DOI 10.5162/EUROSENSORSXXXVI/OT10.125

Harvesting body temperature to power wearable systems using sputtered flexible thermoelectrics

Joshua Curry, Marion Specht, Zhuo Feng, Abiodun Komolafe, Chris Craig, Daniel Hewak, Nick Harris, Ioannis Zeimpekis and Katrina A. Morgan
University of Southampton, Southampton, SO171BJ, United Kingdom

Corresponding Author's e-mail address: **jsc3g14@soton.ac.uk**

Summary:
Across the domain of Internet-of-Things sensors, a key factor which restricts the long-term operation of devices is energy. This restriction becomes especially prominent as the size of devices is decreased and flexibility is needed, for example in body-worn applications. This publication documents the design, optimisation, fabrication and verification of a novel flexible thermoelectric energy harvesting system for powering body-worn sensors. A solution is produced which is able to transmit temperature information at 25 minute intervals by harvesting 13.6 µW of energy from a 25K temperature difference.

Keywords: energy-harvesting, thermoelectrics, sputtering, optimisation, bluetooth

Background and Motivation

Energy harvesting systems for wearable technologies are often engineered to provide energy output during certain activities, for instance when the user is in a lit room or actively doing exercise. Few technologies can sustainably power a system at night or during periods of inactivity.

Thermoelectric energy harvesting devices are a technology which could potentially supplement this power deficit, by providing small amounts of power during inactive periods to allow for the continuous operation of devices, generated from the heat output of the user's body, thus removing the need for overnight charging [1]. Creating these in a flexible and wearable format, however, is challenging, owing to restricted power output caused by the thin film design.

In this work we have created an optimised flexible thermoelectric generator, using the deposition method of sputtering. Sputtering is a large-area and scalable technique that offers high degrees of material tuneability and control, ideal for producing flexible thermoelectric generators (f-TEGs) that offer energy outputs required by applications such as an Internet-of-things (IoT) sensing device [2].

Whilst several sputtered thermoelectric generators are proposed in existing literature [3], few are combined with real-world IoT devices in a system, due to the nanowatts of power produced. This work harnesses the power generated by the optimised flexible thermoelectric generators, and powers Bluetooth system, highlighting thermoelectrics potential for an energy harvesting system for wearable sensors.

Optimised f-TEGs

This work showcases the design, optimisation and manufacture of a novel flexible thermoelectric generator (f-TEG) for wearable applications. Traditional antimony telluride (Sb_2Te_3) and bismuth telluride (Bi_2Te_3) were selected as the p-type and n-type thermoelectric materials, owing to their high thermoelectric performance and allowing demonstration of improvements on current state-of-the-art. They are manufactured by sputtering onto a polyimide substrate, chosen to withstand the heat treatment needed to enhance material properties, whilst maintaining flexibility (see Fig 1b) [4]. Optimisation includes thermoelectric leg length (see Fig 1a), thermoelectric thickness, crystallinity and deposition speed. The aim of this was to achieve a manufacturable thermoelectric generator, with peak performance (see Fig 2).

f-TEGs powering a Bluetooth system

16 f-TEG units are connected in series to produce a maximum voltage which is capable of powering an energy-harvesting sensing device. The electrical energy output is then connected to an e-peas AEM2094 energy-harvesting SoC solution and NRF52 Bluetooth low-energy sensing device which could be utilised to relay data from a temperature sensor to a mobile device for collection and monitoring.

Results

The optimum design has a leg length of 6 mm, an overall area of 13 cm^2, and is 135 µm thick. The output power density for a single optimised generator at a 25K temperature difference is 0.33 µW/cm2.

Connecting 16 of the f-TEGs in series resulted in the voltage and current shown in Figure 3a, when swept through load resistances in a range of 0Ω to 1kΩ. For the test duration, the temperature differential was maintained at 24K (18°C cold-side, 42°C hot-side) and the load resistance was varied. A maximum power output of 38µW was achieved with a 20K temperature difference.

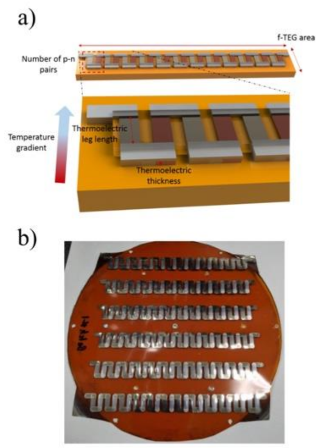

Fig. 1. a) 3D schematic of a f-TEG, with n-type and p-type thermoelectric legs connected electrically in series and thermally in parallel, on a polyimide substrate. b) Photograph of 6 fabricated f-TEGs sputtered in a scalable way.

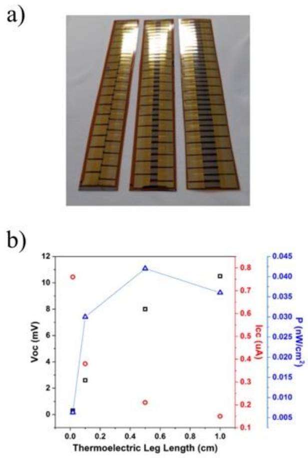

Fig. 2. a) Photo of thermoelectric generators with three different leg lengths (b) Output voltage, current and power density for thermoelectric generators with varying leg length, demonstrating optimised leg length.

When connected to the AEM2094 energy-harvester and Bluetooth device, the arrangement of f-TEGs was successfully utilised to charge a 6600 µF capacitor bank at 13.6 µW, allowing sensor data values to be transmitted once every 25 minutes with a 25 °K difference.

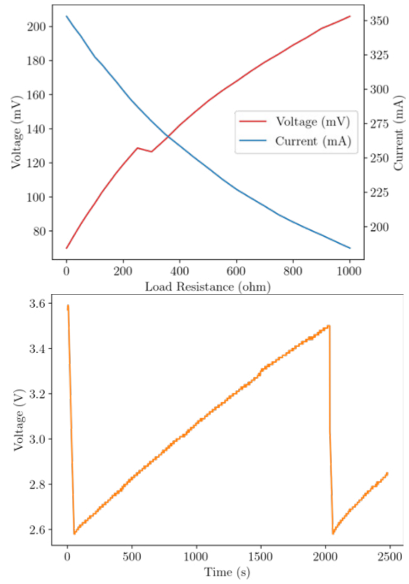

Fig. 3. a) Output of 16 f-TEGs in series at a variety of load resistances at 24K temperature differential b) Capacitor voltage over time demonstrating the harvester charging a capacitor.

Figure 3b shows the voltage held in the capacitor bank over time, with successful charge cycles switching power into the IoT sending device and allowing it to transmit the value of a temperature sensor to a nearby Bluetooth data collector.

This demonstrates this f-TEG systems capability as a chosen energy harvesting technology for body worn sensors, providing continuous power. Next steps are to sew this into a garment to perform body worn tests.

Funding

This work was funded by EU Horizon (825143) “Smart2Go”, EPSRC “Smart Cloth” (EP/X016730/1) and the UKRI Impact Accelerator Account fund.

References

[1] Wen, DL., Deng, HT., Liu, X. et al. Wearable multi-sensing double-chain thermoelectric generator. Microsyst Nanoeng 6, 68 (2020).

[2] Morgan, K.A., Tang, T., Zeimpekis, I. et al. High-throughput physical vapour deposition flexible thermoelectric generators. Sci Rep 9, 4393 (2019).

[3] Kong, D., Zhu, W., Guo, Z., & Deng, Y. High-performance flexible Bi2Te3 films based wearable thermoelectric generator for energy harvesting. Energy, 175, 292–299. (2019).

[4] Morgan, K.A., Zeimpekis, I., Hewak, D. Enhancing thermoelectric properties of bismuth telluride and germanium telluride thin films for wearable energy harvesting, Thin Solid Films Volume 741 (2022).