Adhesive free PVDF copolymer focused transducers for high frequency acoustic imaging

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1. Introduction

Scanning acoustic microscopy (SAM) is a wide field nondestructive and noninvasive technique. It was utilizing to observe the microscopic area on the surface of the sample and also beneath the sample of industrial objects, biological tissues and tissues for last several decades.[1-4)] The commercial high frequency acoustic transducers are made from ceramic, single crystal, or thin films of piezoelectric materials. In commercial acoustic transducers, the piezoelectric material is mounted on the flat side of a buffer rod. A concave spherical sapphire lens rod typically used to focus the acoustic energy through a coupling fluid onto the sample plane. In acoustic microscopy, water is the most common coupling media. The refractive index of water is 1.33 and sapphire is 7.3.[5)] The impedance mismatch (so called refractive index) between refractive lens rod and coupling media leads to reduce the sound transmissivity, bandwidth reduction, and geometrical aberration of the focusing beam. The Ferroelectric polyvinylidenefluoride (PVDF) and its copolymer PVDF trifluoroethylene [P(VDF-TrFE)] are widely used for making ultrasonic sensors and transducers.[6-8)] The application of P(VDF-TrFE) piezoelectric copolymer has also been broadened from hydrophone fabrication to ultrasonic imaging and further to photoacoustic imaging. These polymer-based transducers are also capable of provide a much better acoustic matched (PVDF refractive index=1.43) with commonly used materials like water, human tissues and have better broadband receiving performance for a small scanning area. The powder or palate like PVDF copolymer materials are flexible to some extent, and relatively easy to process. These polymers are very suitable materials for achieving high frequencies with a large bandwidth for ultrasonic sensors and transducers.[9)] A motivation of this paper is to demonstrate a new approach to fabricate high frequency P(VDF-TrFE) acoustic focused transducer employing adhesive free layer-by layer deposition methods. In the transducer fabrication process, the polyethyleneimine (PEI) has been selected as acoustic lens material for several reason like; good thermal stability, good impedance match to the PVDF copolymer, and very low acoustic attenuation.[10)]

2. Transducer fabrication

The fabrication process initiated by engraving the four spherical cavities of 2 mm diameter on polyethyleneimines (PEI) polymer substrate with dimension of 30×30 mm^2 and 0.85 mm in thickness using the milling drill. The tip of the milling drill was drilled 0.65 mm into the material, leaving a 0.2 mm space to the opposite flat PEI surface. The outer peripheral diameter of the spherical cavities was 2 mm, as shown Fig. 1.

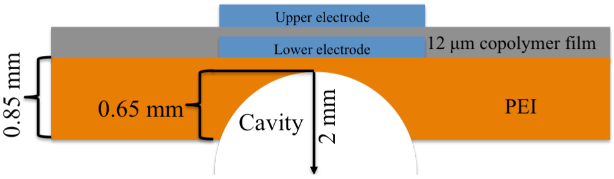

Fig. 1. Schematic diagram (side view) of the proposed PVDF copolymer focused transducer

A thin layer of silver ~80 nm was sputtered on the flat side of the PEI substrate pointing away from the cavity. The sputtering was done through a high-resolution metal mask to obtain the first electrode (lower) layer. After that, fluid phase P(VDF-TrFE) (80:20, molar ratio) dissolved in appropriate amount of solvent was spin coated on top of the patterned electrode. Then, the fabricated transducers were then degassed in 1 mbar vacuum chamber in order to vaporize the solvent. Later, the transducers were annealed at a temperature of 130° C for 2 hours after degassing in the vacuum chamber. At the end of the process, 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 wet processing. The electrical connection from/to the electrodes were done by conductive pins.

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

3. Results and discussion

3.1 Ultrasonic measurement

For the measurement, a broad banded second derivative of a Gaussian pulses were excited employing an arbitrary wave generator (Agilent

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81150A) on one of the electrode layers, which was received as current by the other electrode layer. The received signal was amplified by a current amplifier (FEMTO DHPCA-100). The output potential from the current amplifier was 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. 2 (a) shows the time-domain acoustical reflection induced by the glass reflector for one of the transducer. The corresponding frequency spectra in dB, is shown in the Fig. 2(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%.

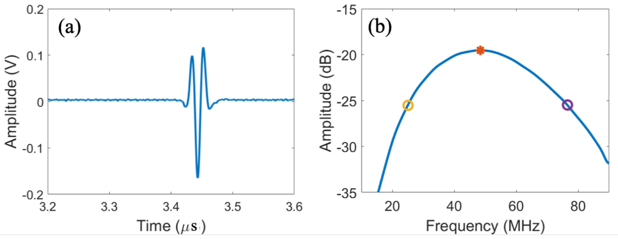

Fig. 2. Ultrasonic measurements of the focused transducer reflections from the glass plate at focal point and ± 10 μm from focal point (b) Frequency spectra in a dB corresponding to (a).

3.2 Acoustic imaging

One of the P(VDF-TrFE) transducer prototypes was mounted in a water tank and scanned in a two-dimensional (2D) plane over a test object. The scanning area of the sample was predefined with a size of 8.4 mm × 4.8 mm of a coin (Norwegian 1 krone). For acoustic imaging of the test sample, a similar experimental setup was reported by our group previously.[11)]

The transducer was focused on the coin top surface, and the voltage amplitudes for each step or pixel were plotted to create 2D images. The images generated for a coin surface from the scanning is shown in Fig. 3(c).

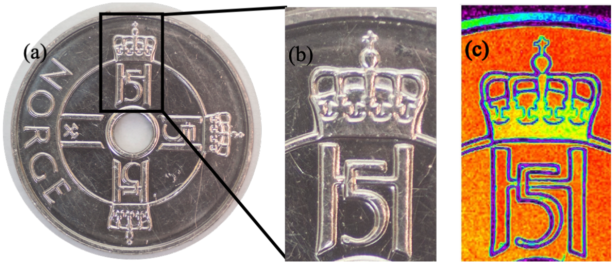

Fig. 3. Optical image of the Norwegian 1-krone coin used as the test sample [Fig. (a)] and fig (b) is the zoomed view of fig. (a) and fig. (c) is the ultrasonic amplitude image within the indicated (optical image) scanning area.

4. Conclusion

The present study has demonstrated to produce a reliable PVDF copolymer focused transducers from a layer-by-layer deposition method by engraving 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 was acoustically characterized by pulse/echo ultrasonic measurements. 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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