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Nondestructive evaluation of surface defects on flexible circuits using high frequency focused polymer transducers

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1. Introduction

Ferroelectric polyvinylidenefluoride (PVDF) and its copolymer PVDF trifluoroethylene [P(VDF-TrFE)] have several unique properties. They are easy to process, and have a rather low acoustic impedance which matches well with water and human tissue[1-4]. Hence, they are widely used for making ultrasonic sensors, transducers, hydrophones and actuators for different application such as biomedical imaging, and nondestructive evaluation of material[1-4]. Although, these piezoelectric polymers and co-polymers demerits from higher attenuation and lower electromechanical coupling properties compare to ceramics, the simplified material processing gives significant advantage for transducers working at high frequencies from 25 to 100 MHz[4]. Recently, we have also shown that the P(VDF-TrFE) can be screen-printed and spin coated to produce high frequency single element and array ultrasonic transducers with Polyetherimide (PEI) as the backing substrate[5-7].

For high frequency focused ceramic or crystal transducers, the acoustic energy is typically focused using a concave spherical sapphire lens rod[8]. The main disadvantage of such design is the impedance mismatch between the refractive lens material (e.g., sapphire) and water, yielding for example, reduced sound transmission, bandwidth reduction, and geometrical aberration of the focusing beam[9]. Some works also employed pre-poled flexible piezoelectric polymer film to fabricate focused transducers[1, 8] where additional adhesive layers are required. These layers may contribute to an increased inhomogeneity (e.g. through thickness variation) and wave reflection from impedance mismatch.

The main aim of the current work has been to build prototype for adhesive-free high frequency ultrasonic transducers using spherical cavities in PEI to focus the sound. These transducers have then been used to image surface variations in flexible electrical circuits. The suggested transducers will have advantages in terms of low production cost, simple electronics, and individual connection to each element.

2. Experiments and Results

2.1 Transducer prototyping

Four spherical cavities with 2 mm diameter were initially engraved in a PEI substrate with the dimension of 30×30 mm^2 size and 0.85 mm in thickness using a milling drill. The PEI polymer is known to have a very good thermal stability, good impedance match to the PVDF copolymer and very low acoustic attenuation[6]. Then, a thin layer of silver was sputtered on the flat side of the substrate pointing away from the cavity. The sputtering was done through a high-resolution metal mask to obtain the first electrode layer. After that dissolved P(VDF-TrFE) (77:23, molar ratio) was spin coated on top of the patterned electrode and annealed at a temperature of 130° C for 8 hours to increase the crystallinity. Finally, the upper electrode with a silver target was sputtered on the top of the P(VDF-TrFE) through another patterned metal mask which completes the assembly process. Both electrodes have thicknesses around 80 nm, while the annealed film gained a thickness 12 μm. An image of the focused transducer panel with four circular apertures and 12 connection points is shown in Fig. 1(a) with an illustration of the used

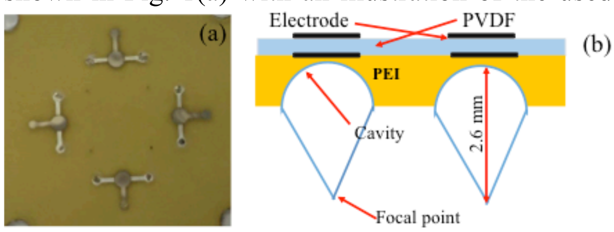

Fig. 1 (a) image of the final focused transducer containing 4 circular apertures, (b) illustration of focal point

cavities in Fig. 1(b) with a focal distance of 2.6 mm.

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

2.2 Ultrasonic measurements

To investigate the transducer response, the lower transducer electrode was driven by an arbitrary waveform generator (Agilent 81150A) with a Mexican hat shaped pulse (2nd derivative of a Gaussian) providing 5 V_{pp} amplitude. The ultrasonic pulse induced by this voltage becomes reflected from a glass plate placed at the focal point of the transducer. The current from this reflection is then pick up by the upper transducer electrode, and amplified by a trans-impedance amplifier (FEMTO DHPCA-100). The output voltage from this amplifier is finally digitized by an oscilloscope (Yokogawa DLM 6054) after averaging over 256 pulse shootings.

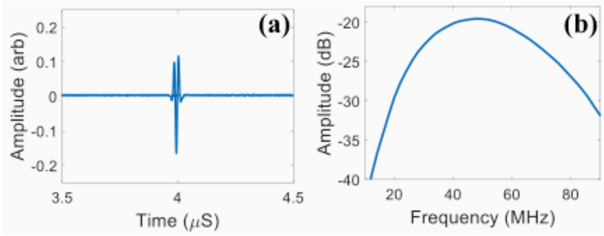

Fig. 2 (a) Ultrasonic measurements of the focused transducer reflections from the glass plate (b) Frequency spectra in a dB corresponding to (a)

Fig. 2 (a) shows the time-domain acoustical reflection induced by the glass reflector for one of the transducer elements. The corresponding frequency spectra in dB, is shown in the Fig. 3(b). The frequency response has been estimated from the ratio between the output and input spectra from the glass reflector. The central frequency response was measured to 48.5 MHz, with a lower and upper -6 dB bandwidths around 25 and 76.5 MHz, yielding a bandwidth of 94.2%. Several factors may influence the measured acoustic responses, like bandwidth limitation in the current amplifier, wave effects (e.g. diffraction and attenuation), and surface roughness of PVDF and PEI.

2.3 Scanning measurements of flexible circuit

The transducer prototypes were used to image flexible of Kapton circuit (thickness 84 μm) with a layered structure. These circuits contain layered structures of patterned copper electrode and PI embedded in a two-side solder mask. The element of the transducer was excited with a second derivative of Gaussian signal and scanned in the x and y direction with 25 μm step length.

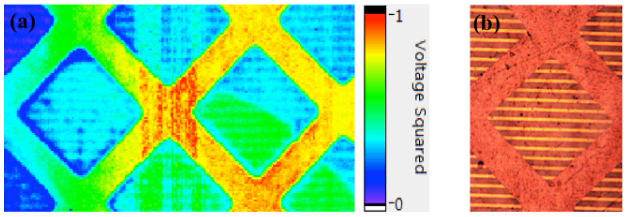

Fig. 3 (a) Acoustic image of the flexible circuit (2.25 × 1.25 mm^2) and (b) corresponding optical image

Fig. 3(a) shows the acoustic image of a sample flexible circuit at focal distance whereas Fig. 3(b) shows an optical image.

3. Conclusion

The present study has shown that it is possible to produce reliable polymer focused transducers from a layer-by-layer deposition method including milled spherical cavies in a PEI polymer substrate. The proposed method which process P(VDF-TrFE) from the fluid phase, is adhesive-free in the sense that it does not require any additional adhesive layers for material binding. The transducer center frequency was estimated to 48.5 MHz with 94.2% bandwidth. The two dimensional scanning showed very detailed surface variations with the expected resolution.

Acknowledgement

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