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Development of Metal Woven Power Generating Fabric

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ABSTRACT

The rapid pace of developments in science and technology provides consumers with a new and improved lifestyle. Textile is one of the important consumer products; it attracts the field of research not only to enhance its basic functionality but also to be smart. Hence, research in the field of smart textile grabs the attention globally, one such being the integration of micro/ nanoelectronics with textile structures. In this context, the concept of wearable thermoelectric generator (TEG) is found to be interesting as it can generate electricity by making the temperature difference between the human body and ambient air, which has been recognized as the Seebeck effect. The power generated by the TEG is proportional to the temperature gradient between the hot and cold junctions.

In this work, a power generating fabric has been developed for converting the human body heat energy to electric energy. The power generating fabric is fabricated through weaving technique with copper and aluminum wires as weft and cotton yarn as warp. Copper and aluminum wires act as P-type and N-type semiconductor to form a thermoelectric column. It is found that the developed fabric generates voltage up to 2.4 mV for the temperature difference of 50º C. The developed fabric can be integrated into normal clothing and can be used to give power supply to devices like RFID tracker, hearing aid, etc.

Keywords: *electro-textiles, seebeck effect, thermos-electric fabric, weaving, wearable devices*

1. Introduction

The boom in personal electronic devices over recent decades has greatly increased the demand for electric power. Despite the immense reduction in energy consumption, personal electronic devices still face issues of maintaining a sufficient power supply, especially for those devices required to run continuously in a state where loading with a heavy battery or being charged with an alternating current line cord becomes difficult. Examples include implantable electronics for environmental monitoring or medical purposes, wireless monitoring systems for health care or biometric parameter collection, and equipment used by individual soldiers. Powering these devices with secondary batteries restricts their flexibility and ability to work in a remote area, while the frequent recharging of the batteries may cause reliability issues. Selfsustaining, maintenance-free electronic systems are highly desirable but challenging to develop [1].

Wearable renewable energy generators or harvesters are an attractive alternative to battery-based systems and can generate power up to a few watts for portable electronic equipment. However, the power generation using wearable harvesters depends on the type of the source, size, and generator efficiency. The human body is a great source of thermal energy and it is responsible for continuously generating heat through metabolic functions. Approximately 100-525 W of heat is released from the human body, which can be converted to electrical power using proper energy conversion techniques. A wearable thermoelectric power generator is, therefore, a logical fit to harvest power from the thermal energy of the body and use the harvested power to operate portable electrical systems [2].

A thermoelectric generator harvests electric power from the heat flow across a temperature gradient. The thermoelectric effect is that, when the junctions of two dissimilar materials are held at different temperature (ΔT), a voltage (V) is generated that is proportional to ΔT. The thermoelectric generating module is comprised of two types of elements, p-type and n-type semiconductor elements. The mechanism of thermoelectric generation is shown in Figure 1. The heat flow from the hot end to the cold end in a thermoelectric material drives the free charge carriers (electrons or holes) in the material to the cold end, resulting in a voltage proportional to the temperature difference via the Seebeck coefficient. In other words, in an n-type semiconductor element with a temperature gradient, the electrons in the high-temperature region are activated and transferred to the low-temperature region. The transfer of electrons generates a thermal electromotive force, and the high-temperature side reaches a high electrical potential. On the other hand, for a p-type semiconductor element with a temperature gradient, the holes in the high-temperature region are activated and migrate to the low-temperature region. The migration of the holes generates a thermal electromotive force, and the low-temperature side achieves a high potential. By connecting an n-type and a p-type thermoelectric material, a net voltage can be established across the P-N junction. The generating performance of thermoelectric materials is usually expressed by the figure-of-merit (ZT) defined by the following equation:

$$ZT = S^2\,\sigma\,T/\kappa \quad \text{---------} \ (1)$$

where S is the Seebeck coefficient (V/K), which is the thermal electromotive force per 1K temperature difference, σ is the electrical conductivity (1/(Ω cm)), κ is the thermal conductivity (W/(cm K)), and T is the absolute temperature (K). A thermoelectric material with large values of σ and S and a small value of κ has a high value of performance index.

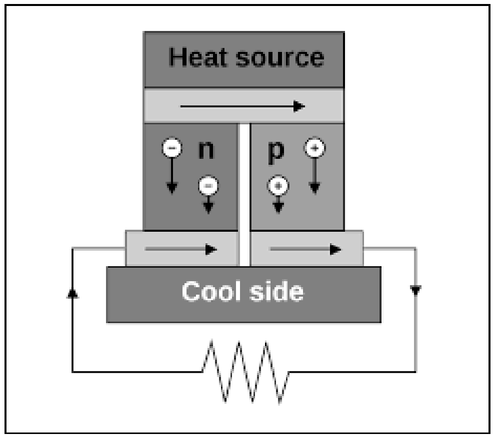

Figure 1. Working mechanism of thermoelectric generator

Several studies have demonstrated wearable TEG devices for human body heat harvesting. Weber et al. used a coiled-up polymer foil TEG for human body applications. The device could generate only 0.8 μW/cm2 power at a temperature difference of 5 K [4]. Jo et al. demonstrated a flexible TEG device with polydimethylsiloxane (PDMS) and poly(methyl methacrylate) (PMMA) mould. The fabricated TEG could generate 2.1 μW power on the human body with a 50 mm × 50 mm device area, which makes the output power only 0.084 nW/cm2 [5]. Lu et al. reported a silk fabric-based flexible TEG device. The maximum power output on the human body was again very small in the range of 15 nW with a 4 cm × 8 cm device area, which makes the output power 0.47 nW/cm2 [6]. Glatz et al. presented a combination of copper and nickel in a thick flexible polymer mould fabricated by photolithography [7]. Most flexible TEGs are not sufficiently flexible to withstand the demands placed on them by human activity. The research described above required the complex fabrication of flexible TEGs. For application forms to the human body, there are watch, buckle and shoe forms. However, the coverage area of these forms is limited compared to the total human body area.

A TEG designed for human use should not interfere with the movement of the wearer. To be comfortable and provide energy harvesting over a wide surface area, it is suitable to use a TEG in the form of clothing that can be worn. At this point, we propose and demonstrate the wearable TEG, made from a combination of fabric and thermocouples. Copper and aluminium wires are used as thermocouples and they are incorporated into the fabric by weaving; this technique is an easy and low-cost process.

2. Materials and Methods

In this work, copper (p-type) and aluminium (n-type) wires were used as a thermocouple. These metal wires sourced from in and around Coimbatore, India. The sourced copper wire had a diameter of 250 microns and the aluminium wire had a diameter of 90 microns. The enamel coating had been given throughout the surface of the wire to prevent a short circuit. The cotton yarn having 30s count was sourced from Coimbatore, India. The power generating fabric was developed on a desk loom.

2.1 Fabrication of Electric Heating Fabric

To develop power-generating fabric copper and aluminium wire were used as weft and the cotton yarn was used as a warp. Because of stable conformation, dense structure, smooth surface, and less shrinkage, the plain weave was selected in this study. In between copper and aluminium wires, 5 cotton picks were inserted. In such a way 40 picks of copper and aluminium wires were inserted into the fabric. The junctions were created at the selvedge side by joining the copper and aluminium on one selvedge side and joining the aluminium and copper on other side. The developed fabric had the size of 12 cm × 12 cm with a GSM of 288 and is shown in Figure 2. The developed fabric had an EPI of 45, a PPI of 40, and a thickness of 0.77 mm.

Figure 2. Image of the developed power generating fabric

2.2 Characterization of Power Generating Property

The core temperature of the human body is about 36 °C, and the ambient temperature is from -10 to 40 °C, depending on the environment. The bottom side of the power generating fabric contacts the human body (Figure 3). The top side is exposed to the outside; there occurs heat exchange with ambient air. The top surface has a relatively low temperature and maintains the temperature difference with the bottom. When the outside temperature is lower, the fabric can get a higher power [8].

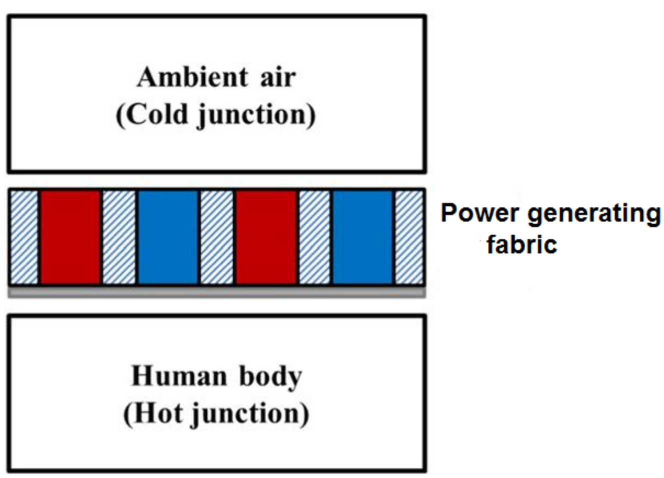

Figure 3. Working concept of the power generating fabric

Figure 4 shows the experimental setup used to study the power generating property of the developed metal woven fabric. The developed metal woven fabric was placed on a heating platform; the other side was exposed to air. To reduce thermal contact resistance, a thin thermal paste was applied to the contact surface between the fabric and the heating platform. The temperature and voltage change were measured by the temperature sensor and the multimeter respectively [9].

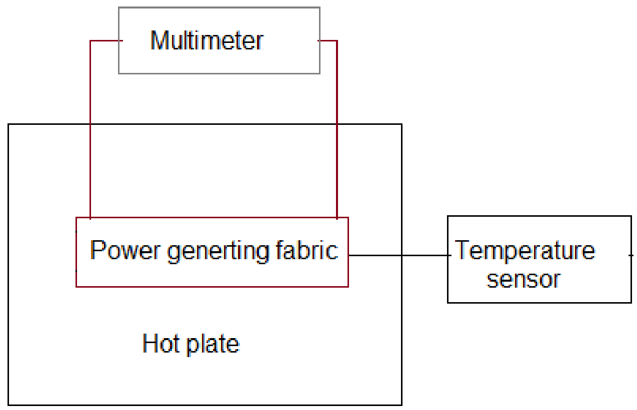

Figure 4. Experimental set up for characterizing power generating property of fabric

3. Results and Discussion

To evaluate the power generating property of the developed fabric, the fabric was placed over a hot plate and the corresponding temperature difference and voltage generated was taken by using a thermometer and a multimeter, respectively. Figure 5 shows the measured output voltage as a function of the temperature difference.

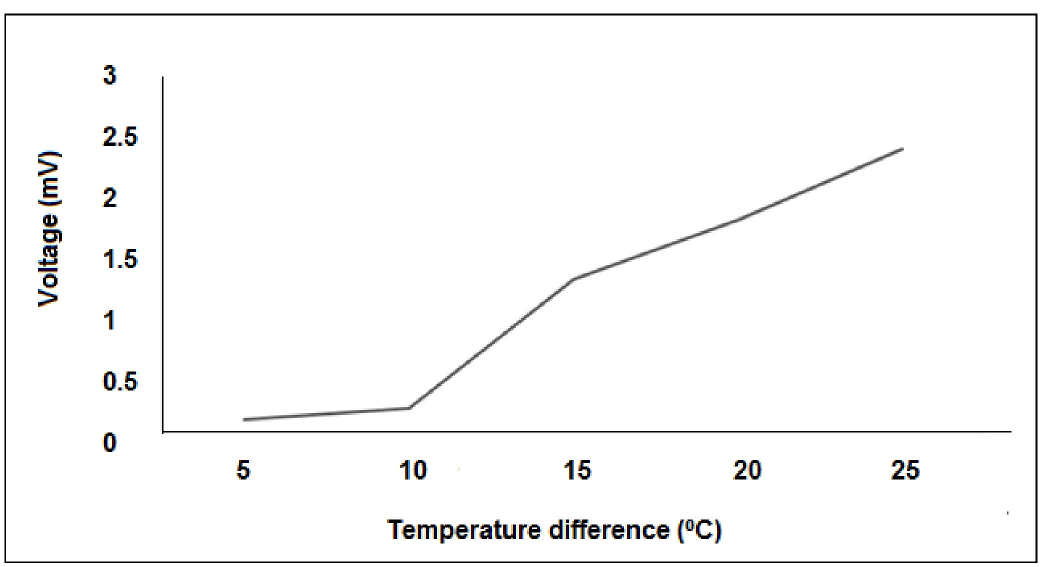

Figure 5. Relation between temperature difference and voltage generation

It was found that a very low voltage was generated up to the temperature difference of 10 ºC. It was observed that there is an increase in voltage generation after the temperature difference of 10 ºC. Thus, the developed power- generating fabric will be effectively generating power when the temperature difference is more than 10 ºC. At the temperature difference of 25ºC, the developed fabric generated a voltage of 2.4 mV and a current of 135 µA. The output power is adequate to give power supply to small electronic devices like hearing aid, RFID tracker, etc.

Conclusion

In this research, we designed and fabricated a power generating fabric by inserting metal wires as weft in weaving for human clothing applications. Copper (p-type) and aluminium (n-type) wires were used as thermocouples and the developed fabric was characterized by using a temperature-controlled hot plate. The developed fabric could generate a voltage of 2.4 mV for a temperature difference of 25 ºC.

The weaving technique used in this work is simple and will be effective for mass production. The proposed power-generating fabric has the feasibility of a wearable device in the form of clothing. The power generating fabric can be applied to clothing for different parts of the body. By simply wearing such clothing to generate electrical energy, it is possible to generate enough energy to use with low-power devices.

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