Electrical Energy Harvesting from Arm Skin Heat using Flexible Thermoelectric Devices

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Abstract. Flexible thermoelectric devices (F-TEDs) converts arm skin heat energy to electrical energy. The F-TEDs composed a polyimide (PIM) substrate, n-Bi₂Te₃ and p-Sb₂Te₃ thermoelements and Cu electrode. The use of PIM provides flexibility to the F-TEDs and low thermal conductivity that helps minimize losses in the effective heat flowing through the good thermoelements. The thermoelements and electrode of F-TEDs were fabricated by DC magnetron sputtering method and annealed at low temperature to good conduction. The thin F-TEDs place on arm skin heat and generated electrical power 0.073 μW at different temperature between the human body and ambient air about 5 – 7 °C.

1. Introduction
Harvesting energy is very interesting in 21 centuries or artificial intelligence (AI) for help, protection, detection, and wearable electronic devices everything in real and long life such as portable, flexible/stretchable human-interactive sensors, displays, energy devices, thermoelectric devices and remote sensors [1 – 2]. Thermoelectric devices (TEDs) are solid-state energy converters and semiconducting properties allows them to be used to convert waste heat into electricity or electrical power directly into cooling and heating [3 – 4]. The TEDs generated micro-scale energy harvesting modules a maximum energy conversion of 2500 mW cm⁻² [5]. The TEDs of thin films of n-type bismuth (Bi₂Te₃) and p-type antimony (Sb₂Te₃) tellurides are obtained by thermal coevaporation with thermoelectric figures of merit (ZT) at room temperature of 0.84 and 0.50 and power factors of 4.87 × 10⁻³ W m⁻¹ K⁻² and 2.81 × 10⁻³ W m⁻¹ K⁻², respectively. [6]. The wearable devices vibration energy harvesting of TEDs can generated 7.4 W cm⁻³ [7 – 8]. However, the TEDs are difficult to application with human body because them substrate hard or inflexible. The flexible technologies are self-powered wearable health, environmental sensing, body-powered devices [9 – 10] and human body harvesting [11]. So that, the F-TEDs are optimized wearable energy harvesting [12]. The F-TEDs can transduced human body heat efficiently and generated electrical power of 2.10 μW at different temperature between the human body and ambient air of 19 K [13 – 16] and 4.78 mW cm⁻² and 20.8 mW g⁻¹ at ΔT = 25 °C. [17]. However, the bulk TEDs placed on the human body converses body
heat, $T_b = 37 \, ^\circ C$ and ambient air, $T_a = 22 \, ^\circ C$ shown poor quality thermal coupling, leads to a very low temperature gradient at the thermoelectric generator terminals and hence low productivity [18]. Which thin TEDs can generated body heat and ambient air up to $28.5 \, \mu W \, cm^{-2}$ about 30% efficiency [19] and applied wearable electronics sensor provide $20 \, \mu W$ continuously with no air flow [20 – 21]. The $\pi$-type of F-TEGs fabricated from the Bi$_2$Te$_3$-Cu and Bi$_2$Te$_3$-Sb$_2$Te$_3$ devices consisted thermoelements of 24 pairs can generate output electrical power of $1 – 4 \, \mu W \, cm^{-2}$ at human body and ambient air different temperature of $2 – 4 \, ^\circ C$ [22].

In this paper, we proposed the F-TEGs for optimize difficult placed on human body skin by depositing n-Bi$_2$Te$_3$ and p-Sb$_2$Te$_3$ thermoelements on low thermal conductivity of PIM use a DC magnetron sputtering method. The electrical power of F-TEGs can evaluate by placed on arm skin heat and ambient air different temperature of $5 – 7 \, ^\circ C$.

2. Materials and Methods

The mask and electrode of thermoelectric thin film designed size width 25 mm and long 50 mm for 14 cells; 28 legs (Fig. 1(a)) and width 50 mm and long 50 mm for 28 cells; 36 legs (Fig. 1(b)). The n and p thermoelements size are width 1 mm and long 15 mm and the gap of n and p 0.5 mm sputtering on a PIM size of 0.35 mm supporting maximum temperature of 300 $^\circ C$. The thin n-Bi$_2$Te$_3$ and p-Sb$_2$Te$_3$ thermoelements on PIM were deposited by DC magnetron sputtering method (Fig. 1(c)), base pressure $3 \times 10^{-5}$ Torr, Ar flow rate of 30 sccm for 30 min before sputtering process. The thin n-Bi$_2$Te$_3$ thermoelement used pressure $1.70 \times 10^{-2}$ Torr, electrical current 100 mA and electrical voltage 630 V sputtering for 1 min in Ar gas. The thin p-Sb$_2$Te$_3$ thermoelement used pressure $1.70 \times 10^{-2}$ Torr, electrical current 60 mA and electrical voltage 530 V sputtering for 1 min in Ar gas. The thin Cu electrode used pressure $1.70 \times 10^{-2}$ Torr, electrical current 100 mA and electrical voltage 500 V sputtering for 2 min in Ar gas. The thin n-Bi$_2$Te$_3$, p-Sb$_2$Te$_3$ thermoelements and Cu electrode annealed in furnace tube vacuum using pressure $5.00 \times 10^{-2}$ Torr at 200 $^\circ C$ for 20 min in Ar gas to obtain the F-TEGs. The F-TEGs connected with thin Cu size thickness 0.35 mm and Cu wide for measuring electrical voltage output and application by placed on arm skin heat for generate electrical power.

![Figure 1](image-url). Schematic diagram of F-TEDS (a) 14 cells, (b) 28 cells and (c) DC magnetron sputtering system

3. Results and Discussion

The F-TEGs of 14 cells and 28 cells are shown in Fig. 2(a) and Fig 2(b), respectively. These figure showed flexible properties and connected with Cu electrical red wide positive and black wide negative indicate excellent thin TEDs and easy for testing electrical voltage and power outputs.
The relationship between different temperature range $0 - 70 \, ^\circ C$ and open circuit electrical voltage of 14 cells and 28 cells are shown in Fig. 3(a) and Fig. 3(b), respectively. The thermometer, multimeter, heater and F-TEDs are setup for measure electricity, as shown in Fig. 3(c). The open circuit electrical voltage values of both F-TEDs are semilary increased with increasing different temperature which maximum value about 50 mV for 14 cell and 75 mV for 28 cell indicate that voltage of 28 cells more than 14 cells about 1.5 time at different temperature range of $0 - 70 \, ^\circ C$ [9 – 12].

![Figure 3](image)

**Figure 3.** Different temperature dependence on open circuit voltage of F-TEDs (a) 14 cells, (b) 28 cells and (c) setup machine system for measure electrical voltage and power

We designed F-TEDs for application with arm skin heat source and reduced heat by ambient air for make different temperature and measuring voltage out put are shown in Fig. 4(a). We placed F-TEDs and digital voltmeter with arm skin for measuring electrical voltage out put and evaluating electrical power, as shown in Fig. 4(b). Moreover, we measured thermal radiation at arm for checking different temperature by thermal camara, as shown in Fig. 4(c). We found the arm skin heat has maximum temperature $34 \, ^\circ C$ and maximum different temperature $12 \, ^\circ C$ corresponding with Lossec M et al. [18].

![Figure 4](image)

**Figure 4.** Application of F-TEDs (a) diagram placed on arm skin and measuring voltage out put (b) placed on arm skin heat and contact with digital multimeter and (c) measure different temperature radiation at arm skin

The relationship between time and output voltage of F-TEDs on arm skin heat of 14 cells and 28 cells are shown in Fig. 5(a) and Fig. 5(b), respectively. The electrical output voltages are different with Fig. 3(a) and 3(b) because they are different the different temperature about 10 times which the arm skin heat and ambient has different temperature $5 - 7 \, ^\circ C$. 

![Figure 5](image)
The relationship between time and the electrical power of F-TEDs of 28 cells placed on arm skin heat at different temperature about 5 – 7 °C and the electrical load (R) size 1 μΩ, \( P = IV = I^2R \); where \( P \) is electrical power and \( I \) is electrical current, as shown in Fig. 6. However, the arm skin heat has low different temperature with ambient air about 5 – 7 °C which obtain a lowest open circuit electrical voltage about 5 – 10 mV [22].

![Figure 5](image1.png)

**Figure 5.** Time dependence on output voltage of F-TEDs on arm skin heat source and ambient temperature (a) 14 cells and (b) 28 cells

![Figure 6](image2.png)

**Figure 6.** Different temperature dependence on electrical power of F-TEDs placed on arm skin heat

4. Conclusions

We can be fabricated the F-TEDs to generate micro electrical power by placed on arm skin heat and cold ambient air at low different temperature about about 5 – 7 °C. We suggested the optimization of F-TEDs by increasing numbers of cells, different temperature, thermal conductivity of PIM and thermoelectric properties of thin thermoelectric materials for increasing electrical power output.

References

[1] Gao M, Li L and Song Y 2017 *J. Mater. Chem. C* **5** 2971
[2] Dewan A, Suat U. A, Karim M. N and Beyenal H 2014 *J. Power Sources* **245** 129
[3] Lon E. Bell 2008 *Science* **31** 1457
[4] DiSalvo F. J 1999 *Science* **285** 703
[5] Veni Selvan K, Mohamed Ali M. S 2016 *Renew. Sust. Energ. Rev.* **54** (2016) 1035
[6] Paulo Carmo J, Miguel Gonçalves L, and Higino Correia J 2010 *IEEE T. Ind. Electron.* **57** 861
[7] Lossec M, Multon, B and Ben Ahmed H 2013 *Energ. Convers. and Manage.* **68** 260
[8] Wahbah M, Alhawari M, Mohammad B, Saleh H, and Ismail M, 2014 IEEE Journal on Emerging and Elected Topics in Circuits and Systems 4 354
[9] Misra V, Bozkurt A, Calhoun B, Jackson T, S. Jur J, Lach J, Lee B, Muth J, Oralkan O’mer, O’ztu’rk M, Trolier-McKinstry S, Vashae D, Wentzloff D, and Zhu Y 2015 Proc. IEEE vol 3(4) p 665
[10] Leonov V and Vullers R.J.M 2009 J. Electron. Mater. 38 1491
[11] Qi, Y and McAlpine C 2010 Energy Environ. Sci. 3 1275
[12] Bahk J. H, Fang H, Yazawa K, and Shakouria A 2015 J. Mater. Chem. C 3 10362
[13] Stark I 2006 Proc. Int. Work-Shop. on Wearable and Implantable Body Sensor Networks (Boston, MA, USA) p 19
[14] Jo S.E, Kim M.K, Kim M.S and Kim Y.J 2012 Electronics Letters 48 1015
[15] Du Y, Xu J, Paul B, Eklund P 2018 Applied Materials Today 12 366
[16] Kim S. J, Ju Hyung W and Jin Cho B 2014 Energy & Environmental Science 7 1959
[17] Jin Kim S, Eol Lee H, Choi H, Kim Y, Hyung We J, Seon Shin J, Jae Lee K, and Jin Cho B 2016 ACS Nano 10 10851
[18] Lossec M, Multon B, Ben Ahmed H, and Goupil C 2010 Eur. Phys. J. Appl. Phys. 52 11103-p1
[19] Krishna T, Seittaluri, Lo H and RAJEEV J. RAM 2012 J. Electron. Mater. 41 984
[20] Suarez F, Nozariasbmarz A, Vashae D and C. Öztürk M 2016 Energ. Environ. Sci. 6 1853
[21] Qinga S, Rezaniac A, Rosendahl L. A and Gou X 2018 Proc. Materials Today 5 p 10338
[22] Huu Trung N, Van Toan N and Ono T 2017 J. Micromech. and Microeng. 27 125006