Flexible thermoelectric devices enable energy harvesting from human skin

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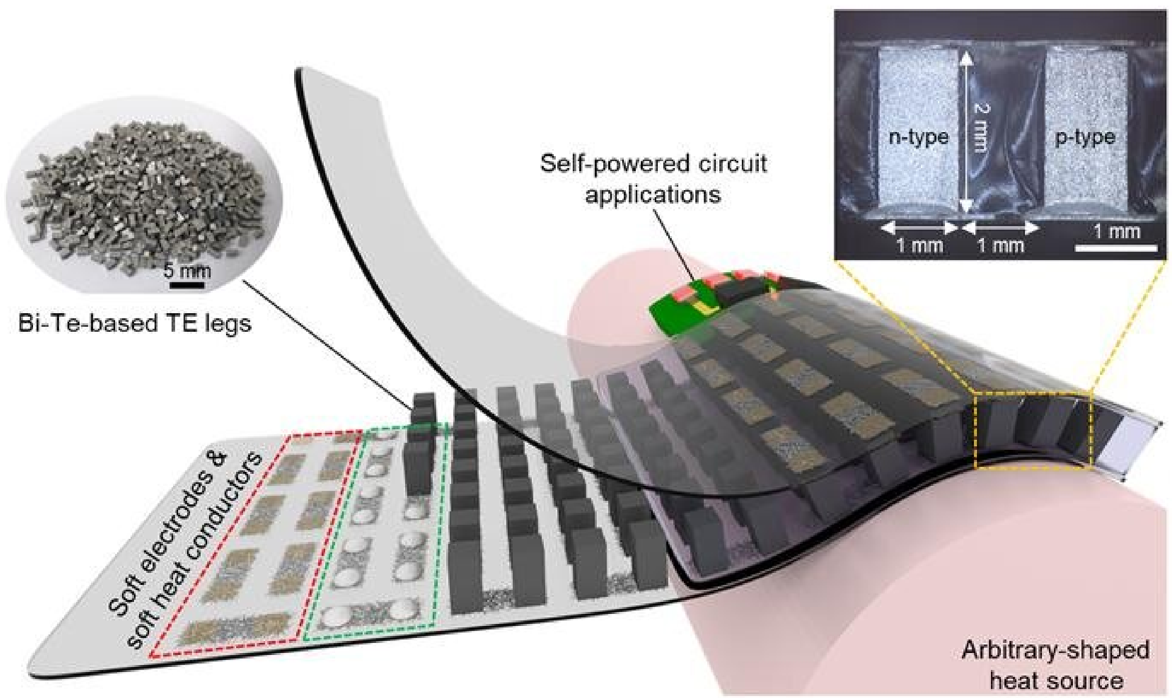

Conceptual illustration of a compliant TEG with soft electrodes and soft heat conductors (s-HCs) for self-powered circuit applications. The left inset is a photograph of bismuth telluride (Bi2Te3)-based thermoelectric (TE) legs and the right inset is an optical image of a cross-section of the compliant TEG. Scale bars, 5 and 1 mm. Credit: Korea Institute of Science and Technology (KIST)

A thermoelectric device is an energy conversion device that uses the voltage generated by the temperature difference between both ends of a material; it is capable of converting heat energy, such as waste heat from industrial sites, into electricity that can be used in daily life. Existing thermoelectric devices are rigid because they are composed of hard metal-based electrodes and semiconductors, hindering the full absorption of heat sources from uneven surfaces. Therefore, researchers have conducted recent studies on the development of flexible thermoelectric devices capable of generating energy in close contact with heat sources such as human skins and hot water pipes.

The Korea Institute of Science and Technology (KIST) announced that a collaborative research team led by Dr. Seungjun Chung from the Soft Hybrid Materials Research Center and Professor Yongtaek Hong from the Department of Electrical and Computer Engineering at Seoul National University (SNU, President OH Se-Jung) developed flexible thermoelectric devices with high power generation performance by maximizing flexibility and heat transfer efficiency. The research team also presented a mass-production plan through an automated process including a printing process.

The heat energy transfer efficiency of existing substrates used for research on flexible thermoelectric devices is low due to their very low thermal conductivity. Their heat absorption efficiency is also low due to lack of flexibility, forming a heat shield layer, e.g., air, when in contact with a heat source. To address this issue, organic-material-based thermoelectric devices with high flexibility have been under development, but their application on wearables is not easy because of its significantly lower performance compared to existing inorganic-material-based rigid thermoelectric devices.

Schematic illustration of hot surface warning gloves with a self-powered LED system and light masking packages.Photographs showing a demonstration of the TEG-attached gloves when they are used to grasp various hot objects such as a bottle and a kettle.The insets show enlarged view of the self-powered system and packages. The conformal contact between the TEG-attached gloves and the 3D surfaces of the heat sources results in a bright "H" sign without any assistance from an external power supply. Scale bars, 5, 5 cm, and 5 mm Credit: Korea Institute of Science and Technology(KIST)

The research team improved the flexibility while lowering the resistance of the thermoelectric device by connecting an inorganic-material-based high-performance thermoelectric device to a stretchable substrate composed of silver nanowires. The developed thermoelectric device showed excellent flexibility, thereby allowing stable operation even when it is bent or stretched. In addition, metal particles with high thermal conductivity were inserted inside the stretchable substrate to increase the heat transfer capacity by 800% (1.4 W/mK) and power generation by a factor higher than three. (When the temperature difference was 40 K or more between both ends of the developed thermoelectric device, 7 mW/cm^2 of electricity was generated. When attached to human skin, 7 $\mu W/cm^2$ of electricity was generated from the body temperature only.) Simultaneously, the researchers automated the entire complex process, from the soft-platform process to the development of the thermoelectric device, thus enabling mass-production of the device.

The developed device can be used as a high-temperature sensor in industrial sites or as a battery-free distance detection sensor for autonomous driving by using the temperature difference inside and outside of a car. Consequently, the device is expected to be able to solve the power-source issue for a battery-based sensor system, which has a risk of explosion in high-temperature environments.

Dr. Seungjun Chung, with KIST, said: "This research showed that it is possible to operate actual wearables such as high-temperature sensor gloves using external heat sources. Going forward, we will develop a flexible thermoelectric platform that can operate wearables with only body temperature. Our research findings are significant in that the functional composite material, thermoelectric device platform, and high-yield automated process developed in this study will be able to contribute to the commercialization of battery-free wearables in the future."

More information: Byeongmoon Lee et al, High-performance compliant thermoelectric generators with magnetically self-assembled soft heat conductors for self-powered wearable electronics, *Nature Communications* (2020). DOI: 10.1038/s41467-020-19756-z

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