demonstrated that such polycarbonate/molecular conductor bilayer (BL) films showed a high piezo-resistive effect and could be embedded in textile as either strain or pressure sensors [6, 7]. This result prompted us to apply the BEDT-TTF-based conductors to engineering conductive fabric whose resistance will be able to respond to small temperature changes. For this purpose polycarbonate films were covered with a thin layer of the highly temperature sensitive \(^{\alpha'}-(BEDT-TTF)_{2}I_{x}Br_{3-x}\) semiconductor [8].

2. Fabric Design

2.1. All organic temperature sensor with electrical detection principle

As a temperature sensor the polycarbonate/\(^{\alpha'}-(BEDT-TTF)_{2}I_{x}Br_{3-x}\) bilayer (BL) film was fabricated; BEDT-TTF=bi(ethylendithio)tetrathiafulvalene. The sensor fabrication was as follows: first a 25 µm thick polycarbonate (PC) film that contain a 2 wt. % of BEDT-TTF, which is a precursor for various organic molecular metals, was prepared. The film was cast on glass support at 130 °C from a 1,2-dichlorobenzene solution of PC and BEDT-TTF. In order to cover the film with the layer of \(^{\alpha'}-(BEDT-TTF)_{2}I_{x}Br_{3-x}\), we exposed the film surface to the vapors of a dichloromethane solution of IBr. The surface of the film easily swells under this treatment that facilitates migration of BEDT-TTF molecules from the bulk film to its swollen surface where they are oxidized by IBr. This redox process induces the rapid nucleation of the \(^{\alpha'}-(BEDT-TTF)_{2}I_{x}Br_{3-x}\) conductor with a consequent formation of the conductive covering layer. The resulting surface-modified films were fully characterized by Scanning Electron Microscopy (SEM) (Fig. 1) and X-ray diffraction analysis. As Fig. 1 shows, the polycrystalline sensing layer consists of submicro crystallites.

![Fig. 1. SEM image of the conductive temperature sensing layer of \(^{\alpha'}-(BEDT-TTF)_{2}I_{x}Br_{3-x}\) formed at the surface of a polycarbonate film.](image-url)
The powder X-ray diffraction data indicate the presence of only \((00l)\) reflections of the \(\alpha^*-(\text{BEDT-TTF})_2\text{I}_x\text{Br}_{3-x}\) conductor suggesting that the covering layer is dominantly formed from \(c^*\)-oriented \(\alpha^*-(\text{BEDT-TTF})_2\text{I}_x\text{Br}_{3-x}\) crystallites. Direct current resistance measurements reveal that the room temperature sheet resistance of the developed film equals to 25-30 k\(\Omega/\text{cm}^2\) and its conductance demonstrates linear temperature dependence in a wide temperature range with sensitivity \(\pm1\%/\text{degree}\) (Fig. 2) that corresponds to the change of the film sheet resistance as 250-300 \(\Omega/\text{cm}^2\) per degree. Therefore, the developed BL film is capable of controlling very small temperature changes (0.01-0.005 degree) as a well definite electrical signal.

![Fig. 2. Conductance temperature dependence of the all-organic temperature sensing polycarbonate/\(\alpha^*-(\text{BEDT-TTF})_2\text{I}_x\text{Br}_{3-x}\) BL film](image)

2.2. All-organic temperature sensing fabric with electrical detection principle

First of all it should be noted that the small part of textile was especially designed for a sensor location: it was completely embedded in polycarbonate plastic. For this purpose the part of a polyester textile was impregnated with the viscous solution of polycarbonate in \(\text{CH}_2\text{Cl}_2\). The polycarbonate/\(\alpha^*-(\text{BEDT-TTF})_2\text{I}_x\text{Br}_{3-x}\) BL film (20×5 mm\(^2\)) was attached to the swollen surface of this impregnated part. Due to such textile impregnation the BL-based sensor was attached to a rigid part of textile that is not experiencing the strain when textile is deformed. At the final stage electrical contacts were attached with graphite paste to the conductive temperature sensing layer (Fig. 3).

![Fig. 3. Photo image of the developed conductive fabric: (1) highly temperature sensing BL film attached to impregnated textile, (2) graphite electrical contacts connecting with two Pt wires (white filaments).](image)
As illustrated in Fig. 4, the temperature dependence of the electrical resistance of the conductive sensing fabric is quasi linear in the range of the human body temperatures, the temperature coefficient of resistance being \( \pm 1\% / \text{degree} \).

![Graph](image)

**Fig. 4.** Electrical resistance response of the developed conductive fabric to temperature variation in the range 23-50 \( \text{\degree C} \).

3. Conclusions

This result shows that the lightweight all-organic polycarbonate/\( \alpha' \)-(BEDT-TTF)\( _2 \)I\(_x\)Br\(_{3-x} \) BL films, which are biocompatible and have good long-term stability, can be successfully used as the highly temperature sensing components in e-textiles. Such textiles are capable of controlling very small temperature changes with accuracy of 0.005 \( \text{\degree C} \), which is significantly better than that reported for commonly used thermistors; for example, the measurement accuracy of a Pt-1000 detector is 0.01 \( \text{\degree C} \).

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