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FLEXIBLE MICROSPEAKER BASED ON BIMORPH PIEZOELECTRIC TRANSDUCER

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Abstract

In order to enhance the sound pressure level in the low frequency range, a polymer-based piezoelectric thin film (PVDF) was utilized in this study instead of ceramic piezoelectric material such as PZT. In addition, a ring-type bimorph piezoelectric transducer was designed to excite a polymeric diaphragm, PDMS thin film, for improving the sound pressure in the low frequency range (<5KHz). Due to the microspeaker was mostly made by polymer-based material; therefore, it exhibits excellent mechanical flexibility for bending deformation, which can not be achieved by ceramic piezoelectric material. Also, the sound pressure level of microspeaker with PDMS diaphragm in the low frequency range was larger than microspeaker with Al diaphragm as indicated in the experimental results. Generally, the enhancement of sound pressure in the low frequency range is due to the light weight and low stiffness of PDMS thin film. Besides, the quality of sound showed low distortion within full frequency range from 200 to 20K Hz. Consequently, a flexible microspeaker was designed and fabricated in this study, the results cab provide the possibility of wearable electronics and flexible consumer products as well as the miniaturization of traditional loudspeaker.
Keywords: PVDF; Microspeaker; Bimorph; FEM

Introduction

Loudspeaker have been widely used in living life, currently, the most common type of loudspeaker is moving-coil driver based on electromagnets, however, it is a task for size reduction due to the permanent magnet, coil, horn-type diaphragm and cabinet. On the other hand, the planar piezoelectric loudspeaker has great potential on smaller and thinner acoustic device especially for the handheld devices. In spite of the advantages of piezoelectric loudspeaker, the response in low frequency range is usually insufficient to provide a good quality of sound due to the stiffness of the ceramic piezoelectric material is too high. In 2003, Lee *et al.* [1] used the polymer piezoelectric material, PVDF, and conductive polymer to manufacture a transparent flexible piezoelectric loudspeaker. The sound pressure level in low frequency range (400 Hz) showed as large as moving-coil type loudspeaker about 80 dB; however, the size is still big (150 mm × 150 mm) for handheld device. In order to downsizing, a more efficient driving mechanism is needed for PVDF-based loudspeaker. Chang [2] reported a trimorph ring transducer for enhancement of piezoelectric excitation. In this study, a new structure of bimorph piezoelectric loudspeaker has developed; the sandwich structure consists of two PVDF piezoelectric films separated by a diaphragm in the middle layer. Firstly, we utilized finite element analysis to understand the effects of the size, thickness and material selection of diaphragm on resulting performance of sound. Then, a prototype of flexible piezoelectric microspeaker with 1cm diameter and 300μm thickness has been fabricated and measured here.

Numerical Simulation

The finite element model was shown in the Fig. 1, and the dimensions for each case also were listed in the Table 1. From Table 2, the first four resonance frequencies for each case with PDMS diaphragm was analyzed by ABAQUS software, if the speaker size is larger or the thickness is thinner, the resonance frequency is decreased. On the other hand, the material of diaphragm also strongly affected with resonance frequency as well as mode shape. By comparison of Table 2 and 3, the resonance frequency is higher for the Al membrane; the reason can be illustrated as Fig. 2. Because Al material has higher Young's Modulus than PVDF the distortion area in the mode 1 is larger than the case with PDMS diaphragm. In addition, the displacement spectra of harmonic analysis for Al and PDMS diaphragm were plotted in Fig. 3(a). The low frequency response for PDMS diaphragm was better than Al diaphragm, furthermore, the displacement could be enhanced if the diaphragm is thinner, shown in the Fig. 3(b).

Table 1. Specifications of Microspeaker for FEM Analysis

	Inner radius r_i	*Outer radius* r_0	*Thickness* t
Case 1	2.5mm	5mm	50um
Case 2	2.5mm	5mm	10um
Case 3	25mm	50mm	50um

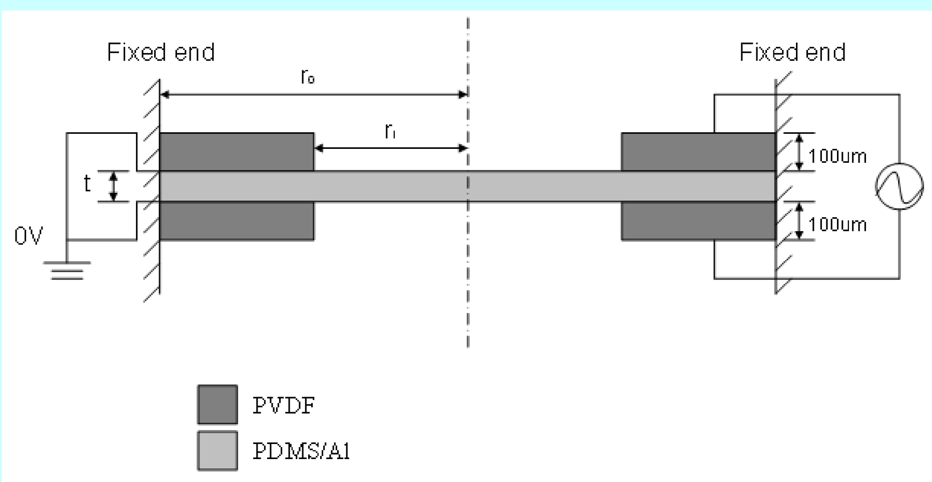

Fig.1 Cross section of the bimorph piezoelectric microspeaker, the applied voltage is 10 Vpp and the boundary condition is modelled as a fixed end at the outer sidewall of ring-type bimorph structure.

Table 2. The resonance frequency for PDMS Diaphragm

	PDMS Diaphragm					
	Case 1		Case 2		Case 3	
	resonance frequency	Mode Shape	resonance frequency	Mode Shape	resonance frequency	Mode Shape
Mode 1	4.286 kHz		0.534 kHz		0.49 kHz	
Mode 2	8.857 kHz		1.158 kHz		1.081 kHz	
Mode 3	8.881 kHz		1.165 kHz		1.089 kHz	
Mode 4	13.91 kHz		2.059 kHz		1.899 kHz	

Table 3. The resonance frequency for Al Diaphragm

	Al Diaphragm			
	Case 1		*Case 2*	
	resonance frequency	Mode Shape	*resonance frequency*	Mode Shape
Mode 1	2.082 kHz		0.724 kHz	
Mode 2	3.373 kHz		1.554 kHz	
Mode 3	3.381 kHz		1.570 kHz	
Mode 4	5.312 kHz		2.218 kHz	

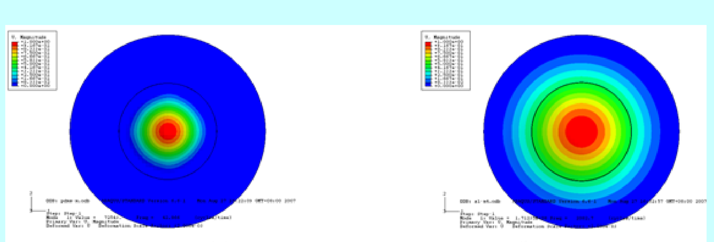

Fig.2 The mode 1 shapes for the case1 model with different membrane materials. (a) PDMS diaphragm microspeaker (b) Al diaphragm microspeaker .

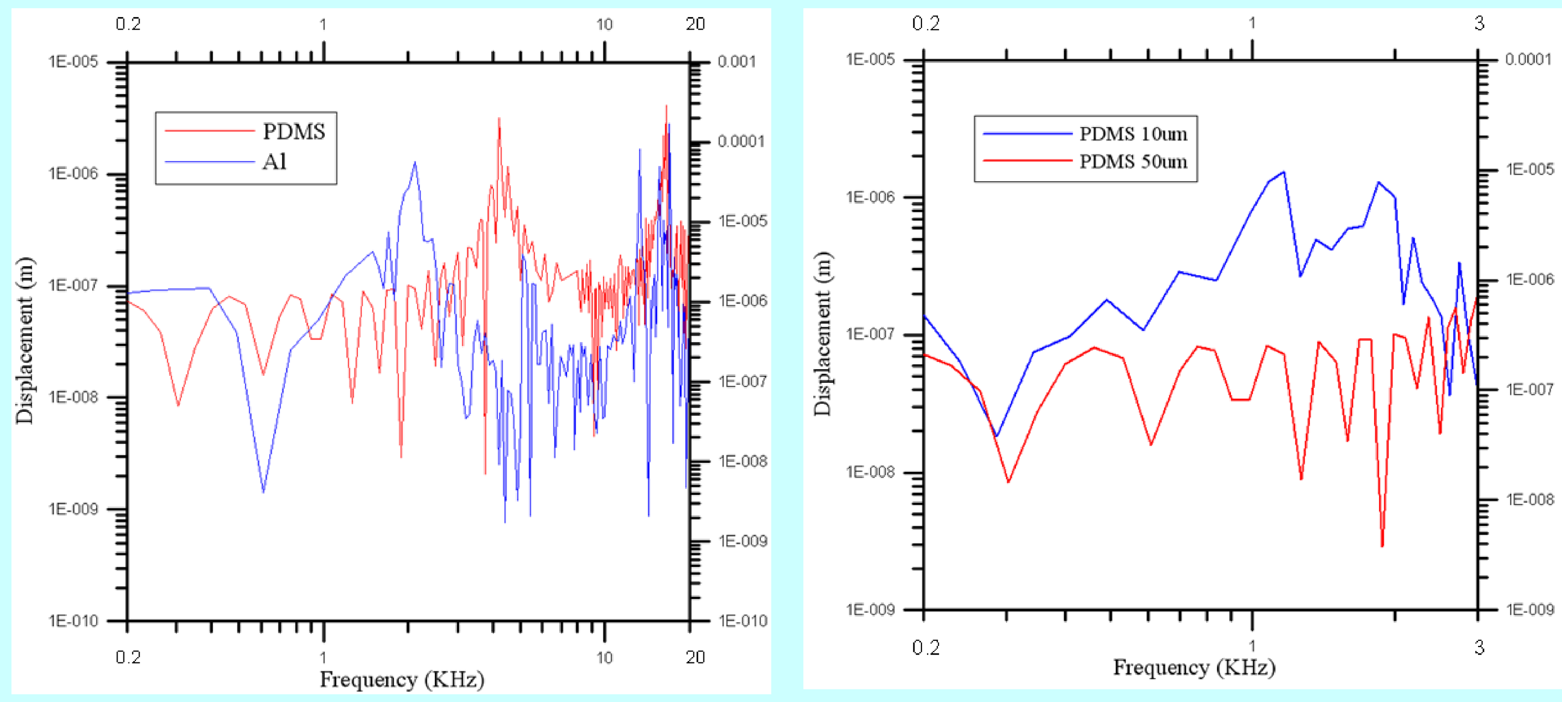

Fig.3 (a) *Harmonic analyses of case1 model with 200 to 20K Hz for different membrane materials, blue line and red line indicate microspeakers with Al diaphragm and PDMS diaphragm, respectively.* (b) Harmonic analysis of Case1 model for different thicknesses of the PDMS diaphragm in the low frequency range between 200 to 3 K Hz. Red line and blue line represent the thickness of PDMS diaphragm 50μm and 10μm, respectively.

Experimental Results

The process steps for fabrication of flexible bimorph piezoelectric microspeaker were illustrated as Fig. 4(a), and the finished prototype can be easily bent by hand shown in the Fig. 4(b). A measurement system has built as Fig. 5 and its background noise level was about 30 dB. Two kinds of microspeaker were measured for the sound pressure level spectrum from 200 to 20K Hz, shown in the Fig. 6. The microspeaker with PDMS diaphragm exhibits higher sound pressure below 5K Hz and above 10K Hz.

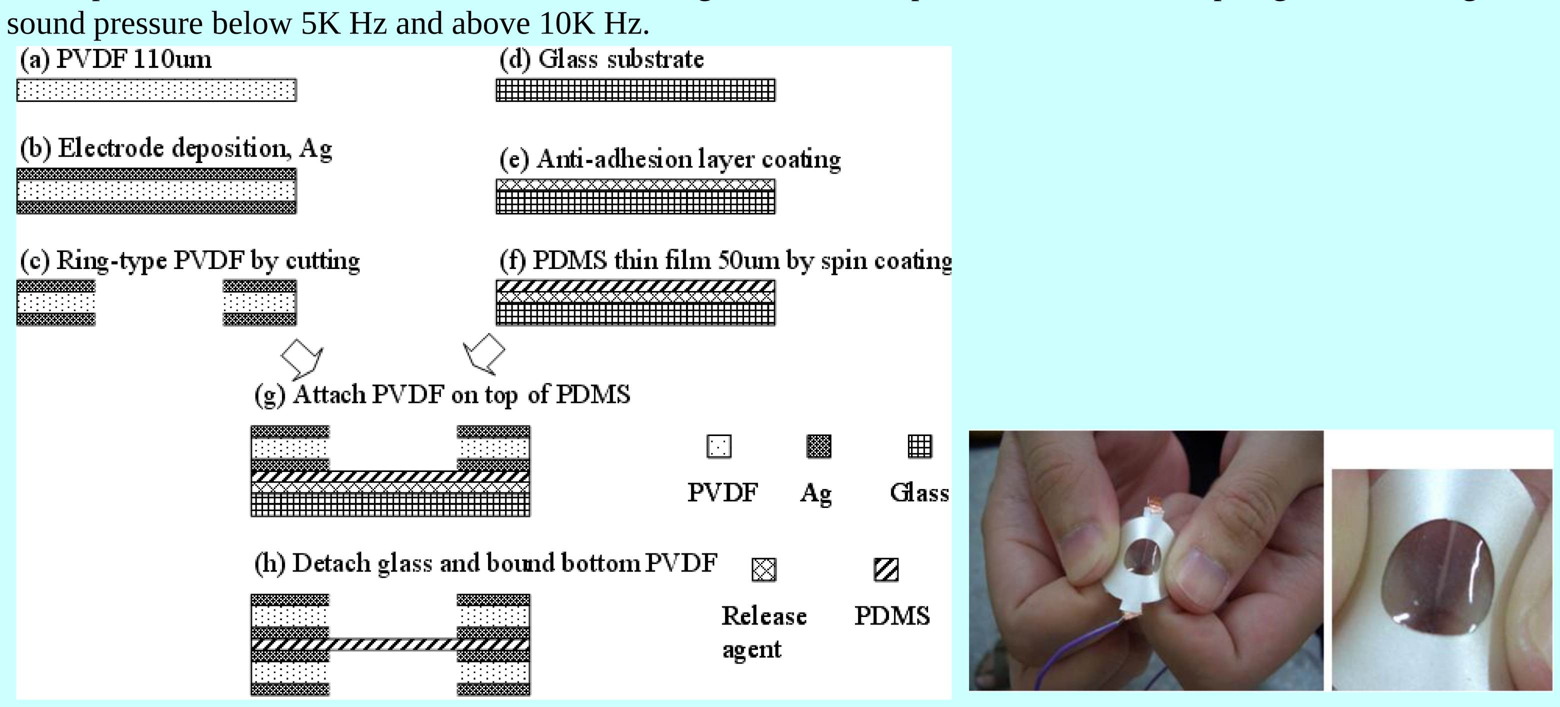

Fig.4 (a) Process steps of flexible bimorph piezoelectric microspeaker; (b) The prototype of flexible microspeaker

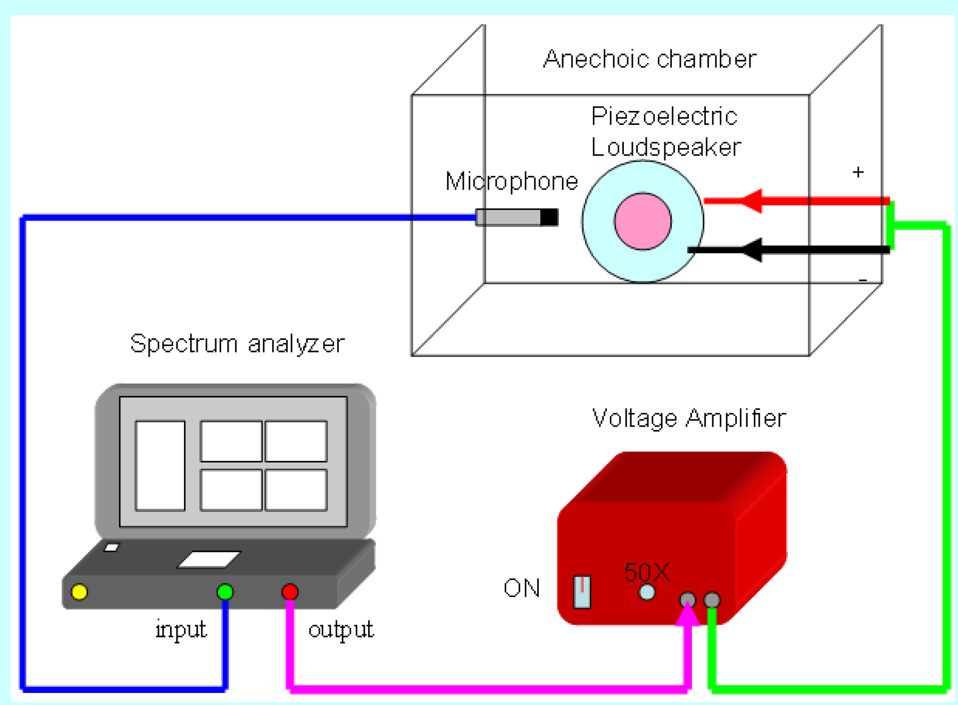

Fig.5 Experimental setup for measurement of sound pressure level spectrum, the instruments are listed as homemade anechoic chamber, standar microphone (G.R.A.S Type 40AC), the spectrum analyzer (B&K 3560C) and the voltage amplifier (LAP400B)

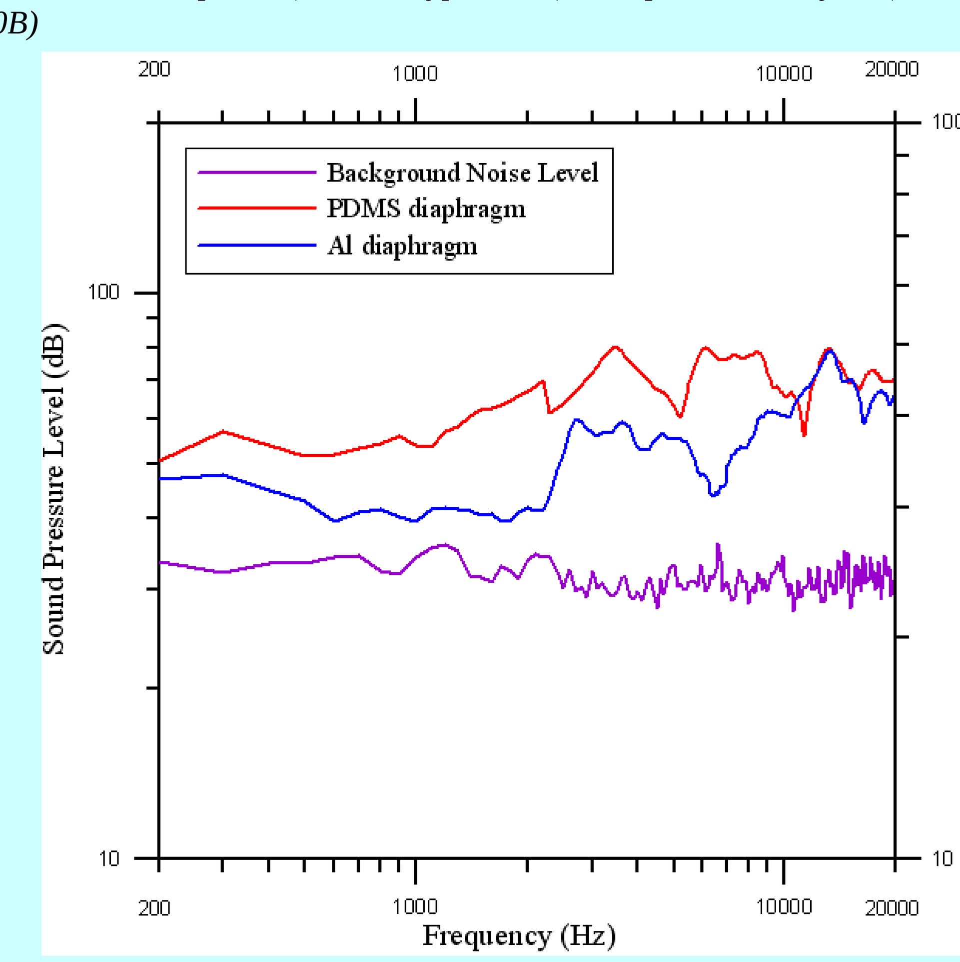

Fig.6 Measured sound pressure level spectra for different membrane material: Blue line is Al diaphragm, Red line is PDMS diaphragm, the distance between microphone and flexible microspeaker is 10mm and the applied voltage is 10 Vpp after amplified. The background noise level was about 30 dB.

Conclusion

The sound pressure and quality of a piezoelectric microspeaker can be improved by bimorph transducer and polymer diaphragm according to the simulation and experimental results. As the size of microspeaker is reduced a thinner diaphragm is needed for better performance, but the difficulty of fabrication will be also increased. In addition, the dynamic performance can also be enhanced by either increasing the input voltage or microspeakers array. The microspeaker has excellent mechanical properties as the applications need to be bent or curved. This study can provide the feasibility of flexible microspeaker and optimization of device design.

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