VOL. 10, NO. 9, MAY 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

OPTIMIZATION OF MICRO THERMOELECTRIC GENERATOR AS A SOURCE OF POWER FOR BIO IMPLANTABLE DEVICES

Jeyashree Y., Vimala Juliet A., C. PrantikBarua, J. Sree Harsha, and Abhilash Mallick
Department of Instrumentation and Control Engineering, SRM University, Chennai, India
E-Mail: jeyashree_christley@yahoo.co.in

ABSTRACT

As the lifespan and power stability of the Implantable Biomedical Devices (IMDs) is quite limited, usage of Micro Thermoelectric Generator (µTEG) powered batteries is seen as a suitable potential solution to come over the drawbacks owing to its tiny size, light weight and recharge free attributes. A µTEG employs body energy harvesting techniques to utilize the temperature gradient within a human body and ambience to provide the electrical energy for various IMDs. In this paper, first we have comprehensively studied and discussed about the potential materials suitable for µTEG. Secondly we have investigated and optimized the material properties and design parameters, by studying various designs to obtain efficient power. A poly-SiGe based, 800x800x8000µm µTEG was made to convert the temperature gradient formed between the body heat that is 310 K and ambient temperature of 298 K and by this, the power generated was found to be 1.062×10^{-6} W for a single µTEG. The performance of the µTEG and its biocompatibility to power the IMDs was evaluated and summarized. Thus, it was found that this device can be utilized to power the bio-implants.

Keywords: bio-implantable devices, bridge design, MEMS, micro thermoelectric generator, output power.

INTRODUCTION

Biomedical devices have bridged the medical and engineering practices providing an overall enrichment of health care. It has helped design and build pioneering devices (organs and artificial limbs, new-generation imaging machines, advanced prosthetics and more). Biomedical devices include both living tissue and artificial materials used for implantation. The selection of a suitable material to place in the human body may be the most difficult task faced by biomedical engineers. Certain metal alloys, ceramics and composites have been used as implantable materials. Implanted biomedical devices are the potential drug-dosing approach to the patients who suffer from severe or chronic diseases like heart disease, cancer and diabetes. To supply durable and stable power to implantable biomedical devices (IMDs) is one of the most challenging issues. Biomaterials must also be non-toxic, chemically inert, stable, and functionally strong enough to endure the repeated forces of a lifetime.

The most commonly used batteries in IMDs are Li-ion batteries, which has a lifespan of about 10-15 years [1]. For most cases, these devices have to be replaced owing to the dead batteries inside [2, 3]. Therefore, extracting energy from ambient sources to extend the lifespan of power supply system for IMDs has attracted a lot of attentions of researchers. Extracting power from ambient sources is usually known as energy harvesting. Recently, micro-electromechanical systems (MEMSs) based energy harvesters are expected to be one of the potential solutions to supply electrical power to IMDs, owing to its tiny size, light weight and recharge-free attributes. Extracting energy from human body could be one of the most convenient methods to prolong the lifespan of IMDs. Human body provides a rich source of energy. The ambient temperature gradient within a human body varies from 25°C-37°C.

OPTIMIZATION OF MATERIAL PARAMETERS

Poly Silicon-Germanium (Poly-SiGe) can be chosen as a thermoelectric material due to its comparative advantages, such as lower thermal conductivity and ease of processing, over other materials. Poly-SiGe is chosen to fabricate a surface micro-machined thermopile and eventually a wearable thermoelectric generator (TEG) to be used on a human body. To enable optimal design of advanced thermocouple microstructures, poly-SiGe sample materials prepared by two different techniques, namely low-pressure chemical vapor deposition (LPCVD) with *in situ* doping and rapid thermal chemical vapor deposition (RTCVD) with ion implantation have been illustrated. [4] Relevant material properties, including electrical resistivity, Seebeck coefficient, thermal conductivity and specific contact resistance, was noted. It is more advantageous for sample materials with a comparatively large Seebeck coefficient, such as poly-SiGe. The contact material between the bridges has been chosen as Ti6Al4V**,** also known as grade 5, Ti-6Al-4V or Ti 6-4, mainly because of its biocompatible properties. It is the most commonly used titanium alloy. It has a chemical composition of 6% aluminum, 4% vanadium, 0.25% (maximum) iron, 0.2% (maximum) oxygen, and the remainder titanium. It is significantly stronger than commercially pure titanium while having the same stiffness and thermal properties (excluding thermal conductivity, which is about 60% lower in Grade 5 Ti than in CP Ti). Among its many advantages, it is heat treatable and has an excellent biocompatibility and a high combination of strength, corrosion resistance, weld and fabric ability. [5]

OPTIMIZATION OF THERMO LEG LENGTH AND CROSS-SECTIONAL AREA

The proposed design includes p type Poly Si-Ge and n type Poly Si-Ge as thermo elements and Ti6Al4V as the interconnect material. The design is with vertical heat flow and vertically fabricated thermocouples and it has less contact resistance. The thermo elements are arranged in a bridge like pattern connected thermally in parallel and electrically in series, while the thermo elements are interconnected to each other by Ti6Al4V.

Thus for analysis, Poly Si-Ge is considered as thermo-element. The thickness of Ti6Al4V is considered as 2µm, gap between the thermo elements as 10µm, cross-sectional area of the thermocouple as 6.4x10^5 µm², hot side temperature (T_h) as 310K and cold side temperature (T_c) as 298K.

One of the main requirements in improving the performance of the TEG is the optimum geometry of the generator in which the length and cross sectional area of the generator has high impact on the performance. The thickness also must be optimized such that both the power output and conversion efficiency are maximum.

The following formulas are used to optimize the leg length in accordance to the maximum power that is attained. Seebeck coefficient of p type and n type Poly SiGe is calculated using the formula

$$= \frac{ZK}{} \div^{1/2} \tag{1}$$

The variation of voltage with respect to the length of the thermo leg is calculated using the formula [6].

$$V = \frac{N\alpha(T_h - T_c)}{1 + 2rl_c / l} \tag{2}$$

The variation of current is calculated with respect to the length of thermo leg using the formula

$$I = \frac{A\alpha(T_h - T_c)}{2\rho(n+1)(1 + 2rl_c / l)} \tag{3}$$

The variation of power is calculated with respect to the length of thermo leg using the formula.

$$P = \frac{\alpha^2 AN(T_h - T_c)^2}{2\rho(n+1)(1 + 2rl_c / l)} \tag{4}$$

Where
α = Seebeck coefficient
K =Thermal conductivity
K_c = Thermal conductivity of the contact layer
r = K_c/K
N = No. ofuTEG
A = cross-sectional area
ρ = Electrical resistivity
ρ_c = Electrical resistivity of the contact layer
n = $2\rho_c/\rho$
l = thickness of the leg
l_c = thickness of the contact layer

Table-1. Material properties of thermoelectric materials.

Material	p poly-SiGe	n poly-SiGe	Ti6Al4V
Seebeck coefficient (V/K)	-179	131	NA
Electrical conductivity(S/m)	34482.75		56179
Thermal conductivity(W/m K)	34		6.7
Reference	[7]		[8]

The length is varied along with the cross sectional area to achieve a feasible design. In accordance to the design, the cross sectional area is fixed and the leg length is optimized to attain the maximum power. A plot of length verses the power obtained is shown in Figure-1. A power of 1.062×10^{-6} W was obtained with a single thermopile at an optimum length of 8000µm.

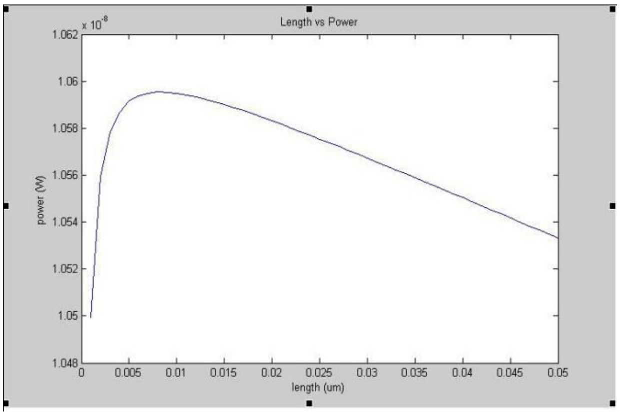

Figure-1. Output Power of a single thermocouple as a function of thermo leg length for the given temperature range.

DESIGN IN COMSOL

Bridge type design (2×2 thermocouple.)

The thermoelectric equations as given in [1, 2, 3, 4] are included in the COMSOL multi-physics. A thermocouple with optimum thickness, length and optimum material parameters has been designed and simulated in COMSOL. The temperature distribution in a 2×2 thermocouple is shown in Figure-2 and voltage distribution in a 2×2 thermocouple is shown in Figure-3. The simulation results show that a 2×2 thermocouple can generate a voltage of 0.002V with hot side temperature of 310K and cold side temperature of 298K.

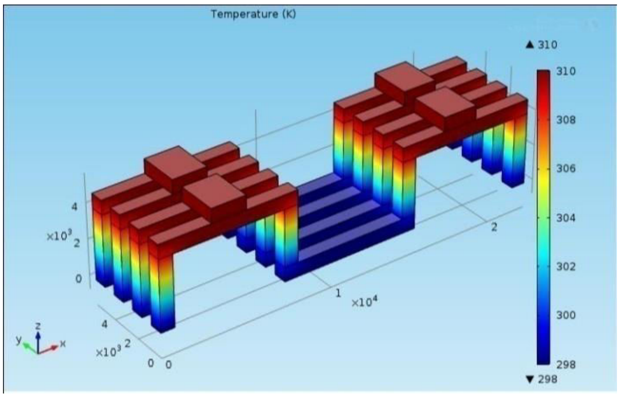

Figure-2. Temperature distribution for a 2×2 thermocouple.

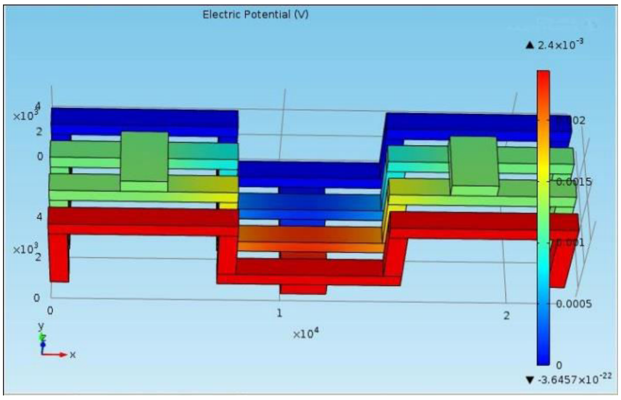

Figure-3. Voltage distribution for a 2×2thermocouple.

Bridge type design (m×n thermocouple)

The bridge type design consisting of more thermocouples connected in series and in parallel has to be designed and simulated in COMSOL. To obtain a power of 100µW, we require 1500 thermocouples in series and 100 in parallel in a similar design to that of the basic matrix.

CONCLUSIONS

The µTEG's biocompatibility was discussed and the potential materials and its parameters to obtain a suitable bridge design were simulated using COMSOL. The temperature and electric potential characteristics were obtained and hence the performance of the µTEG was optimized. With this design, a power of 1.062×10^{-6} W was obtained with a single thermopile at an optimum length of 8000µm. This can be further multiplied using multiple devices to get the appropriate power output of 100µW. The bridged design also provides a better reliability with that of only vertical or horizontal schemes. This design also provides a better Thermal coupling as per its optimized structure [9].

REFERENCES

[1] http://electronics.howstuffworks.com/everyday-tech/lithium-ion-battery2.htm.

[2] Haddad SAP, Houben RPM, Serdijn WA. The evolution of pacemakers. IEEE Eng Med Biol Mag 2006; 25(3):38-48.

[3] Si P, Hu AP, Hsu JW, Chiang M, Wang Y, Malpas S, *et al.* Wireless power supply for implantable biomedical device based on primary input voltage regulation. In: Proc 2nd IEEE conf industrial electron appl; 2007. pp. 235-9.

[4] Characterization and optimization of polycrystalline $Si_{70\%}Ge_{30\%}$ for surface micromachined thermopiles in human body applications. Ziyang Wang, Paolo Fiorini, Vladimir Leonov and Chris Van Hoof.

[5] http://www.aerospacemetals.com/titaniumalloys/titanium-ti-6al-4v-ams-4911/properties.html.

[6] Rowe, D.M, ed., "Thermoelectrics hand book: Macro to Nano", CRC Press, Boca Raton, London/New York (2006).

[7] Characterization of Heavily Doped polysilicon films for CMOS-MEMS Thermoelectric Power generators.-Jin Xie, Hanhua Feng. http://www.aerospacemetals.com/titanium-ti-6al-4v-ams-4911.html.

[8] Human powered MEMS-based energy harvest devices. Chung-Yang Sue, Nan-Chyuan Tsai ⇑ Department of Mechanical Engineering, National Cheng Kung University, Tainan 70101, Taiwan.