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The Study of the Inductive Coil to the Acoustic Performance of Electromagnetic Driven Microspeaker

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Abstract

Electromagnetic driven MEMS speakers using Polydimethylsiloxane (PDMS) membrane have been investigated to obtain a better sound pressure level (SPL) respond in low frequency regime. The comparison between measure and COMSOL simulation of fabricated microspeakers shows that the copper coil and its electrical feedthrough have a strong effect on the rigidity of the membrane thus on the SPL. Without considering the feedthrough effect, wide bandwidth starting at low frequency can be obtained while the coil is placed in the centre of the membrane, whereas placing the coil close to the membrane border instead will give a better response in low frequency with feedthrough effect

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Keywords: hearing aids; microspeaker, coil placement; MEMS; audio

1. Introduction

One tenth of the world population suffers from hearing loss and 278 million of them cannot have normal conversation without hearing aids that raise the issue of accessibility [1]. In the previous work [2], a micromachined electromagnetic (EM) microspeaker was developed with the lowest power consumption, i.e. 1.76mW for 106dB sound pressure level (SPL)@1kHz in a 2c.c. coupler of Brüel & Kjær as shown in Fig. 1 for hearing aids application. The microspeaker driven by Lorentz force was designed with a PDMS membrane where copper coils are placed. For maximizing the magnetic field in the coil, a NiFe soft magnet ring and a NdFeB hard magnet are placed on the

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border and under the center part of the membrane, respectively. However, it was found that good SPL results in low frequencies are limited with such a miniaturized speaker. In this work, we will investigate the inductive coil in the EM microspeaker and then propose a design scheme for further power reduction resulting from better acoustic performance in low frequency.

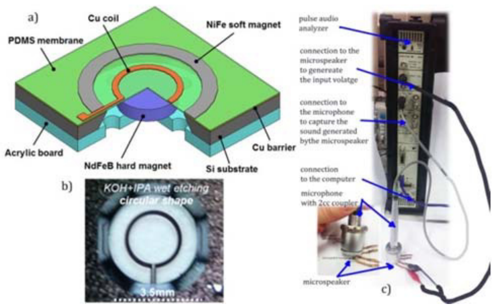

Fig. 1. (a), (b) fabricated microspeaker; (c) Brüel and Kjær measure instruments.

2. Experimental design

In the study, two kinds of microspeakers with different membrane diameter and design are shown in Fig. 2. Two microspeakers were designed with the 3 µm thick membranes, which are 3.5mm in diameter with a 7 turns coil placed at 900 µm from the center and 2.5 mm one with a 5 turn coil placed at 850µm from the center, respectively. The Iron-nickel (NiFe) soft magnet placed on the border of the membrane has a thickness of 10 µm and a width of 400 µm, and the Neodymium (NdFeB) hard magnet has a thickness of 1.5mm and a diameter of 2mm. The speakers were all fabricated using the prior developed process [2].

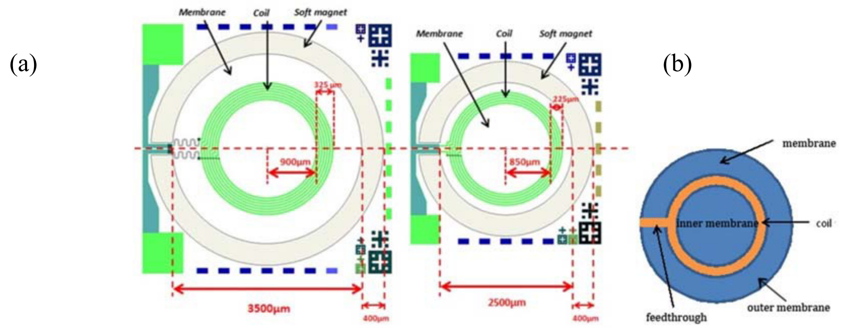

Fig. 2: (a) Details of the two sizes microspeaker, (b) feedthrough, inner and outer part membrane placement

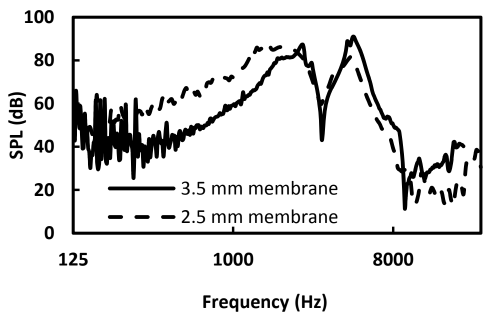

Fig. 3: experimental results for two sizes microspeaker

3. Characterization and discussion

The fabricated microspeakers were characterized and validated with COMSOL simulation. Theoretically, bigger is the speaker lower is the output frequency with larger SPL. However, experimental SPL results show similar acoustic characteristics in both fabricated microspeakers as shown in Fig. 3. Fig 4 shows that the simulation without considering the feedthrough, i.e. electrical interconnects to the coil shown in Fig. 2 (b), gives a close result for the small microspeaker where the coil is placed close to the border of the membrane (Fig. 4 (a)), whereas the simulation for the big microspeaker where the coil is right in the middle of the membrane doesn't match with the measurement (Fig. 4 (b)).

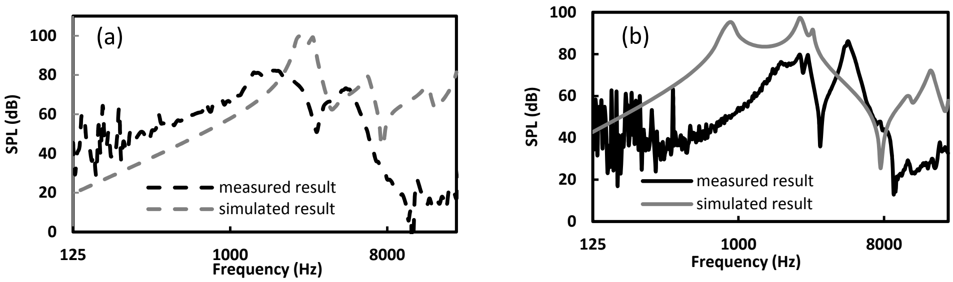

Fig. 4: simulated and measured results for: (a) 2.5 mm, (b) 3.5 mm microspeaker without feedthrough

It infers that the rigidity of outer membrane could be affected by the feedthrough. The microspeaker with a small feedthrough can have a more close simulation result in comparison with the one with a significant outer membrane. Indeed, by considering the feedthrough in the simulation of the large speaker, the result becomes similar to the measured one as shown in Fig. 5. The comparison shows that the Cu coil and its feedthrough exhibit a strong effect on the membrane rigidity thus on the SPL response. This conduces to a new microspeaker design using the placement of the coil to change the output SPL bandwidth.

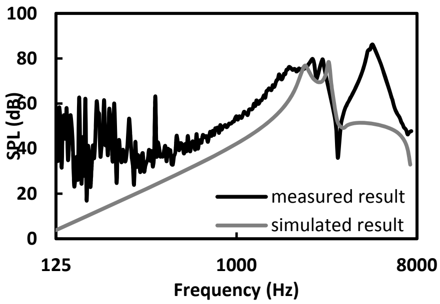

Fig. 5: measured and simulated SPL results for 3.5 mm microspeaker with feedthrough

Figure 6 and 7 show the simulation results of the speaker SPL output with and without the feedthrough effect, respectively. With the effect, different coil positions would induce different output sound bands in terms of frequency. Placing the coil close to the border of the membrane will induce a better response in low frequency, whereas placing the coil in the center will induce better response in high frequency (Fig. 6 (a)). The feedthrough affects the rigidity of the outer part of the membrane, wherefore the inner membrane (Fig.2 (b)) has the biggest effect on the SPL (Fig. 6 (b)). When the coil is close to the center, the active membrane becomes small and the SPL response becomes better for high frequency. On the other hand, when the coil is far from the center, the active membrane becomes large and the result is better for low frequency. Alternatively, without the effect, better acoustic response in low frequency can be realized in a miniaturized speaker merely by placing the coil close to its center (Fig. 7 (a)). The rigidity of the speaker membrane is only affected by the coil placement and therefore the outer membrane can move more easily (Fig. 7 (b)). Consequently, closer the coil is in the center bigger all membrane can move for having a good response in low frequency.

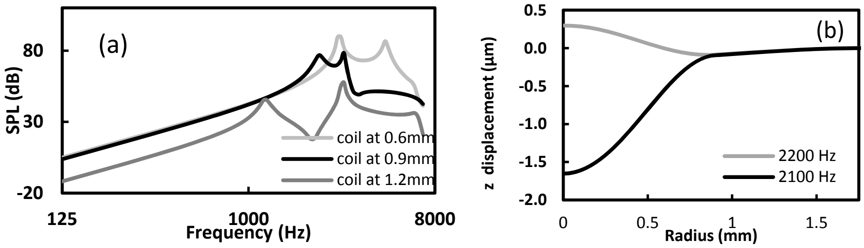

Fig. 6: (a) SPL at different coil placement (from the middle of the 3.5 mm membrane) with feedthrough; (b) Vertical membrane displacement from the center (0 mm) to the border (1.75 mm) of the membrane with feedthrough

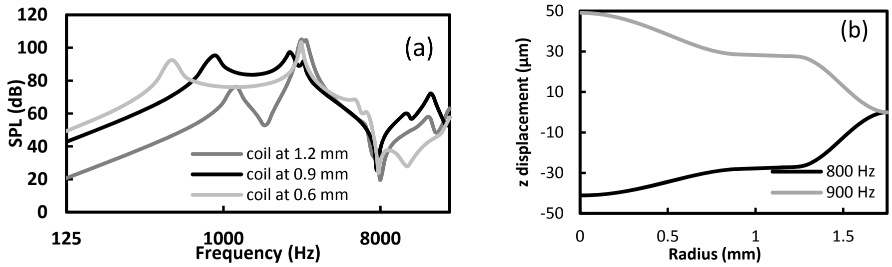

Fig.7: (a) SPL at different coil placement (from the middle of the 3.5 mm membrane) without feedthrough; (b) Vertical membrane displacement from the center (0 mm) to the border (1.75 mm) of the membrane without feedthrough

Smaller is the speaker more difficult it is to have good output sound in low frequency. Compared with other works [3], [4], the change of the coil placement can improve microspeaker performance in low frequency. In our design by resolving the feedthrough effect, the speaker with 3.5 mm diameter membrane placed with 7 turns coil at 0.6 mm from the center can have as good result in terms of its low frequency response as the one with four time bigger membrane from Shahosseini et al paper [3], and compared to a similar microspeaker in term of size [4], the start frequency of our design can be 10 times smaller.

4. Conclusion

The coil placement on the membrane has a strong effect on the microspeaker’s sound pressure level. Getting rid of the feedthrough and placing the coil close to the centre can significantly improve the response in low frequency.

Acknowledgement

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