HUMAN BODY HEAT ENERGY HARVESTING USING FLEXIBLE THERMOELECTRIC GENERATOR FOR AUTONOMOUS MICROSYSTEMS

Sung-Eun Jo[1], Myoung-Soo Kim[1], Min-Ki Kim[1], Hong-Lae Kim[1], and Yong-Jun Kim[1]
[1]*School of Mechanical Engineering, Yonsei University, Republic of Korea*

ABSTRACT

This paper reports on a thermoelectric generator (TEG) used for converting human body heat energy to electrical energy. The proposed TEG was composed of a polydimethylsiloxane (PDMS) substrate and thermocouples. The use of PDMS provides flexibility to the TEG and low thermal conductivity that helps minimize losses in the effective heat flowing through the thermocouples. The proposed TEG was fabricated by simple dispenser printing for thermoelectric materials. The fabricated TEG was attached to the human body and generated electrical power of 50 nW when the temperature difference between the human body and ambient air was 7 ◦C.

KEYWORDS

Thermoelectric generator, Human body heat, Flexible

INTRODUCTION

Energy harvesting gives the possibility to build autonomous microsystems. Especially, energy harvesting would be ideal for implantable microsystems because it can supply the electrical energy without replacement of the battery [1]. Among various energy harvesting methods, thermoelectric energy harvesting on human body has advantages that human body heat is steady and large [2]. However, from the viewpoint of the curvature of the human body, typical TEGs may be not suitable for applying to human body because most typical TEGs are composed of thermocouples on a rigid substrate. On the other hand, flexible TEGs transduce the human body heat efficiently since the flexible TEGs can be tightly attached on the skin [3]. Although several studies have implemented flexible TEGs, the techniques required a complicated and precise photolithography fabrication process [4, 5]. In this paper, a TEG which comprises PDMS and thermoelectric materials is proposed. The proposed harvester was highly flexible through the PDMS structure and was simply fabricated by dispenser printing technology.

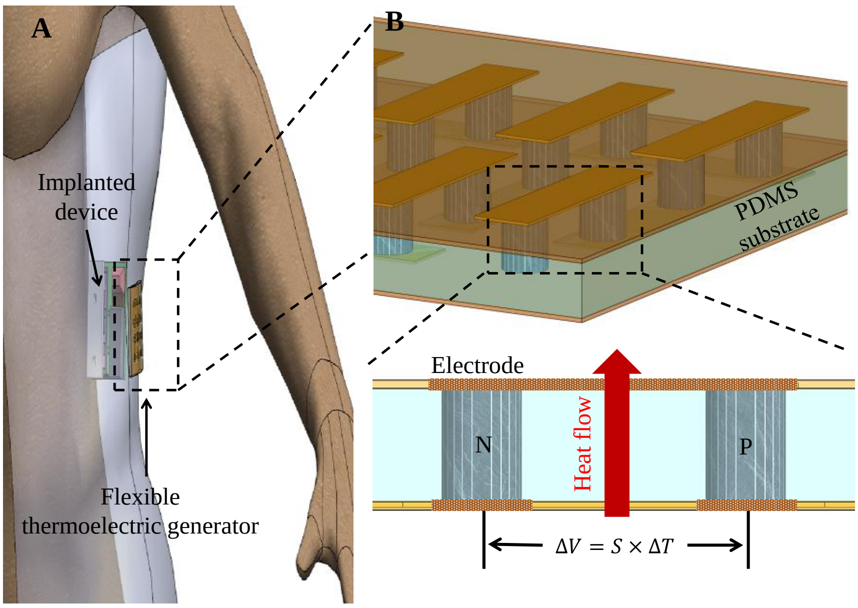

Figure 1: (A)An implanted device and a flexible TEG, (B)Schematic view of the proposed TEG

DESIGN AND FABRICATION

A schematic of the proposed TEG is shown figure 1. This TEG comprises thick PDMS film that includes thermocouples. PDMS is a flexible polymer with a low thermal conductivity. Thus, the use of PDMS reduces thermal losses of effective heat flow that flows through the thermoelectric material. The thermocouples are composed of series connections between N-type and P-type thermoelectric materials. This series connection defines hot and cold junction. The defined hot junction is exposed to higher temperature, and the defined cold junction is exposed to lower temperature. When heat is applied to hot junctions, electrical potential is generated by Seebeck effect. The generated voltage is proportional to the temperature difference between the hot and cold junctions of the thermocouples as follows:

$$\Delta V = n \times S \times \Delta T \qquad (1)$$

where ΔV is the generated voltage (V), n is the number of thermocouples, S is the Seebeck coefficient of the thermoelectric materials (V K^{-1}) and ΔT is the temperature difference between the hot and cold junctions (◦C).

Figure 2A shows the fabrication process of the proposed TEG. A PDMS film with holes was formed on the poly(methyl methacrylate) (PMMA) mold. The PDMS film was released and the holes were filled with the mixtures of Bi_2Te_3 nano-powder and polymer binder by dispenser printing. After curing the thermoelectric materials, flexible printed circuit boards (FPCB) were attached on top and bottom of the TEG for interconnects. The fabricated TEG had 4 hot and cold junctions in a 25 mm × 50 mm area, respectively. The fabricated TEG is shown in figure 2B.

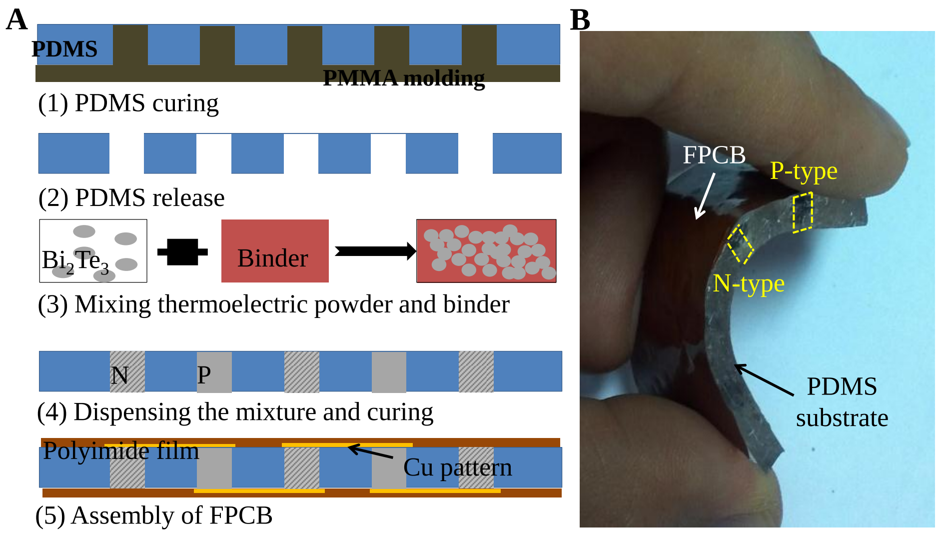

Figure 2. (A)Fabrication process, (B)The fabricated TEG

EXPERIMENT

The fabricated TEG was evaluated by the experimental setup shown figure 3. The experimental setup was composed of a heating unit and cooling unit. A DC power supply unit provided constant and regulated electrical power to the heating unit. In order to measure the temperature difference between the heating unit and cooling unit, thermocouple temperature sensors was attached on the each unit surface. The output signal of the fabricated TEG was measured by an oscilloscope, a microammeter. The electrical characteristic of the TEG was also measured by a RLC meter.

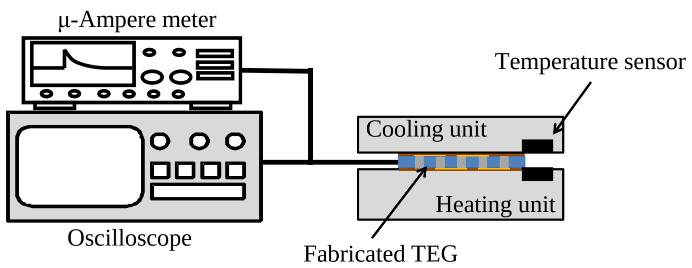

Figure 3. Experimental setup

RESULT AND DISCUSSION

Figure 4 shows the temperature difference as a function of the temperature of the heat source when the ambient temperature was 25 ◦C. It was possible to retain the temperature difference between top and bottom layer (ΔT) when the heat source temperature was close to the human body temperature.

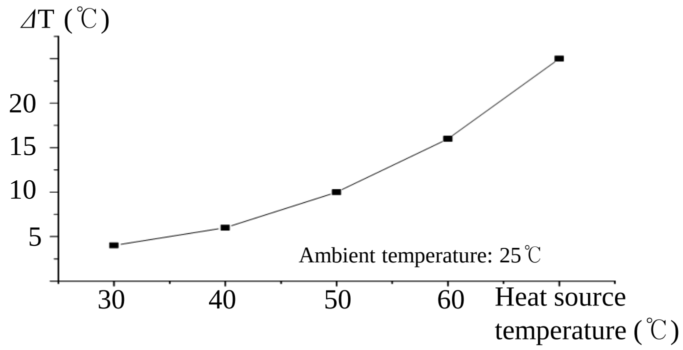

Figure 4. Temperature differences between top and bottom layer of the TEG as a function of the heat source temperature(ΔT)

Fig.5A and 5B show the measured output voltage, current and output power of the TEG as a function of ΔT, respectively. The TEG generated voltage at various temperature ranges with the average output voltage, 10.25 μVK^{-1} per thermocouple. When the temperature difference, ΔT, linearly increased the output power of the TEG increased.

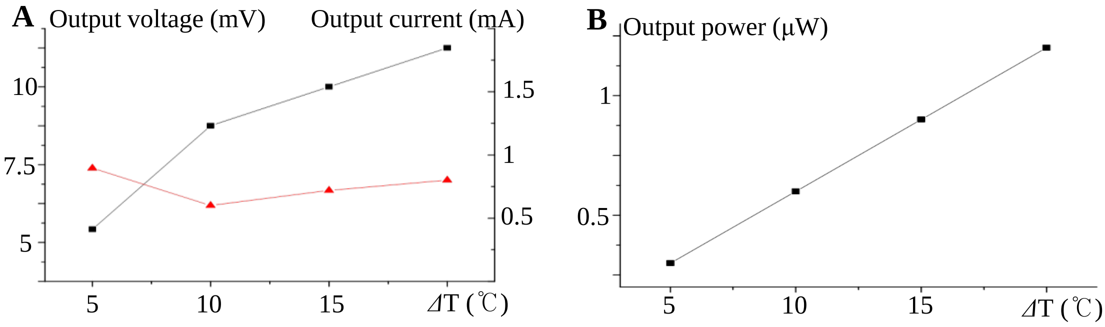

Figure 5. (A)Output voltage and current, (B)Output power as a function of top-bottom temperature difference

The fabricated TEG was finally attached on the human body. The ambient temperature and body temperature were measured by precision temperature sensor. It was confirmed that the skin temperature was constant at 32.5 ◦C although the fabricated TEG was attached on the skin. When the temperature difference between ambient and body was 7 ◦C, the output voltage and current of the attached TEG was 5 mV and 10 μA. The output power was 50 nW and it was very small value, but the TEG generated output voltage continuously with movement of the body.

As stated earlier, the output power of TEG is proportional to the number of thermocouples, Seebeck coefficient and the temperature difference between hot and cold junctions. There are several ways to increase the output power of TEG such as enhancing of Seebeck coefficient of the thermoelectric materials or improvement of the TEG design. First, enhancing of the coefficient is material issue and it is difficult to change the material characteristic. However, the temperature difference and the number of thermocouples are relatively easy to change through improvement of the device design. In the view point of the design improvement, flexibility of TEG has great advantage because the flexible TEG can have large area with many thermocouples. The use of PDMS in this study gave flexibility to TEG and the temperature difference between each junction was large due to its low thermal conductivity. Although, the generated electrical power of the fabricated TEG on the human body was not large, the TEG showed feasibility of converting human body heat to electrical energy.

CONCLUSION

In this study, a flexible TEG was fabricated and evaluated. The proposed TEG was composed of thermocouples and PDMS body. The thermocouples were inserted into the PDMS body by dispenser printing technology. From the experimental result, it was shown that the fabricated TEG could generate electrical power when the temperature difference between each junction was not large. Finally, the fabricated TEG was attached to human body and it showed the feasibility of harvesting human body heat.

ACKNOWLEDGMENTS

This research was supported by the MKE (The Ministry of Knowledge Economy), Korea, under the ITRC (Information Technology Research Center) support program supervised by the IITA (Institute of Information Technology Assessment (NIPA-2011-C1090-1111-0006) and the Priority Research Centers Program through the Ministry of Education, Science and Technology (2009-0093823).

REFERENCES

[1] A. Yadav, et al., "Fiber-based flexible thermoelectric power generator ", Journal of Power Sources, vol. 175, pp. 909-913 (2008)

[2] Y. Qi, M.C. McAlpine, "Nanotechnology-enabled flexible and biocompatible energy harvesting", vol. 3, pp. 1275-1285 (2010)

[3] I. Stark, "Thermal Energy Harvesting with Thermo Life", IEEE BSN Proceedings (2006)

[4] K. Itoigawa, et al., "Fabrication of flexible thermopile generator", journal of micromechanics and microengineering, vol. 15, pp. S233–S238 (2005)

[5] L. Francioso, et al., "Flexible Thermoelectric Generator for Wearable Biometric Sensors", Proc. Conf. on IEEE Sensors, pp. 747-750 (2010)

CONTACT

Yong-Jun Kim, 82-2-2123-2844, yjk@yonsei.ac.kr