Flexible thermoelectric system based on inorganic bulk materials

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Abstract. This paper reports the flexible thermoelectric system based on inorganic bulk materials. Due to its structural design, while the bulk inorganic thermoelectric materials were used, it shows enough flexibility to be adopted on irregular surface such as human skin. To measure the thermoelectric performance, the refrigeration and power harvesting were conducted on human skin. It successfully refrigerate the human skin about 3.3 K power with the portable battery. And the 78-μW power output was achieved with 7.2-mV voltage on human skin.

1. Introduction
Thermoelectric phenomena is the energy conversion between thermal and electric energy and it has been used for waste heat recovery or refrigeration. But due to its structural limitation, its application has restricted to only flat surface so that the researches on flexible thermoelectric devices has been investigated. In case of mainly researched flexible thermoelectric devices, however, those are manufactured based on polymer materials[1, 2] or printed inorganic materials[3] for the flexibility. But due to its fabricated orientation, it is hard to make the temperature difference and shows the lower thermoelectric performance compared to bulk inorganic materials. In this investigation, flexible thermoelectric devices has been manufactured based on bulk inorganic materials which shows high thermoelectric performance with structural design and it shows high flexibility which can enhance its application fields.

2. Experiment

2.1. Material synthesis
Bi-Te based inorganic thermoelectric materials were synthesized at high temperature after sealed into the quartz tube with vacuumed. The melt grown materials were ball-milled for 1 h with 500 rpm. The ball-milled powder were sintered with using SPS (Spark Plasma Sintering) at 723 K for 10 min.

2.2. Device manufacturing
Sintered materials were polished in the shape of 5-mm cubic and electroplated with Ni /Au for the electrical contact. Each polished elements gets then stuck in holder made of Bakelite and holders are connected with commercial wires through holes on holders. And flexible wires are soldered as the electrodes for the flexibility as in Figure 1.
3. Result

3.1. Refrigeration on human skin
The flexible thermoelectric device was applied on human skin for the refrigeration integrated with cool-gel as the heat sink. The portable battery was used as the power source for the refrigeration in which 1.27 A current flew through the thermoelectric device. It successfully refrigerated the human skin about 3.3 K as shown in Figure 2. Since the commercial portable battery was used as the power source, it proposed the possibility for the mobile refrigerator for the human skin.
3.2. Power generation on human skin

The flexible thermoelectric device was also applied on human skin for the power generation. Since the inorganic bulk thermoelectric materials, which showed high thermoelectric performance near room temperature, were used, it produced 78-μW power output with 7.2-mV output voltage as shown in Figure 3. The output power density was about 4.8 μW/cm² which was high enough for the further application.

![Figure 3. Output power with voltage from body heat harvesting](image)

4. Conclusion

In this research, flexible thermoelectric system is manufactured by structural design based on inorganic bulk material which shows high thermoelectric performance and stability. From those characteristics, it is successfully applied on human skin for both energy harvesting and refrigeration for further applications. For the refrigeration, it successfully refrigerated the human skin with 3.3 K temperature drop powered by portable battery. Oriented from its structural design, the size of the thermoelectric device can be further enlarged for the application. For the body heat harvesting on human skin, it produced 78 μW power with 7.2 mV voltage output. Considering the size of the device, the output power density was about 4.8 μW/cm² which is the highest among the application of flexible thermoelectric device on human skin. The structural design proposed in this paper shows the possibility for the usage of the inorganic based thermoelectric device to be enlarged.

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