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Micro Thermoelectric Harvesting Device for Electromagnetic Micro Speaker in Hearing Aid Application

Mohammed Aslam K. A.[*], John Joseph[**] and Vimala Juliet A.[***]

Abstract: This paper presents a energy harvesting using micro scale thermoelectric generator is a promising approach to supply power in ultra low power devices. Here a microelectromechanical systems (MEMS) based thermoelectric generator is used to power up an electromagnetic micro speaker in Hearing aid applications. Electromagnetically actuated micro speaker reduces form factor, power consumption and increases energy efficiency in hearing aid applications. Thermoelectric generator uses a Seebeck principle which utilizes the temperature gradient between the human body (310K) and ambient temperature (298k). For electromagnetic micro speakers, low driving voltage is a unique characteristic. A low power electromagnetic micro speaker with a PDMS membrane for hearing aid is modeled. 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 less vibration for the micro speaker, which results in better hearing and safe for the hearing aid. The modeling and analysis is done using ANSYS and COMSOL Multiphysics.

Index Terms: Microelectromechanical systems (MEMS), micro speaker, Thermoelectrics, μTEG, ANSYS, COMSOL, hearing aids.

1. INTRODUCTION

Hearing loss is major public health issues that is the third most common physical condition after arthritis and heart disease. It is estimated that around 360 million people worldwide have disabling hearing loss. People with hearing loss can benefit from hearing aids and other assistive devices. Current production of hearing aid meets less 10 percent of global need.

However, using the MEMS technology to fabricate micro speaker and micro thermoelectric generator for hearing device is challenging because of certain critical requirements such as small size, low driving voltage, high output sound pressure level, low energy consumption. MEMS can extract energy from thermal gradients, vibration and light exposure. The extracted can be stored in rechargeable batteries or storage capacitors.

People around the world must replace the button cell batteries in hearing aids devices. 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 amount of energy from external sources such as solar energy, thermal energy, or human body which are suitable for low power portable or eventually a wearable devices. Hearing aids are among wearable medical devices which have been modified in recent years and are becoming very less energy consuming. Therefore, energy harvesting could be successfully applied to the hearing aids.

This paper represents a microelectromechanical systems (MEMS) based electromagnetic speaker which provides power supply using a micro thermoelectric generator (μTEG) that extracts energy from the human tissue warmth. Electromagnetic micro speaker reduces the form factor, power consumption and increase

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energy efficiency in hearing aid devices. A μTEG uses energy harvesting technique to make use of the temperature differences within the human body and ambience to give electrical energy for the micro speaker.

Small form factor and low power consumption are important criteria for developing hearing aids. Currently researches on hearing aid are mainly focusing on the improvement of power efficiency for micro speaker [1].

2. DESIGN OF THE MICROSPEAKER

For the low power applications in hearing aids, the micro speaker should be designed with a large acoustic membrane deflection which is important for producing a high sound pressure level (SPL) in an ear canal [1]. Electromagnetic actuation design shows a great potential for the fabrication of low power micro speakers, which can further boost the hearing aid system performance. This paper presents a technique to reduce the form factor and cost in hearing aids, using energy efficient MEMS technology. The speaker has a thin diaphragm on a silicon substrate actuated by the Lorentz force [2]. The actuation mechanism and diaphragm deflection are modeled and simulated using CATIA and ANSYS. In this paper polydimethylsiloxane (PDMS) membrane is used. Since the PDMS has lower elastic modulus, i.e. 6.3 MPa, good for having a higher sound pressure output and the PDMS has superior material characteristics like hydrophilic to water, and it has been widely used for MEMS fabrication [1]. Different actuation mechanisms have been developed for microspeaker applications which include piezoelectric, electrostatic, and electromagnetic actuation. Piezoelectric and electrostatic mechanisms are less attractive for hearing-aid applications because of their low conversion factor and the use of high voltage. EM actuation is more efficient mechanism and generates high sound pressure for hearing aids.

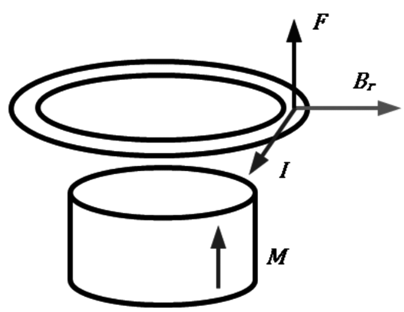

Figure 1: Electromagnetic actuated mechanism

Figure 1 shows the principle of electromagnetic actuated mechanism and electromagnetic micro speaker is modeled. The micro speaker consists of a micromachined membrane in a silicon wafer with an electroplated coil bonded to a back plate with a small magnet[8]. The Cu barrier layer can strengthen the micromachined silicon substrate for enduring the possible damage from fabrication process. 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: [2]

$$F = I\,l \times B \tag{1}$$

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

$$dp = \frac{1.4\,P_0}{V_0}\,d \tag{2}$$

Where P_0 is the pressure of the atmosphere and V_0 is the volume of ear cavity. The generated sound pressure level (SPL) is defined as:[1]

Table 1
Dimensions for the micro speaker model

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

$$\mathrm{SPL} = 20 \log_{10} \frac{d_{\mathrm{P}}}{\mathrm{P_{ref}}} \,(\mathrm{dB}) \qquad (3)$$

Where Pref is 20 μPa.

A. Mechanical Model

The vibration of the diaphragm of the microspeaker behaves like a second order system and is described by: [1]

$$\mathrm{F} = \mathrm{M}\frac{d^2 w}{dt^2} + \mathrm{R}\frac{dw}{dt} + \frac{w}{c} \qquad (4)$$

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 micro speaker is developed in ANSYS by using the following dimensions given in the above table and model developed is shown in Figure 2.

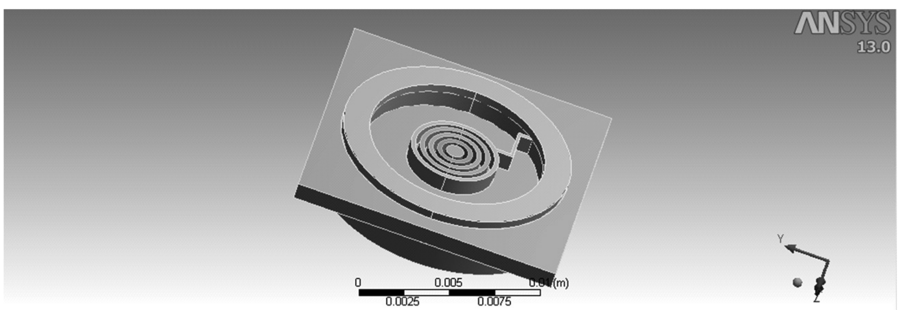

Figure 2: Model of electromagnetic micro speaker in ANSYS

B. Magnetic Field Analysis

To maximize and provide a uniform distributed driving force on coil, both soft magnet and permanent magnet were integrated into this device to induce magnetic flux to be perpendicular to the current carrying coil [2]. The high permeability produced by the soft magnet forms a low reluctance path and thus focusing the magnetic flux through the air gap. The cross section area of the soft magnet was designed to be large enough to avoid the saturation of flux density.

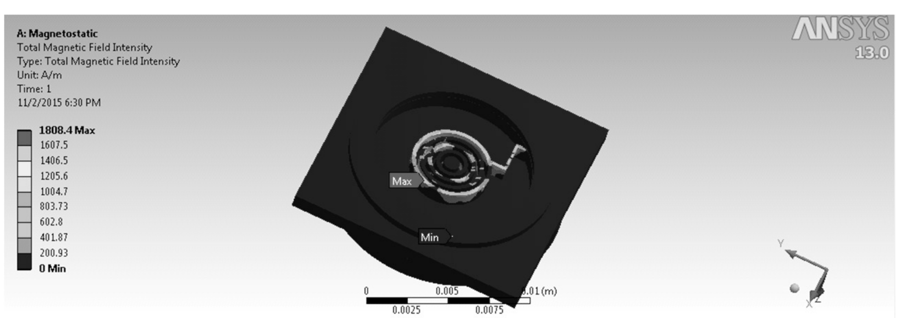

Figure 3: Simulation result of magnetic field intensity

C. Load-deflection of the Diaphragm

For better efficiency and frequency response the mass of the moving part of the micro speaker should be minimized [2]. Here, only a thin flexible membrane with one coil forms the sound generation plate and the heavy magnet were placed on the other side of the device. Figure 4 shows the typical deformed shape of the micro speaker which is modeled using the dimensions given in the Table 1 simulated by Ansys simulator.

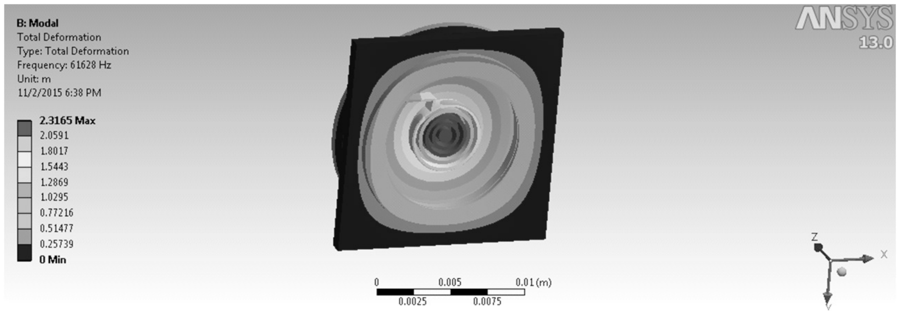

Figure 4: Simulation of total deformation of the micro speaker

3. MICRO THERMOELECTRIC GENERATOR

A micro thermoelectric generator (TEG) is reliable, scalable and does not require any moving parts like vibration energy transducers. As a result, 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 give 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 moving of charged carriers to generate a terminal voltage. Figure 3 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 from hot surface and forms a current. Here the top layer of the μTEG is attached to a hot 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. [3]

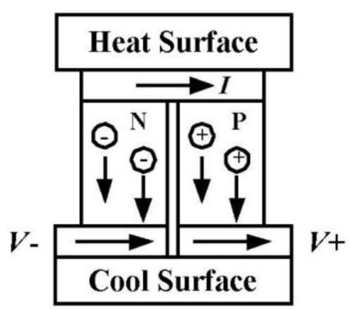

Figure 5: Illustration of operation mechanism of a μTEG

In [Egbert 2007], the figure of merit (FOM) of μTEG is defined as:

$$Z = \frac{\alpha^2}{K\rho} \tag{5}$$

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.

4. DESIGN OF THERMOELECTRIC GENERATOR

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

The proposed design includes n type Bismuth telluride (and *p* type Antimony telluride as the thermo elements and Ti6Al4V as the interconnect material. Both Bismuth telluride and Antimony telluride shows better FOM at room temperature, hence these materials are selected for modeling. [5]

Bismuth telluride is chosen as thermoelectric material because it is one of the best performing room temperature thermoelectric with a temperature-independent thermoelectric effect, FOM between 0.8 and 1.0. Hence Bismuth and Antimony telluride are 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. [6]

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 [7]:

$$V = \frac{N\alpha(T_H - T_C)}{1 + \frac{2rl_c}{l}} \tag{6}$$

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

$$I = \frac{A\alpha(T_H - T_C)}{2\rho(n+1)\left(1 + \frac{2rl_c}{l}\right)} \tag{7}$$

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

$$P = \frac{\alpha^2 AN(T_H - T_C)^2}{2\rho(n+1)\left(1 + \frac{2rl_c}{l}\right)} \tag{8}$$

Where

α = Seebeck coefficient

K = Thermal conductivity

K_c = Thermal conductivity of the contact layer

$r = K_c/K$

N = No. of μTEG

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

lc = thickness of the Ti6Al4V contact layer

Design Using COMSOL

1. *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 6 shows the Bridge type design of a 2 × 2 μTEG. A single 2 × 2 thermocouple can generate a voltage of 0.002 V with a cold side temperature of 298K and hot side temperature of 310 K. [9]

Figure 7 and Figure 8 shows the temperature and voltage distribution of a simple 1 × 1 micro thermoelectric generator COMSOL model.

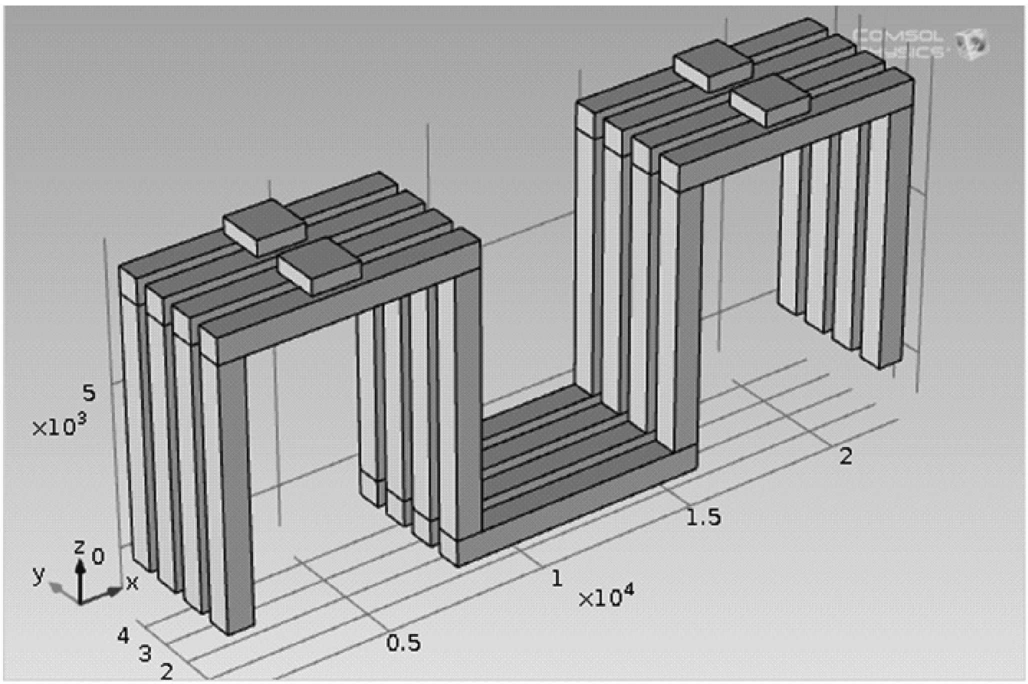

Figure 6: Bridge design of 2 × 2 μTEG

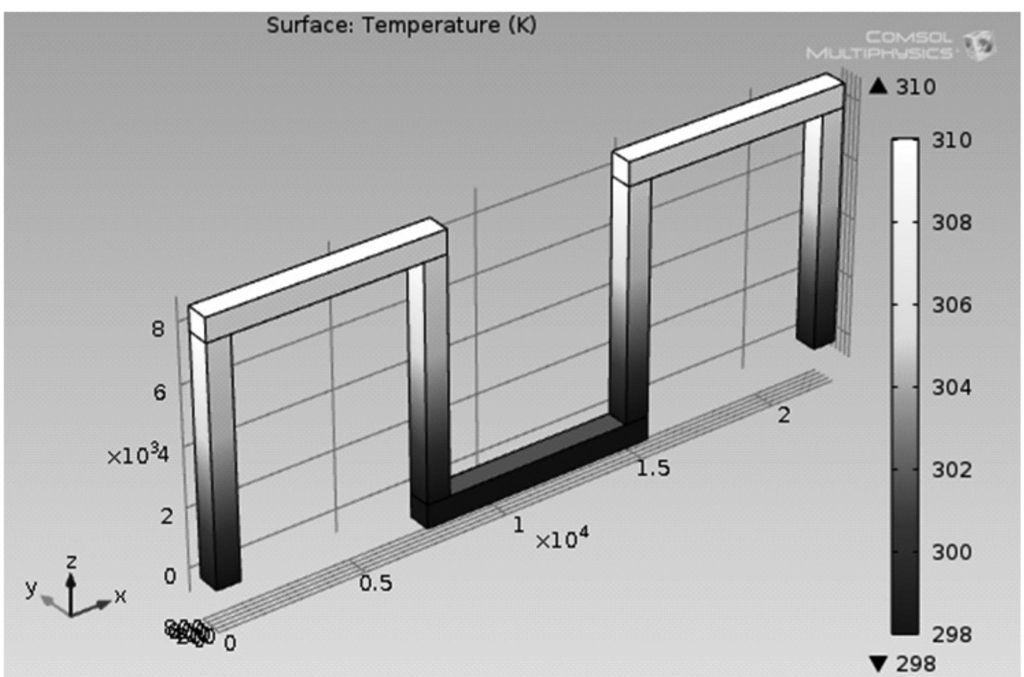

Figure 7: Temperature distribution of 1 × 1 μTEG

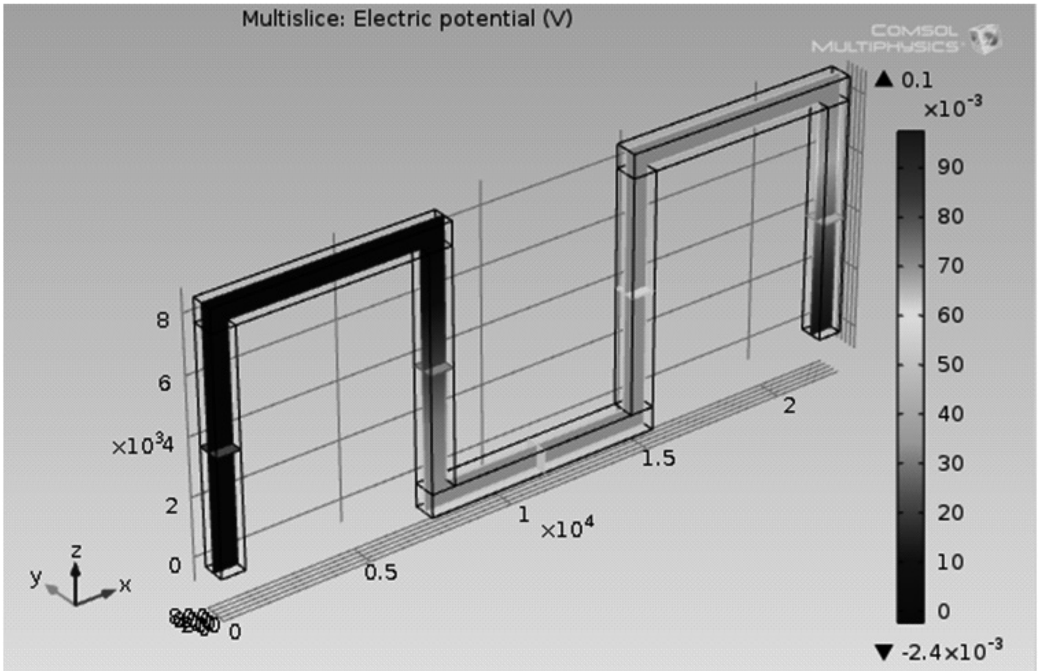

Figure 8: Voltage distribution of 1 × 1 μTEG

This can be further multiplied using multiple devices to get the appropriate power output of mW to provide supply for the Hearing Aid. 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.

5. CONCLUSION

This paper has provided a design and model of an electromagnetic micro speaker 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.

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References

1. Y. C. Chen, and Y. T. Cheng; ―A Low-Power milliwatt Electromagnetic Microspeaker using a silicon membrane for hearing aids application, Microsystems Integration Laboratory, Department of Electronics Engineering & Institute
2. Ming-Cheng Cheng,Wen-Sheh Huang and Star Ruey-Shing Huang; ―A silicon microspeaker for hearing Instruments, MEMOS Lab National Tsing-Hua University, Taiwan, pp. 859–866, (2004).
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.,―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 2015.
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., ―Thermoelectrics hand book: Macro to Nano, CRC Press, Boca Raton, London/New York (2006).

8. MichaelJ.D. Hedges and Yiu Lam; ― Accuracy of Fully Coupled Loudspeaker Simulation Using COMSOL, Monitor Audio Ltd, Salford University COMSOL Conference 2009 Milan.

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

10. H. Hirayama, T. Kimura, Theoretical analysis of the human heat production system and its regulation, Proceedings of the 37th SICE Annual Conference. International, 1998.