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Acoustic field evaluation of adhesive-free polymer transducers used for high frequency imaging

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1. Introduction

Quantitative acoustic imaging and characterization using ultrasonic transducers has emerged as a tool for the noninvasive micro-structural characterization of the materials. It can also be used to determine surface and subsurface mechanical properties of piezoelectric materials, thin films, nondestructive testing, anisotropic phonon propagation, and in biology[1-5]. Polymer based piezoelectric materials such as ferroelectric polyvinylidenefluoride (PVDF) and its copolymer PVDF trifluoroethylene [P(VDF-TrFE)] can used for high frequencies, large bandwidths ultrasonic sensors and transducers[6-11]. They are also flexible, easy to process, and provide a relatively good acoustic match to water, human tissue and compare to many other polymer materials. The impedance mismatch between materials (e.g., between sapphire and water for ZnO transducer) is a limiting factor in the design due to for instance, reduction in sound transmission and bandwidth, and an increased geometrical aberration of the focused transducer beam[12, 13].

In this paper, we have demonstrated a new method for producing adhesive free high frequency acoustic transducers. The construction will eliminate problems imposed by additional adhesive layers (e.g. impedance mismatch and attenuation). In high frequency acoustic transducer it is also an important parameter of the acoustic field strength in near and remote field. In terms of experiments, this invaluable information is absent in the literature.

The main aim of this work has been to generate prototypes of the proposed transducer design and to analyze them in terms of acoustic performance and pressure field distributions. For each prototype containing four elements with central frequencies around 32 MHz, the acoustic field is mapped both in the near and remote field using a needle hydrophone system.

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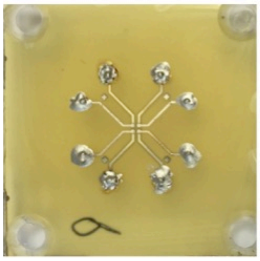
2. Experiments and Results

2.1 Transducer fabrication

The prototypes are based on P(VDF-TrFE) (77:23, molar ratio) powder as the raw material, and build on top of a polyethyleneimines (PEI) polymer substrate acting as the backing material.



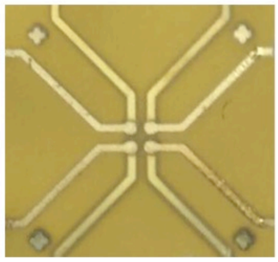


Fig. 1(a) Image of the transducer containing all for elements, (b) shows the magnified view of the Fig 1a

The PEI material was chosen due to good thermal stability, good impedance match to the PVDF copolymer, and very low acoustic attenuation[14]. At the same time it allows us to determine the transducer properties from reflections occurring from the PEI-air interface on the opposite side of the substrate[15]. More details regarding the assembly process can be found in Ref. [11]

An image of the complete transducer with 4 elements is shown in **Fig. 1a,** with a magnified view in **Fig. 1b**. From the image the active area of the element the side length, the height and the major diagonal was estimated to be around 180, 435, and 471 µm, respectively. The pitch distance between the center to the center of the element was around 700 µm. For initiating the piezoelectric effect on the P(VDF-TrFE) thin layer, the transducers were polarized at room temperature. A high voltage AC source was connected to the lower electrodes, while the upper ones were connected to ground.

2.2 Ultrasonic measurements

The transducer response was first investigated by looking at the acoustic pulse reflection from the PEI backside, using the setup described in Refs[9, 10]. Here in **Fig. 2a** shows the acoustical reflections in the time domain, while **2b** shows the corresponding spectra.

From **Fig. 2b,** we notice that the maximum response occurs around 45.75 to 46.25 MHz with the standard deviation of 0.204 MHz.

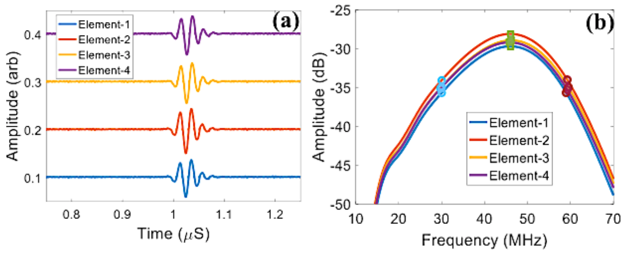


Fig. 2a Acoustic reflections from the PEI (four elements) with small bias added for separation of acoustic pulses (b) Frequency spectrum in a dB corresponding to all 4 transducers

The -6 dB bandwidths were around 29 to 29.5MHz with the standard deviation of 0.24 MHz. One should be aware of several factors that may influence the measured acoustic responses, for example, the bandwidth of the used instruments (e.g., the current amplifier's 80 MHz bandwidth), and wave effects such as diffraction and attenuation and surface roughness of PVDF and PEI.

2.3 Acoustic field measurements

The acoustic pressure fields were generated by a single transducer, in the same time emitted acoustic fields were imaged in a scanning tank using a 75 μm needle hydrophone with a 1-30 MHz bandwidth (precision acoustics)[16]. **Fig. 3** demonstrates the acoustic field imaged at different distances from the transducer plane. For these measurements a single transducer element was excited with the second derivative of a Gaussian pulse, and the radiated acoustic field was imaged using the hydrophone at different distances. The acoustic field pressures were recorded at an increasing manner with respect to excited transducer and receiving hydrophone.

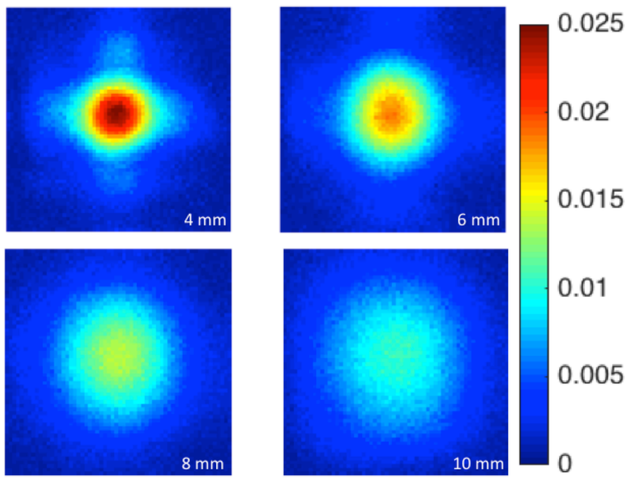


Fig. 3 Hydrophone measurements of a single transducer at different distances such as 4, 6, 8, and 10 mm with respect to hydrophone

3. Conclusion

Multi element adhesive-free transducers were built and characterized in terms of acoustic reflection and hydrophone measurements. All four transducer elements showed a consistent broad banded ultrasonic spectrum with maximum frequency responses around 45.75 to 46.25 MHz with very small standard deviation of 0.204 MHz. The hydrophone measurements show pressure fields yielding good rotational symmetry both in the near and remote fields. The manufacture processes for the high frequency polymer transducers are relatively straightforward compare to conventional acoustic transducers available in the market. This adhesive free copolymer high frequency transducer may find new avenue in the field of non-destructive evaluation of automotive or aerospace industry.

Acknowledgement

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