EVALUATING AND COMPARING PERFORMANCE OF DIFFERENT SHAPES IN DESIGNING DIAPHRAGMS FOR IMPLANTABLE HEARING AID APPLICATIONS

N. Z. FARDIN[a*], H. T. FARSHI[b]
[a]*Young Researchers and Elite Club, Ilkhchi Branch, Islamic Azad University, Ilkhchi, Iran.*
[b]*Department of Electrical Engineering, Ilkhchi Branch, Islamic Azad University, Ilkhchi, Iran*

The human ear receives the sound signals from the ambient and converts those signals to the electrical domain and transmits them to the brain. According to the prevalence of human hearing impairments and necessity of using the hearing aid, this paper has been concentrated on the design of microphones to be implanted inside the ear. The intended design for this application is using micro-electro-mechanical technology and piezoelectric material. In order to optimal design, the proposed octagonal diaphragm was simulated in COMSOL software and was compared with available designs (Square and Hexagonal). According to the evaluated parameters, the designed diaphragm has the center diaphragm's displacement and the first resonant frequency, 0.113 nm and 380 kHz respectively. The used piezoelectric material is AlN.

(Received January 7, 2016; Accepted March 18, 2016)

Keywords: implantable hearing aid, piezoelectric microphone, MEMS, AlN.

1. Introduction

The ear is a sensitive organ which receives sounds and converts its motion waves to an electrical signal and sends it to the brain. The human ear is able to understand frequencies between 20 Hz and 20 kHz. The ear includes three different parts: external ear (for receiving waves), middle ear (for useful vibrations) and inner ear (for starting nerve stimulation) [1].

External ear canal is a tube with approximately 2–3 cm length and 1 cm^3 volume which ends to the eardrum. Sound vibrations are transmitted by the air to the end of the tube; afterwards, they spread to the middle ear through the solid and liquid environments [2,3].

The middle ear is located in a bony cavity called tympanic cavity and is reached the throat by the Eustachian tube. The oval window transfers the eardrum vibrations to the inner ear through the middle ear bones and the round window causes vibrating the liquid within the inner ear [4]. The inner ear consists of two organs: the semicircular canals which serve as the body's balance organ and the cochlea which serves as the body's microphone.

According to the studies, 17 out of 1,000 children aged under 18 and 314 of the 1,000 people aged 65 years suffer from this disease in America. In addition, it is estimated that by 2015, more than 700 million people will suffer from the slight hearing [5].

The hearing aids can be classified into four groups according to their position:

Behind the ear (BTE), inside the ear (ITE), inside the canal (ITC) and completely in the canal (CTC) [6,7].

The main purpose of the hearing aids is development of implantable microphone in the ear. About 50 years ago, the dimensions of the microphones were large (approximately 4 $\times$ 6 mm with 6 mm height) which their performance was limited by electromagnetic and mechanical noises and they could not neutralize these factors. Therefore, this type of microphones had a very low sound quality.

*Corresponding author: zargarpour.n@gmail.com

By developing micro electro mechanical (MEMS) technology (about 20 years ago), the size of microphones were became smaller; as a result, the cost was reduced and some other advantages were obtained [8]. MEMS microphones can be produced in one of the piezoresistive, capacitive or piezoelectric methods. Despite requiring high bias voltage in capacitor microphones, using this type of microphones is more common than the others [9]. It should be noted that the word piezo is a Greek word and it means pressure. Having a large dynamic range, no need to input power, very accurate displacement, low power consumption and fast response time (at least μm) are the main advantages of pizoelectric microphones [10-14]. Meanwhile, piezoelectric microphone has been proposed with hexagonal diaphragm by using micro-electro-mechanical technology in order to design implantable hearing aid in [15].

In this paper, our goal is to study an octagonal diaphragm with corresponding sizes to the hexagonal and square diaphragms proposed in [15] in order to achieve maximum central diaphragm's displacement and first resonant frequency through a simulation process in COMSOL software. Considering the results of the simulations the octagonal diaphragm presents better efficiency in terms of the mentioned parameters in contrast to the other diaphragm's shapes.

2. Material and Methods

In this section, designing of the proposed Micro Electro Mechanical piezoelectric Microphone's Diaphragm has been presented. In addition, the achieved results from simulations and their comparisons with other designs have been illustrated.

2.1 *The design of proposed Micro Electro Mechanical piezoelectric Microphone's Diaphragm.* According to the previous experiments in [15], achieving the maximum central displacement, stress and strain distribution as well as the first resonant frequency for the MEMS microphone's diaphragm, highly depends on its shape. Therefore, designing and selecting appropriate shape plays an important role for the performance of the diaphragm.

In this paper, the octagonal shape has been considered in designing proposed diaphragm for MEMS microphone micro-electro-mechanical microphone's diaphragm due to utilizing in implantable hearing aid application. The considered conditions for the process of designing includes: applied pressure of 10 Pa, damping 0.0001, frequency range of 20 Hz to 20 kHz, thickness of the diaphragm with 10 μm, piezoelectric material of AlN, Substrate of Si. The simulations have been done in COMSOL software. Then, the simulation results of the square and hexagonal diaphragms [15] have been compared with octagonal diaphragm under identical conditions.

Mesh analysis and 3D simulation of the proposed diaphragm have been shown in Fig. (1-a , 1-b).

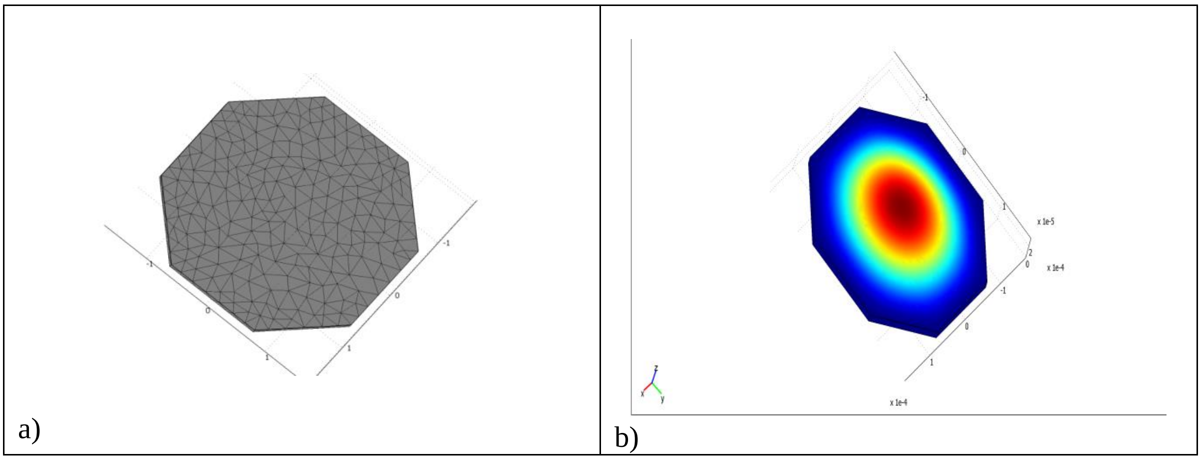

Fig. 1: (a),(b) The proposed octagonal diaphragm with a radius of 350 μm.
a). 3D mesh analysis of octagonal diaphragm with a radius of 350 μm.
b*). Analysis of 3D center displacement of the octagonal diaphragm with a radius*

of 350 µm.

Also the applied piezoelectric and substrate material in the proposed structure was AlN and Si, respectively. Their details of properties are listed in Table 1.

Table1: Material properties used in the proposed diaphragm.

Material	Young's modulus(GPa)	Poisson ratio	Density (kg/m^3)
Si	166	0.23	2330
AlN	330	0.24	3300

2.2 The simulation results of the micro-electro-mechanical piezoelectric microphone's diaphragm.

In this section, analyses of the resonant frequency and the diaphragm's central center displacement have been simulated with Octagonal shape in the COMSOL software. In the simulations, it is assumed that the diaphragm is symmetric and linear. As it was explained in Section the design of proposed MEMS piezoelectric Microphone's Diaphragm, for designing of the proposed diaphragm, Octagonal shape is considered. To achieve optimum dimension, the Octagonal diaphragm has been analyzed and simulated in three different dimensions. Results of the performed simulations for the considered shape along with different dimensions and comparing the Octagonal diaphragm with Hexagonal and Square diaphragms have been provided in the following sub-sections.

2.3 Central displacement of the diaphragm.

This parameter is an important factor in designing a diaphragm. Provided that the diaphragm is linear, then the more center displacement of it will cause more favorable performance. The obtained results of simulations for evaluating the center displacement of the octagonal diaphragm with radiuses of 176µm, 350 µm, and 700 µm are 0.077nm, 0.113nm, and 1.97nm, respectively (Figure 2).

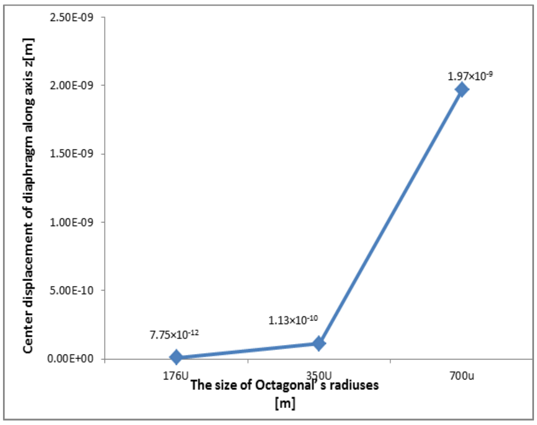

Fig. 2: comparison of the average center displacement of the octagonal diaphragm with a radius of 176 µm, 350 µm and 700 µm in term of frequency range (20 Hz-20 kHz).

The center displacement of the octagonal diaphragm with three different radii radiuses has been compared with the central displacement of hexagonal and square diaphragms in [15] and the experiments results have been shown in Figure 3.

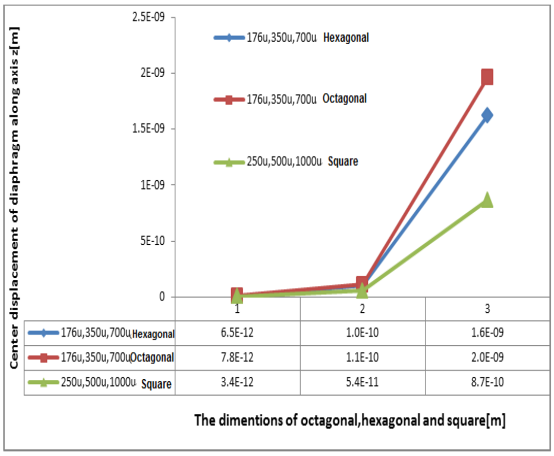

Fig.3: Comparison of the average center displacement of the Octagonal diaphragm with Hexagonal and Square diaphragms in term of frequency range (20Hz-20 kHz).

It can be seen from the Fig (2-3), increasing the dimension in all three shapes (square, hexagonal and octagonal) leads to increase the amount of center displacement in the diaphragms. As it can be inferred from the above Figures an octagonal diaphragm's efficiency with radius 350µm is more acceptable for the medical application, in contrast to the other dimensions or shapes. For instance the octagonal diaphragm smaller than 350µm (176µm) will have less center displacement and the octagonal diaphragm with greater dimensions (700µm and 1060µm) would not be suitable for the implantable hearing aid application. Therefore, octagonal diaphragm is the suitable shape for using in implantable hearing aid applications.

2.4 The first resonant frequency of the diaphragm

The first resonant frequency of the diaphragm should be specified in the design. The results of the first resonant frequency simulations of the diaphragm for the octagonal, hexagonal and square shapes with dimensions corresponding 350µm (in terms of the hearing frequency range) have been illustrated in Figure 4.

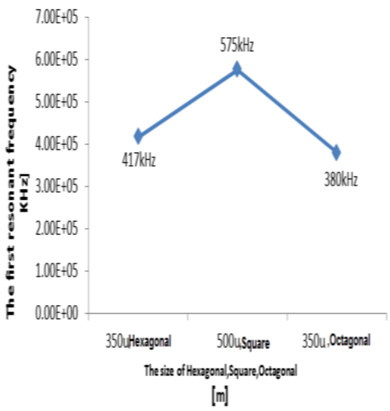

Fig. 4: Comparing the resonant frequency of Octagonal, Square and Hexagonal diaphragms.

According to figure 4, it can be seen that the first resonant frequency of square diaphragm with side length of 500 µm is greater than the first resonant frequency of hexagonal and octagonal diaphragms with radius of 350 µm.

3. Conclusion

In this study, the proposed diaphragm's dimensions have been considered proportionally to the implantable hearing aid application. Besides, the proposed diaphragm's dimensions are suitable for medical applications and also have a good performance. For designing the piezoelectric micro-electro-mechanical diaphragm, it has been considered an octagonal shape with three various dimensions and it has been compared with hexagonal and square shapes with the corresponding sizes. Meanwhile in this paper, the used piezoelectric material has been chosen AlN because of its high sensitivity and stress. The analyses and simulations have been done in the COMSOL software. The obtained simulation results show that the Octagonal diaphragm with diameter of 700 µm and thickness of 10 µm under the same condition has more center displacement than the Square and Hexagonal diaphragms with corresponding dimensions. Under applied pressure of 10 Pa along the Z axes, damping 0.0001 and frequency range of 20Hz to 20kHz, the first resonant frequency and the center displacement of the Octagonal, Hexagonal and Square diaphragms are380 kHz,419.96 kHz, 575.18 kHz and 0.113 nm,0.101 nm,0.054 nm, respectively. Due to the difference of 111and 209 percent of center displacements in the Octagonal diaphragm, compared to the displacements of the hexagonal and square shapes, it is deduced that using the octagonal diaphragm is favorable to the implantable hearing aid applications.

References

[1] RJ. Oliveira, et.al. Journal of the American Academy of Auiology **8**(6), 401 (1997)

[2] A. Sowell.. The Bat's Ear as a Diffraction Grating. Master's thesis, Accession Number: ADA164098, Pagination or Media Count. 1983

[3] R. Pavey et.el .. Bat Predation on Eared Moths. A Test of the Allotonic Frequency Hypothesis, Wiley& Oikos, **81**, 143 (1998).

[4] RJ. Roeser. et.el., Journal of the American Academy of Audiology, **8(**6), 391 (1997)

[5] M. Suyog et.al. International Journal of Engineering Science and Technology(IJEST), **4** (04),1544 (2012)

[6] S. Haynes et. al . Ear Implantable Hearing devices. An Overview, Trend in Amplification, **13**(3), 206 (2012)

[7] A. Vujanic, R. Pavelka, N. Adamovic, Ch. Kment, S. Mitic, W. Brenner, G. Popovic,. Development of a Totally Implantable Hearing Aid. ,PROC.23r International Conference On Microelectronic, (pp. 235-238). 2002

[8] R. Littrell,. High Performance Piezoelectric MEMS Microphone, Dissertation submitte in partial fulfillment of the requirements for the degree of doctor of Philosophy in the university of Michigan. 2010

[9] L. Seob, et.al.. Piezoelectric microphone built on circular diaphragm. Sensors. Actuators **144**, 367 (2008)

[10] M. Niu, et.al. Journal of Microelectromechanical Systems, **12**, 892 (2003).

[11] S. Ko,et. al. Sen. Actuators, **103**, 130 (2003).

[12] S. Lee, et.al. Journal of Microelectromechanical Systems, **5**, 238 (1996)

[13] C. Han, E. Kim, Fabrication of dome-shaped diaphragm with circular clamped boundary on silicon substrate. in: Proceedings of the IEEE Conference MEMS, Orlando, USA (pp. 505–510). 1999

[14] S. Yi, E. Kim, Piezoelectric microspeaker with compressive nitride diaphragm. in: Proceedings of the IEEE Conference MEMS, Las Vegas, USA (pp. 260–263) 2002

[15] N.Zargarpour, Advanced in Bioresearch, society of Education, India, **5**(2), 56 (2014)