ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DESIGN OF ELECTROMAGNETIC MICROSPEAKER POWERED BY HUMAN BODY ENERGY HARVESTING FOR HEARING AID

Mohammed Aslam K. A., John Joseph and Vimala Juliet A.
Department of Electronics and Instrumentation, SRM University, Kattankulathur, India
E-Mail: aslam798@gmail.com

ABSTRACT

This paper presents microelectromechanical-systems (MEMS)-based electromagnetic micro speaker which is powered using micro thermoelectric generator (µTEG) that extracts energy from the human tissue warmth. Electromagnetically actuated micro speaker reduces form factor, power consumption and increase energy efficiency in hearing aid applications. A µTEG uses energy harvesting method to utilize the temperature differences within a human body and ambience to provide the electrical energy for the micro speaker. In this paper a model that includes the micro speaker and micro thermoelectric generator is described with various domain performances. These domains will be coupled where necessary and the model will focus on efficient power and high sound pressure level (SPL).

Keywords: microelectromechanicalsystems (MEMS), microspeaker, ANSYS, hearing aids, thermoelectrics, µTEG, COMSOL.

INTRODUCTION

With the great development of MEMS technology and its widening use, more needs have been put on long-live, small size power MEMS. MEMS can extract electric energy from vibration, thermal gradients and light exposure. The extracted energy can be stored in re-chargeable batteries. However, the extracted power is low and hence by lowering the consumption of electronic device makes it possible to envisage self-sufficiency from the power source.

Low-power consumption and small form factor are two important criteria in the development of hearing aids for long term operation. The speaker component would consume at least a half of total power in hearing aids and the recent researches are mainly focusing on improvement of power efficiency for microspeaker designs. The microspeaker uses the moving-coil driver. The finite-element method (FEM) and equivalent circuit model are utilized to simulate the mechanical and acoustic behaviour of the microspeaker.

People around the world must replace the button cell batteries in their hearing aids. Unfortunately, batteries are a source of environmental waste. Alternative to battery, energy harvesting technologies are increasingly gaining interest. Energy harvesters, those are able to recover small amounts of energy from external sources such as solar power, thermal energy, or human body are suitable for low power portable or wearable devices. Hearing aids are among wearable medical devices which have been modified in recent years and are becoming less energy consuming. Therefore, energy harvesting could be successfully applied to the hearing aids.

In addition to hearing aids, other types of in-ear devices such as electronic hearing protectors and communication ear pieces could also be benefited from energy harvesting technologies.

DESIGN OF THE MICROSPEAKER

Electromagnetic driven actuation design has shown a great potential for the fabrication of low power microspeakers, which can further boost the hearing aid system performance. For the low power application in hearing aids, the speaker should be designed with a large acoustic membrane deflection which is crucial for producing a high sound pressure level (SPL) in an ear canal. In this paper polydimethylsiloxane (PDMS) membrane is used. Since the PDMS has lower elastic modulus, i.e. 6.3MPa, good for having a higher sound pressure output and the PDMS has superior material characteristics like hydrophilic to water, chemical inert and it has been widely used for MEMS fabrication, using the PDMS as acoustic membrane.

The device consists of a micromachined membrane in a silicon wafer with an electroplated coil bonded to a back plate with a small magnet. The Cu barrier layer can strengthen the micromachined silicon substrate for enduring the possible damage from fabrication process. Electromagnetic actuation is chosen in this design because of its large driving force over a large air gap and a low driving voltage. When the current flows through the coil, a force is generated this actuates the membrane to move and radiates sound. The driving force in the current-carrying coil is determined by Lorentz force, and the force can be derived as,

$$F = I\,\vec{l} \times B$$

The dimension of the microspeaker and ear cavity is small compared to the wavelength of the sound; the sound pressure is normally distributed uniformly in the volume. The pressure change is proportional to the volume displacement of the diaphragm, and is expressed by

$$dP = \frac{1.4P_0}{V_0} dV$$

The generated sound pressure level (SPL) is defined as

$$\text{SPL} = 20log_{10}\frac{dP}{P_{ref}}(dB)$$

Where P_{ref} is 20µPa.

VOL. 11, NO. 3, FEBRUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-1. Dimensions for the microspeaker model.

Material	PDMS	NiFe soft magnet	NdFeB hard magnet	Cu coil	Si substrate	Acrylic board	Cu barrier
Membrane diameter	3.5mm	260 µm	160 Mm	380 µm	-	-	-
Membrane thickness	3.3µm	7µm	2mm	1.2 µm	0.6 µm	15 µm	0.09 µm

MECHANICAL MODEL

The vibration of the diaphragm of the microspeaker behaves like a second order system and is described by

$$F = M\frac{d^2w}{dt^2} + R\frac{dw}{dt} + \frac{w}{c}$$

Where M is the total mass including the coil, the diaphragm and air load and c is the compliance of the suspension system. A mechanical model of electromagnetic microspeaker is developed in ANSYS by using the following dimensions given in the below table and model developed is shown in Figure-1.

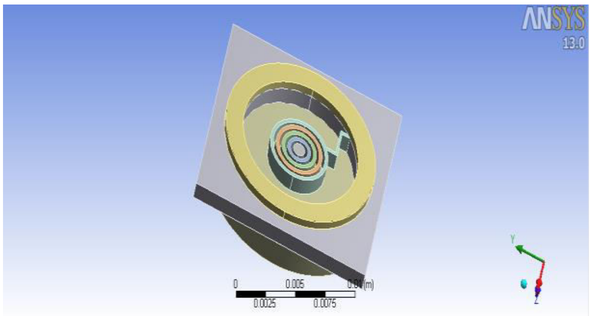

Figure-1. Model of electromagnetic microspeaker in ANSYS.

MICRO THERMOELECTRIC GENERATOR

Micro TEGs are scalable, reliable and do not require any moving parts like vibration energy transducers. As a consequence, it is very attractive in micro scale energy harvesting systems, such as human body powered biomedical devices. Micro TEGs usually consists of multiple couples of p-type and n-type thermoelectric legs, which can output electrical energy by employing the temperature differences between the hot surface(e.g. human body) and the cold surface (e.g. ambient). These thermocouples are connected usually electrically in series and thermally in parallel to effectively make use of the restricted surface area. When there is a temperature across a µTEG, Seebeck effect causes the moving of charged carriers to generate a terminal voltage. Figure-2 illustrates the operation mechanism of µTEG. The top layer of the µTEG is attached to a heat surface, while the bottom layer is placed near a cool surface. Due to the temperature difference, the electrons (or holes) in the N-type (or P-type) material flow towards the cool surface and forms a current.

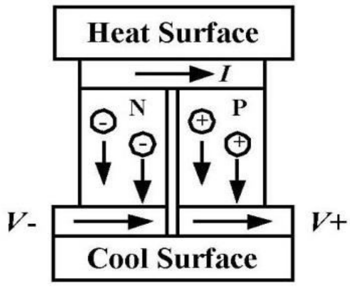

Figure-2. Illustration of operation mechanism of a µTEG.

In (Egbert, 2007), the figure of merit (FOM) of a µTEG is defined as

$$Z = \frac{\alpha^2}{K\rho}$$

Here α is the Seebeck coefficient that is material dependent, K is the Thermal Conductivity, and ρ is the electrical resistivity. Improving the FOM from a device or Material perspective is one area of active research in thermoelectric community

DESIGN OF MICRO THERMOELECTRIC GENERATOR

The human body is rich source of energy. The ambient temperature gradient within a human body varies from 25˚C - 37˚C.

The proposed design includes p type Bismuth telluride (Bi_2Te_3) and n type Bismuth telluride (Bi_2Te_3) as the thermo elements and Ti6Al4V as the interconnect material. Bismuth telluride is chosen as thermoelectric material because it is one of the best performing room temperature thermoelectric with a temperature-independent thermoelectric effect, ZT, between 0.8 and 1.0. Bi_2Te_3 is chosen to fabricate a surface micro-machined thermopile and eventually a wearable micro thermoelectric generator (µTEG) to be used on a human body. The contact material between the thermocouple bridges is chosen as Ti6Al4V mainly because of its excellent biocompatible properties. Among its many advantages, it is corrosion resistance, heat treatable and a high combination of strength.

The following formulas are used to leg length in order to maximize the power that is obtained.

The variation in voltage with respect to the length of thermo leg using the formula:

$$V = \frac{N\alpha(T_H - T_C)}{1 + \frac{2rl_c}{l}}$$

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

$$I = \frac{A\alpha(T_H - T_C)}{2\rho(n+1)(1+\frac{2rl_c}{l})}$$

The variation in power with respect to the length of thermo leg using the formula

$$P = \frac{\alpha^2 AN(T_H - T_C)^2}{2\rho(n+1)(1+\frac{2rl_c}{l})}$$

Where
α = Seebeck coefficient
K =Thermal conductivity
Kc = Thermal conductivity of the contact layer
r = Kc/K
N = No. of uTEG
A = cross-sectional area
ρ= Electrical resistivity
ρ_c = Electrical resistivity of the contact layer
n = $2\rho_c/\rho$
l = thickness of the thermo leg
l_c = thickness of the Ti6Al4V contact layer

DESIGN USING COMSOL

Bridge type design (2×2 thermocouple)

The thermoelectric equations as given in are included in the COMSOL multi-physics. A thermocouple with optimum length, thickness and material parameters are designed and simulated in COMSOL. Figure-3 shows the Bridge type design of a 2×2 μTEG. A single 2×2 thermocouple can generate a voltage of 0.002V with a cold side temperature of 298K and hot side temperature of 310K.

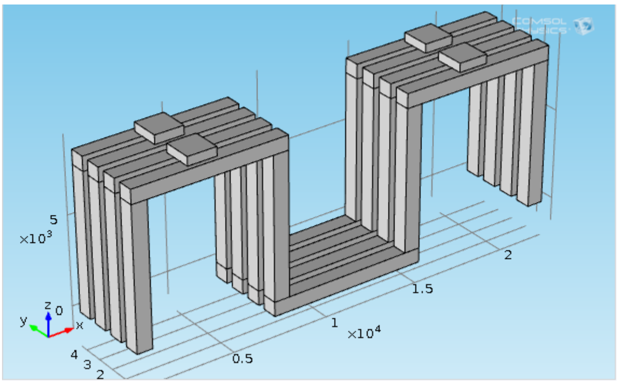

Figure-3. Bridge design of 2×2 μTEG.

CONCLUSIONS

This paper has provided a design and model of an electromagnetic microspeaker powered using a micro thermoelectric generator (μTEG). Obliviously, one TEG is not sufficient, so we need an array of them in order to reach the necessary amount of voltage and current. It is not convenient to feed directly the hearing aids but it is necessary to pass through a conditioning circuit, regulator and batteries for backup.

REFERENCES

[1] Y. C. Chen, and Y. T. Cheng. 2011. A Low-Power milliwatt Electromagnetic Microspeaker using a PDMS membrane for hearing aids application. Microsystems Integration Laboratory, Department of Electronics Engineering & Institute of Electronics, National Chiao Tung University, Taiwan, MEMS 2011, Cancun, Mexico, January 23-27..

[2] Ming-Cheng Cheng, Wen-Sheh Huang and Star Ruey-Shing Huang. 2004. A silicon microspeaker for hearing Instruments. MEMOS Lab National Tsing-Hua University, Taiwan, pp. 859–866.

[3] Chao Lu, Vijay Raghunathan and Kaushik Roy. Micro-Scale Energy Harvesting. Department of Electrical and Computer Engineering, Purdue University, USA.

[4] Jeyashree Y., Vimala Juliet A., C. PrantikBarua, J. Sree Harsha and Abhilash Mallick. 2015. Optimization of Micro Thermoelectric Generator as a source of Power for bio implantable device. ARPN Journal of Engineering and Applied Sciences, vol. 10, no. 9, May.

[5] https://en.wikipedia.org/wiki/Thermoelectric_materials.

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

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

[8] MichaelJ.D. Hedges and Yiu Lam. Accuracy of Fully Coupled Loudspeaker Simulation Using COMSOL.

[9] Monitor Audio Ltd, Salford University COMSOL Conference 2009 Milan.

[10] Y. Jeyashree, Pheba Cherian and A.Vimala Juliet. 2013. Micro Thermoelectric Generator - A source of Clean Energy. International Conference on Microelectronics, Communication and Renewable Energy (ICMiCR-2013).