Engineering Research Center for Wireless Integrated MicroSystems
Associated Grants and Contracts

PROJECT DESCRIPTION

Title: *A Micro Thermoelectric Generator for Microsystems*

Graduate Student: Niloufar Ghafouri (EECS) — *Faculty Advisor: Khalil Najafi (EECS)*
Post Doc: Hanseup S. Kim (EECS) — *Work Began: 06/01/2007*
Research Scientist: Becky L. Peterson (EECS)

Funding Source: DARPA

Project Goals:

The rapid growth in implantable electronic systems has increased the demand for on-site, small volume, and replacement-free energy sources as opposed to conventional batteries. On-site energy scavenging from various environmental sources including ambient heat, solar energy, and vibrations has been introduced as an efficient and promising approach. Thermoelectric generators have advantages in reliability, absence of moving parts, and silent operation. Therefore, despite their high cost and low efficiency, there has been an increased interest in waste heat energy conversion by the fabrication of micro thermoelectric generators (micro-TEG). Power provision is one of the challenging requirements for microsystems on hybrid beetles. This work focuses on the use of body heat generated by beetles as an energy source. The goal of this project is to develop a micro-TEG with the area of approximately 1cm^2 that is capable of generating 20–50μW/cm^2/°C.

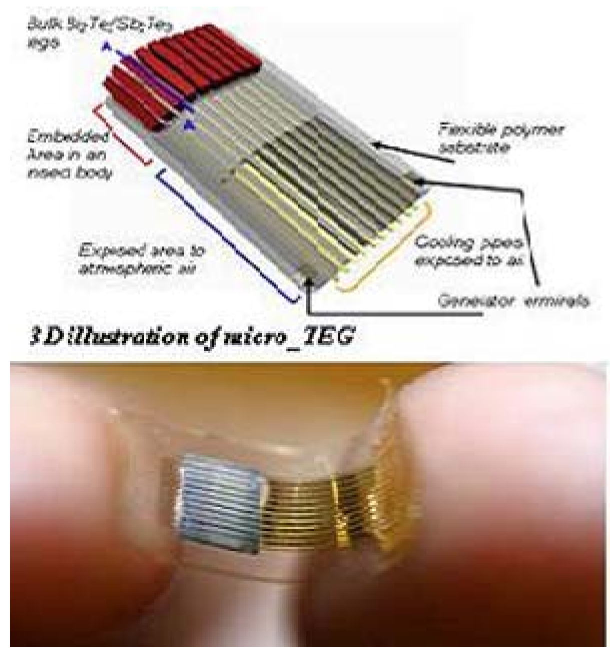

Figure 1: Implantable and flexible micro-TEG.

Approach and Methodology:

Thermoelectric generators utilize the Seebeck effect for the conversion of heat to electrical energy. These generators are made of thermopiles, connected electrically in series and thermally in parallel, placed between hot and cold junctions. Thermoelectric material efficiency is determined by the figure of merit, ZT, which depends on the Seebeck coefficient, electrical resistivity, and thermal conductivity. To achieve the project goal, extensive research and development has been done: 1) to experimentally determine the maximum temperature difference across the beetle body-environment before and during flight, 2) to fabricate, and test thermoelectric generators formed on flexible substrates, 3) to develop implantation guidelines for optimal placement of the device, and 4) to design heat pipes to maintain the temperature difference. Figure 1 illustrates the overall structure of a micro-TEG composed of Bismuth/Antimony Telluride legs and metal lines as thermocouples on a flexible SU-8 substrate. The generator is then encapsulated in a bio-compatible material. The cold side of the generator needs to extrude from the body in the form of heat pipes for maximum output power. The entire device is flexible, so it can be implanted inside the beetle at the pupa state, allowing growth around the device.

Role in Supporting the Strategic Plan and Testbeds:

This project develops the technologies that support any self-powered remote microsystem and sensor network. The design of a thermoelectric generator prototype will be the basis for thermal energy scavenging in many other applications. The technology also supports the thermoelectric cooling of the micro-column for the WIMS μGC testbed.

Results and Accomplishments:

Temperature distribution over a beetle body was measured to locate the potential TEG placement. The maximum body-ambient temperature difference was about 11°C, measured on the back of the beetle close to the wing base. Implantation of dummy chips has been performed inside the beetle during pupa stage to study their developmental stability. The survival rate of the pupas with chips implanted in their back was significantly higher than those with abdominal implantation. The fabricated micro-TEGs were tested by placing an external microheater near the hot junction, while the temperature on the cold side remained approximately constant due to the effect of the heat pipes. The temperature changes on both sides of TE legs were measured with the integrated thermistor. The measured output power density at the maximum temperature difference in beetles, 11°C, was 15μW/cm^2.

Relevance to Other Work:

The proposed research would result in the development of an implantable and miniaturized thermoelectric generator on a flexible substrate which has a number of applications in the biomedical area.

Plans for the Coming Year:

The primary goals for the coming year are to modify the design and fabrication of a thin-film-based thermoelectric generator and also design control and regulator electronics for interfacing micro-TEGs with the rest of the implanted microsystem. Additional plans include developing micro-TEG implantation guidelines and characterizing it in the fully-grown beetle.

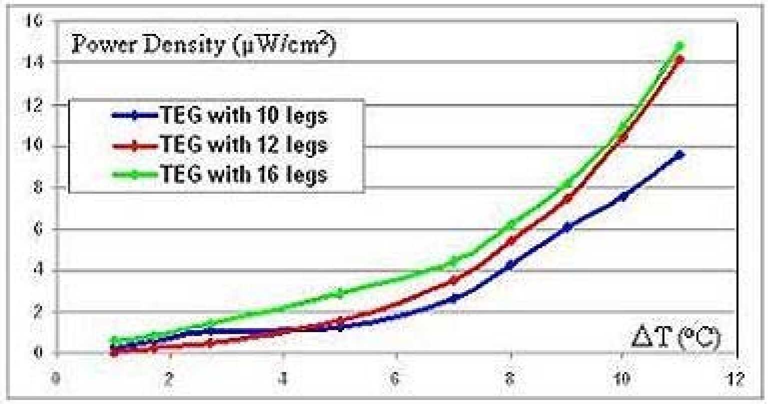

Figure 2: Measured power density vs. temperature difference.

Fabricated Micro-TEG Properties	Implanted area size (mm^2)	Exposed area size (mm^2)	ΔT (° C)	Max # of TE Legs	Max Power Density (μW/cm^2)
	8 (2×4)	24 (6×4)	11	16	15

Expected Milestones and Dates:

- Develop proper fabrication technologies for the thermocouples *(Completed)*
- Fabricate the second generation of micro-TEG prototype based on TE thin film with modified design (01/15/2010)

Expected Contributions, Deliverables, and Company Benefits:

- Develop micro thermoelectric generator for MEMS or IC-based microsystems
- Transfer the work on thermoelectrics to MEMS companies for a variety of applications beyond energy scavenging

References and Recent Publications:

1. N. Ghafouri, H. Kim, M. Atashbar, and K. Najafi, “A Micro Thermoelectric Energy Scavenger for a Hybrid Insect,” *IEEE SENSORS 2008*, pp. 1249–1252, 2008.
2. E. Romero, T. Galchev, E. Aktakka, N. Ghafouri, H. Kim, M. Neuman, K. Najafi, and R. Warrington, “Micro Energy Scavengers,” *COMS 2008,* Puerto Vallarta, MX, September 2008, (Best Paper/Presentation Award).
3. H. Sato, C. W. Berry, B. E. Casey, G. Lavella,Y. Yao, J. M. VandenBrooks, and M. M. Maharbiz, “A Cyborg Beetle: Insect Flight Control Through an Implantable, Tetherless Microsystem,” *MEMS 2008,* pp. 164–167, 2008.