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ORIGINAL ARTICLE

A New Method for Using Piezoelectric Diaphragm in Implantable Hearing Aid within the Ear

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ABSTRACT
Most audio devices are required such as mobile phones and hearing aid microphone with high quality, small size and low cost. In this paper, studies have been described in the field of micro electro mechanical piezoelectric microphone based on the hexagonal diaphragm. In order to optimize the design, the proposed diaphragm has been simulated in the COMSOL software and it has been compared the various parameters. Based on the results of the simulations, the hexagonal diaphragm performs better than square diaphragm. According to the evaluated parameters, the proposed designed diaphragm is appropriate for using in medical applications such as implantable hearing aid in the ear.In addition, Al Naspiezo electric-material has been used in this type of microphone.
keywords:*Piezoelectric microphone, diaphragm, Micro electromechanical system(MEMs), Implantable hearing aid in the ear, Aluminum nitrate (AlN).*

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INTRODUCTION

The human ear receives sound signals and converts them to the electrical ones, then transmits them to the brain. The human ear is able to understand frequencies between 20Hz to 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].
According to the studies, 17 out of 1000 children aged under 18 and 314 of the 1000 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 [2].
In order to provide a solution to the impaired hearing problem,this paper is focused on designing hearing aids. Depending on the rate of deafness, different types of the hearing aids can be used. The hearing aids can be classifiedinto4groups according to their position: Behind The Ear (BTE), Inside The Ear (ITE), Inside The Canal (ITC) and Completely in The Canal (CTC)[3, 4] Japan is a pioneering country in development of the totally implantable hearing aid (TIHA) from 20 years ago. TIHA in the ear has led to reduction of utilizing traditional hearing aids [5]. The hearing aids usually consist of amplifier, speaker and microphone [6].Considering the fact that microphones of the hearing aids are the most important element, the studies in this paper are concentrated on designing more efficient microphone for utilizing in implantable hearing aid. Converting the audio signals to electrical is the main task of microphones. According to[7] microphone can be used in various fields.In this paper a new design of diaphragm for the implantable microphones has been proposed. For accurate designing of the diaphragm, various shapes such as hexagons and squares with different dimensions have been studied and simulated. The proposed diaphragm's dimensions have been considered to be compatible for medical use in manufacturing the implantable hearing aids.In order to evaluate, compare and select the desired shape for the diaphragm as well as the analysis related to the diaphragm's center displacement and its first resonant frequency, a series of simulations have been performed in the COMSOL software.It should be noted that the design of the proposed micro-electro-mechanical piezoelectric microphone is a new step in medical applications

such as implantable hearing aid in the ear. This paper is organized as follows: section 2 describes the micro-electro-mechanical microphone's diaphragm design. The results of the COMSOL simulations have been presented in section 3. Finally in Section 4, the conclusions have been provided.

METHODOLOGY (DESIGNING PROCEDURE)

The design of proposed Micro Electro Mechanical piezoelectric Microphone's Diaphragm

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 play an important role for the diaphragm. In this section, the designing and selection of the appropriate shape for the use in the implantable hearing aid in the ear are the main aim, so that maximum performance is achieved.

In this paper, two different shapes (square, hexagonal) have been considered for designing proposed 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 20Hz to 20kHz, thickness of the diaphragm with 10 μm, piezoelectric material of AlN, Substrate of Si.The simulations have been done in COMSOL software.

Based on the results of the simulations, hexagonal diaphragm with radius of 350 μm is desirable for the medical application of the implantable hearing aid. Mesh analysis and 3D simulation of the proposed diaphragm have been shown in Fig(1-a , 1-b).

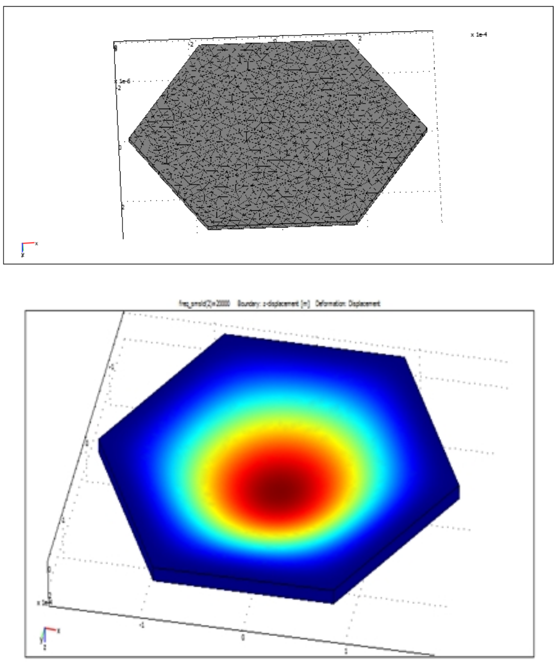

Fig.1 The proposed hexagonal diaphragm with a radius of 350μm. a). 3D mesh analysis of hexagonal diaphragm with a radius of 350 μm. b). Analysis of 3D center displacement of the hexagonal diaphragm with a radius of 350 μm.

Also the applied piezoelectric and substrate material in the designation are AlN and Si, respectively. Their details of properties are listedin Table1.

Then, Simulation of the design is provided in more detail, in section 2-1.

Table1. Material properties used in the proposed diaphragm.

Material	Young's modulus(GPa)	Poisson ratio	Density $\left(^{kg}/_{m^3}\right)$
Si	166	0.23	2330
AlN	330	0.24	3300

The Simulation Results Of The Micro-Electro-Mechanical Piezoelectric Microphone's Diaphragm

In this section, analysis of the resonant frequency and the diaphragm's center displacement have been simulated with square and hexagonal shapes in the COMSOL software.In the simulations, it is assumed that the diaphragm is symmetric and linear. As it was explained in Section3.1, for designing of the proposed diaphragm, both square and hexagonal shapes are considered.To achieve optimum dimension and shape, each of the diaphragm shapes has been analyzed and simulated in four different dimensions. Results of the performed simulations for each of considered shape along with different dimensions have been provided in the following subsections.

CENTER DISPLACEMENT OF THE DIAPHRAGM

This parameter is an important factor in designing a diaphragm. The obtained results of simulations for evaluating the center displacement of the hexagonal diaphragm with radiuses of 176µm, 350 µm, 700 µm and 1060 µm are 0.065nm, 0.102nm, 1.62nm, 9.14nm, respectively (Fig.2).

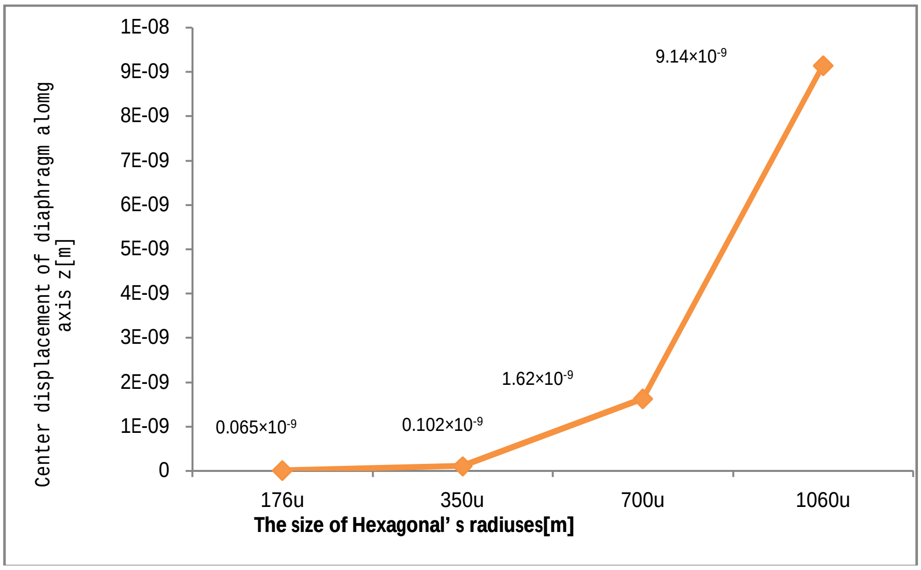

Fig2.Comparison of the average center displacement of the hexagonal diaphragm with a radius of 176 µm,350 µm, 700 µm and 1060 **in term of frequency range (20Hz-20kHz).**

For the square shape of diaphragm with corresponding dimensions to the radius of the hexagonal (250µm, 500 µm, 1000µm, 1500µm) the simulations have been done to evaluate their center displacement and the achieved results are 0.0034 nm ، 0.054nm ، 0.87nmand4.54nm , respectively (Fig 3).

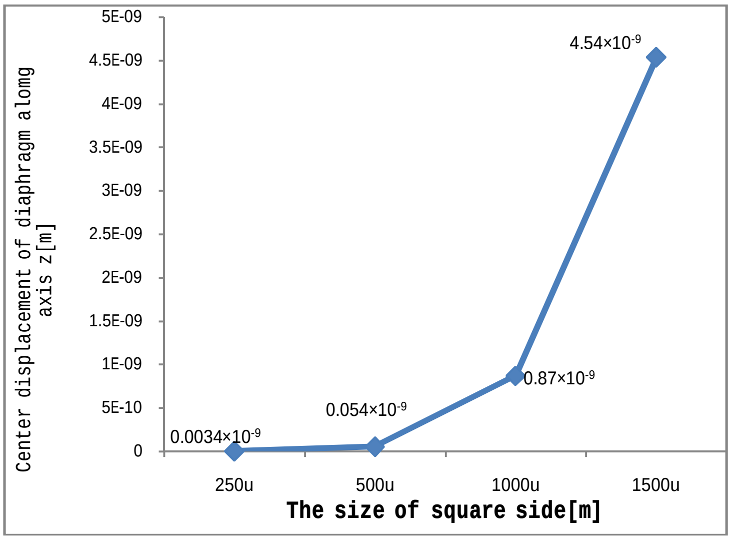

Fig3. Comparison of the average center displacement of the square diaphragm with a radius of 250µm, 500 µm, 1000 µm and 1500 in term of frequency range **(20Hz-20kHz).**

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

RESULT AND DISCUSSION

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 hexagonal and square shapes with dimensions corresponding 350μm (in terms of the hearing frequency range) have been shown in Fig 4.

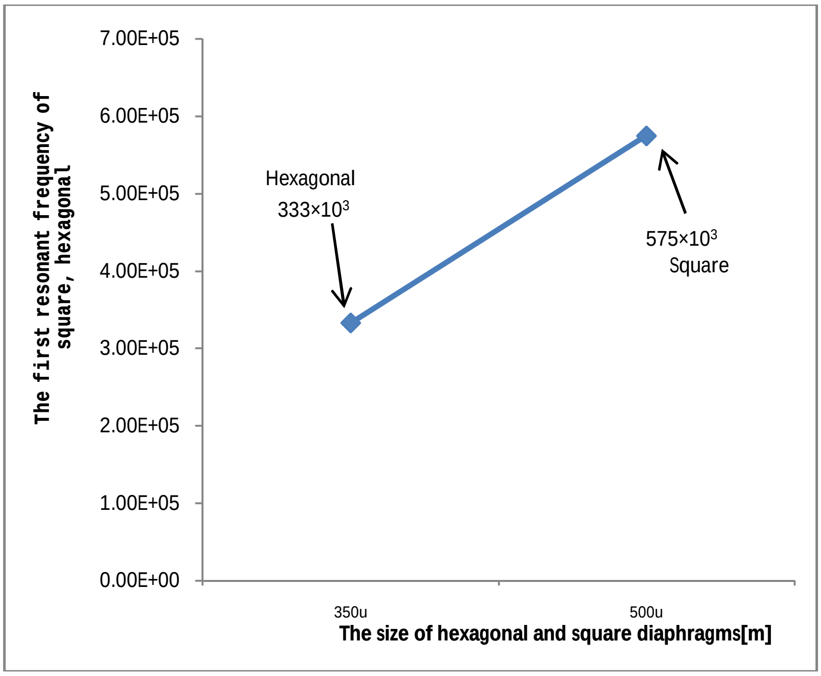

Fig4.Comparing the resonant frequency of square and hexagonal diaphragm.

CONCLUSION

In this study the MEMS Piezoelectric Microphone's Diaphragm was introduced for the first time, to be utilizing in medical applications such as the hearing aid. Besides, the proposed diaphragm's dimensions have been considered proportional to the implantable hearing aid application. In order to have accurate evaluations, it has been considered two shapes of square and hexagonal with four various dimensions for the proposed diaphragm. The analyses and simulations have been done in the COMSOL software. The obtained simulation results show that the Hexagonal diaphragm with diameter of 700 μm and thickness of 10 μm under the same condition has more center displacement than the square diaphragm with corresponding dimension.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 Hexagonal and square diaphragms are419.96 kHz, 575.18 kHz and 0.101 nm, 0.054 nm, respectively. According to the difference of 187 percent of the center displacement of the diaphragms, the using of Hexagonal shape is desirable for the used diaphragm in the implantable hearing aid in the ear.

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