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Fabrication and evaluation of a conductive polymer coated elastomer contact structure for woven electronic textile

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ABSTRACT

This paper reported a novel innovation of electrical contact structure in flexible device technology. A coating of poly(3,4-ethylenedioxythiophene) poly(4-styrenesulfonate) (PEDOT:PSS) as a solid electrolytic layer deposited on silicone elastomer structure is employed in composing the electrical circuit through a large area of woven electronic textile (e-textile), and functions as the electrical contact between weft and warp (interlaced) fiber ribbons. It was observed that the elastomer structure itself had no major damage after 10^6 cycles load test with a force of 1 N (≈100 MPa). The resistance of PEDOT:PSS coated elastomer structure in contacted with the plain PEDOT:PSS coated polyethylene terephthalate (PET) ribbon with a force of 10 mN was measured at about 300 Ω. These results show a promising durability and electrical transfer ability within the limitations of materials employed for reel-to-reel continuous processes. From the bending experiments using flexible sheet by weaving PET ribbon cables, the structure enhances the flexibility and stability of electrical contact in the woven e-textile better than those of the ribbons without it.

1. Introduction

In recent years, flexible electronic devices have generated a growing interest in various fields of research, not only information technology and communications, but also health science and power generation [1–9]. Among the recent applications for flexible devices are electronic textiles (e-textiles) developed for human life sciences [1,8,10]. Woven e-textiles employ multi-functional fibers for composing electrical circuit by weaving [11–13]. Fig. 1 illustrates the schematically principal components of woven e-textile, i.e., MEMS component, electrical contact structures, conductive fiber including wiring and insulator cables. The interlaced fibers enable the device to function via the physical contact, and in consequence the electrical transfers, from power supply fiber to device integrated fiber. The forms of fibers used in e-textiles can be either string or ribbon.

Most of the e-textile development in the past employs the integration of MEMS component to the finished textile [14] whilst in the reel-to-reel continuous fiber processing, total principal components of desired device can be fabricated directly onto the fibers without needs of assembly. The reel-to-reel continuous fiber processing systems have been established at Macro Bio Electromechanical Autonomous Nano Systems (BEANS) Center, BEANS Laboratory, Tsukuba, Japan since 2008. The system creates the sheet devices using the following processes: die-coating [15], nanoimprinting, inkjetting, annealing and weaving. Each of the process components can be rearranged or repeated with any sequence, apart from the weaving process which has to form the final step.

Electronic circuit on a large area woven textile maintains electric contacts between weft and warp (interlaced fibers) to make the current flow throughout the entire fabric but when the e-textile is deformed, an air gap can occur between the weft and warp, causing a disruption in the flow of the electric current in the area (Fig. 2). Therefore, the contact structure which makes the connection between weft and warp with the distance is required. As we reported in previous study, a micro cantilever array realized on a ribbon cable was employed [16–18]. It was a reliable structure as electrical contact for woven e-textile, however, had a need for intermittent and time-consuming fabrication processes due to the use of multiple thermal imprinting processes. Therefore we proposed a novel conductive polymer coated silicone elastomer as the electrical contact structure [19].

In this paper, new data which is necessary for the electronic applications is added and we also report on the more detailed characteristics of the structure.

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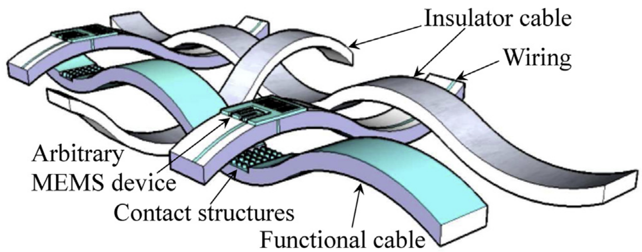

Fig. 1. Schematic diagram of a weaving fiber concept for flexible sheet device applications.

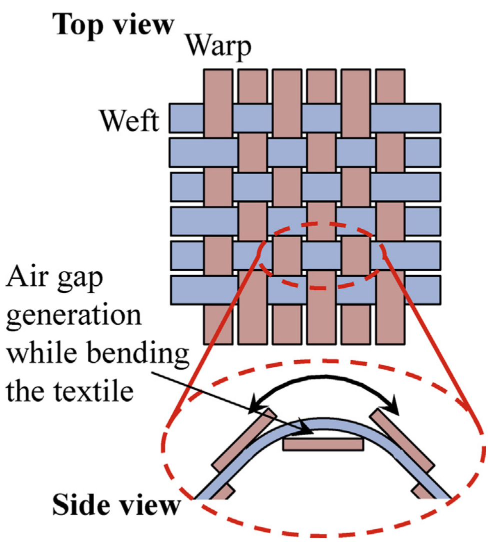

Fig. 2. Schematic diagram of functioning position of contact structures and the generated air gap between weft and warp during the deformation of the e-textile.

2. Fabrication for a conductive polymer coated elastomer structure

In this work, a conductive polymer coated silicone elastomer realized on a polyethylene terephthalate (PET) ribbon cable is employed. The fabrication is started from coating PET ribbon cable with hydrophilic poly(3,4-ethylenedioxythiophene) poly(4-styrenesulfonate) (PEDOT:PSS) (Denatron PT-400MF, Nagase ChemteX Corporation) with the thickness of 1 μm following by hydrophobic PEDOT:PSS (Clevios PH 1000, H.C. Starck GmbH) with the thickness of 1 μm using die-coating method. Both hydrophilic and hydrophobic PEDOT:PSS are thermally cured at 110 °C for 10 min individually. It is noted that the PEDOT:PSS is the conductive polymer material in the liquid form, and hardened by applying heat. The thickness of the coating material is controlled by the feed speed of the fiber. Then a 10 μl drop of silicone emulsion (KM-2002T, Shin-Etsu Chemical Co., Ltd.) is dropped on the hydrophobic PEDOT:PSS coated cable using a micropipette. The droplet takes the form of a hemispherical shape on the cable due to its surface hydrophobicity. The specification of the silicone emulsion used in this work is shown in Table 1. After annealing at 110 °C for 15 min, the hydrophilic and hydrophobic PEDOT:PSS are also coated on the silicone structure using the micropipette, and thermal curing at 110 °C for 10 min individually. It is noted that PET used in this work has the glass transition temperature of about 110 °C. Therefore, low temperature curing at 110 °C is performed in all fabrication processes. Fig. 3 illustrates the schematic diagram of those steps. This structure is fabricated faster than the previous micro cantilever array structure by reel-to-reel continuous fiber processing as shown in Fig. 4 because it can be formed only by die-coating and dispensing techniques. Fig. 5 shows a SEM image of the structure on PET ribbon cable. The height of the structure is about 1.5 mm.

Table 1
Specification of silicone emulsion used in this study.

Specific gravity	1.04
Viscosity (mPa s)	5500

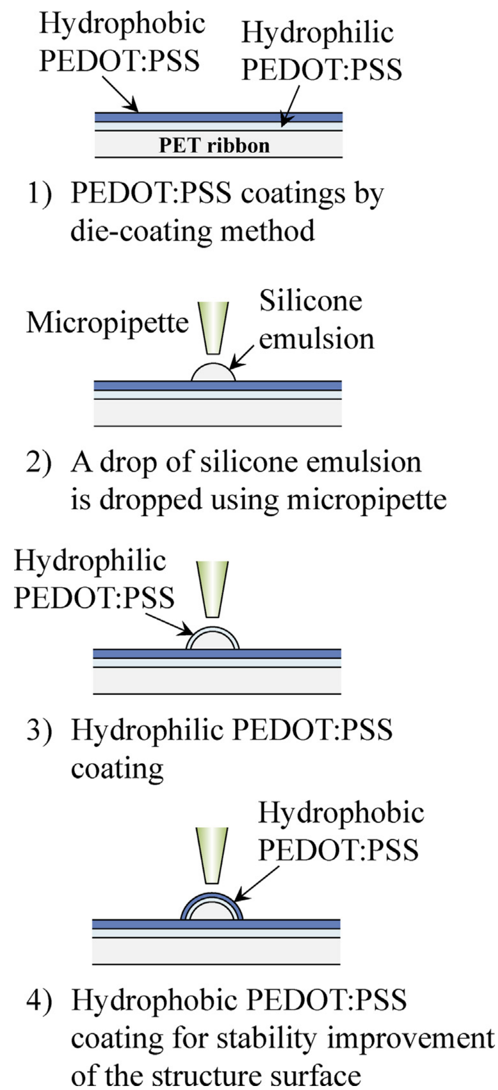

Fig. 3. Process flow for PEDOT:PSS coated silicone elastomer contact structure realized on PET ribbon cable.

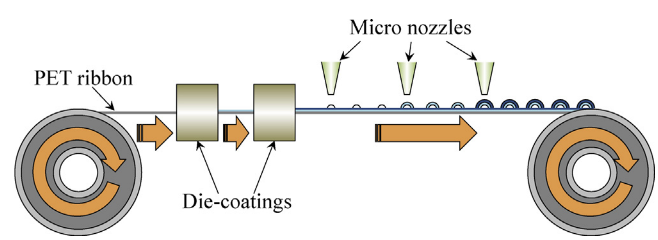

Fig. 4. Schematic diagram of reel-to-reel continuous fiber process and equipment.

3. Mechanical and electrical contact behaviors and characterizations

To confirm the durability for the long-term use as a flexible contact structure, we carried out 10^6 cycles load test in air with a force