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Evaluation of adhesive free crossed array PVDF copolymer transducers for high frequency imaging

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1. Introduction

The polymer polyvinylidene fluoride (PVDF) and its copolymer with trifluoroethylene (PVDF-TrFE) are widely used as piezoelectric material in ultrasonic sensors and transducers. The broadband characteristics of these materials make them suitable for nondestructive evaluation (NDE), underwater acoustic, and medical imaging [1-4]. They are also flexible, easy to process, and provide a relatively good acoustic match to water, human tissue, and many other polymer materials.

For high frequency ultrasonic imaging using array sensors, one of the major challenges is to obtain similar properties between individual array elements. Uniformity in terms of bandwidth and acoustic energy output are especially important. The main aim of this work has been to build prototypes for high frequency ultrasonic transducers based on so-called crossed electrodes. These prototypes with 16 elements and central frequencies around 100 MHz, are characterized and evaluated in term of uniformity.

2. Experiments and Results

2.1 Transducer fabrication

The transducer prototypes were produced with power of P(VDF-TrFE) (77:23, molar ratio) as the starting point. This copolymer power was mixed with an appropriate amount of solvent to produce the desired layer thickness from spin coating. The 16 element crossed array was built on the top of a polyethyleneimines (PEI) polymer substrate also acting as the transducer backing material. This particular polymer has a very good thermal stability and good impedance match to the PVDF copolymer. PEI also imposes very low acoustic attenuation [5], allowing us to estimate the transducer properties from reflections occurring from the PEI-air interface on the opposite side of the substrate [6].

A plasma cleaner was used to increase the wettability of the PEI substrate with 50×50 mm size. Then, silver was sputtered on top of the substrate through a patterned metal mask, to obtain the first electrode layer with thicknesses ~80 nm. After that, the P(VDF-TrFE) solution was spin coated on top of the patterned electrode, degassed under 1 mbar atmosphere to vaporize the solvent, and thereafter annealed at a temperature of 130° C for 2 hours to increase the crystallinity. The annealed film obtained a thickness around 10 μm. Finally, the upper electrode with a silver target were deposited on the top of P(VDF-TrFE) with the patterned metal mask with thicknesses ~80 nm, which completes the processing.

An image of the complete crossed electrode transducer with 16 rectangular apertures and 8 connection points is shown in **Fig. 1(a)** with the magnified view in **Fig. 1(b)**. From the images the active area of active element size was estimated to be around 270×270 μm^2 with the pitch distance around 130 μm.

In order to make the P(VDF-TrFE) layers piezoelectric, they were polarized at room temperature by connecting a high voltage AC source to the lower electrodes, while the upper ones were grounded.

2.2 Impedance measurements

An electrical LCR analyzer (Agilent E4982A) was used in order to measure the impedance in the frequency ranges from 1 to 200 MHz. For this measurement, it was necessary to calibrated and compensated for the electrode arm using standard loads (open, short, and 50 Ω).

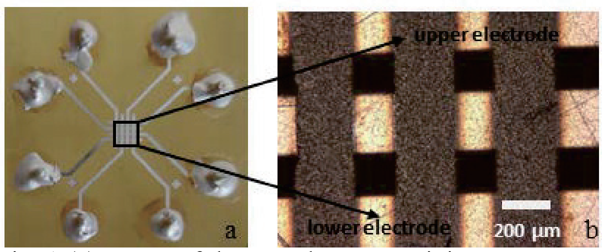

Fig. 1 (a) Image of the transducer containing cross array 16 transducer elements, (b) magnified view of transducer aperture.

The one electrode was driven by the LCR signal, while the other electrode was grounded. The amplitude of the admittance (the inverse of the impedance amplitude) and the phase were measured at all 16 locations were the electrodes crossed (hereafter referred to as elements), as shown in **Fig. 2 (a)** and **(b)**, respectively. A magnified inlet for frequencies between 95 and 105 MHz as a function of the driving frequency, is also shown in Fig 2 (a). For all measurements, the admittance and phase yield fast varying oscillations in almost the entire frequency regime, which are superimposed on top of a background level that increase with frequency. The maximum activity of the oscillations was seen in between 95 to 100 MHz.

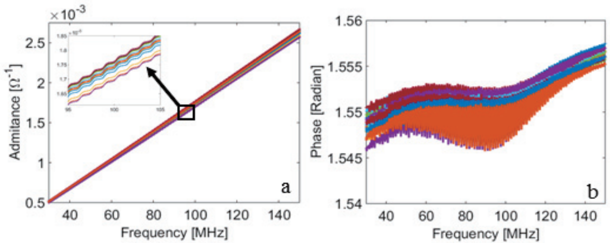

Fig. 2 (a) and (b) Admittance and phase measurements for all 16 elements of the transducers

The fast oscillations are due to the standing ultrasonic waves excited through the PEI-PVDF layered structure. This can be verified both from the oscillation frequency that matches well with the total structure thickness, and by characterization of un-poled films with lacking fast oscillations. Moreover, we observed very small variation in the admittance and phase values between all the 16 elements

2.3 Ultrasonic measurements

For the ultrasonic measurement, an arbitrary signal generator (Agilent 81150A) was used to excite one of the electrodes with a broad-banded pulse (second derivative of a Gaussian). The current induced one a counter-side electrode was then amplified by a current amplifier (FEMTO DHPCA-100) and sampled by an oscilloscope (Yokogawa DLM 6054) capable of digitizing with up to 12 bit accuracy in high resolution modus. For all the measurements, the output of the signal generator was adjusted to provide 5 Volts peak to peak, which turned out to be sufficient for producing a good signal to noise ratio after averaging over 256 pulse shootings.

Fig. 3 (a) shows the first acoustical reflection (FAR) from the PEI backside as a function of time for 4 of the transducer elements. Here, we can see quite identical responses from all elements with very small variation in amplitudes and phase delays. The frequency spectra in a dB corresponding for all 16 elements including the four elements shown in 3(a), are shown in the **Fig. 3(b)**. We have estimated the frequency response for all 16 elements from the ratio between the output and input spectra of the FAR. This ratio in dB is obtained by subtracting the input spectrum from the corresponding output acoustic spectrum in the dB scale. Here, we noticed only 1 dB variation in the acoustic signal amplitude between individual elements.

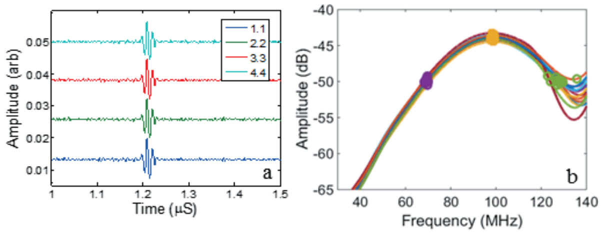

Fig. 3 (a) Acoustic reflections from the PEI (four element) with small bias added for separation of acoustic pulses (b) Frequency spectra in a dB corresponding for all 16 elements including the four element shown in (a)

From the figure, we also calculated a central frequency, where the maximum response occurs for each of the element were around 97.5 to 99.5 MHz with the standard deviation of 0.7 MHz. The -6 dB bandwidths were around 57.5 to 62.5 MHz with the standard deviation of 2.9 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 200 MHz bandwidth), and wave effects such as diffraction and attenuation and surface roughness of PVDF and PEI.

3. Conclusion

The present study has demonstrated that it is possible to produce adhesive free crossed electrode PVDF copolymer transducers for high frequency application. All 16 transducer elements showed a consistent broad banded ultrasonic spectra with maximum frequency responses around 97.5 to 99.5 MHz with very small standard deviation of 0.7 MHz. The -6 dB bandwidth of the elements of the transducers were around 57.5 to 62.5 MHz with the standard deviation of 2.9 MHz.

Acknowledgement

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