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Integration of high frequency PVDF copolymer transducers in microfluidic system for ultrasonic spectral characterization of microparticles

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1. Introduction

Polyvinylidene fluoride (PVDF) and the copolymer with trifluoroethylene (PVDF-TrFE) are biocompatible materials with high chemically resistance. They also provide a relatively good acoustic match to water, human tissue, and the most other polymer materials. Due to these properties and their unique ferroelectric phases, they have been used extensively as piezoelectric materials for sensors, transducers, and actuators [1-9]. Recently, our group have demonstrated that P(VDF-TrFE) could be screen-printed from the fluid phase, together with electrodes of conductive polymers for utilizing in high frequency ultrasonic transducers with polyetherimide (PEI) as the printing substrate [10, 11].

High frequency ultrasonic devices have been used to evaluate microparticles and cells. Examples here are size and concentration measurements in liquid suspensions/emulsions [12, 13], and detection of changes in cells or tissues suspended in solutions [14]. The scattering responses of microparticles that are floating or suspended in water have also been studied by analytical means [12-14], finite element methods (FEM) [13] and resonance scattering theory (RST) [15]. Recently, our group demonstrated that the high frequency P(VDF-TrFE) copolymer transducer made on the flexible substrates PEI (polyetherimide i.e. Ultem) can be used for the evaluation of the microparticle concentration and sizes settled on a glass substrate [16]. The results show that back scattering signal amplitudes and frequencies are quite dependent on particle sizes and concentration. These transducers offer larger flexibility, yield broad banded frequency responses which are essential for ultrasonic analyses of microparticles, cells and tissue.The objective of the current work is to evaluate the backscattering spectral of microparticles resting on different reflecting boundary i.e. directly settling on the PEI substrate.

2. Experiments and Results

The unfocused [P(VDF-TrFE)] copolymer transducers with sputtered (Cr/Au/Cr) electrodes built on top of a polyetherimide (PEI)/Ultem was used in the experiment. The transducer contained 4 active circular aperture elements with the diameter of 1.5 mm and the film thickness of the copolymer was ~12 µm as shown in the **Fig. 1(a)**. A small rectangular acrylic chamber was attached on the backside of PEI substrate i.e. counter side of the circular aperture to confine the microparticles solutions.

The ultrasonic measurement system used to characterize the transducers is shown in **Fig. 1 (b)**. The circular electrodes of transducer were driven by an ultra-wide band signal described by second derivative of the Gaussian shape pulses from an arbitrary waveform generator (Agilent 81150A) with the output of 5 Volts peak to peak. The acoustical signal caused by this pulse were picked up as currents on the counter-side electrode, and sent into the trans-impedance current amplifier (FEMTO DHPCA-100). Finally, a digital oscilloscope (Yokogawa DLM 6054) used to digitize the analog signals with averaging of 256 pulse shootings.

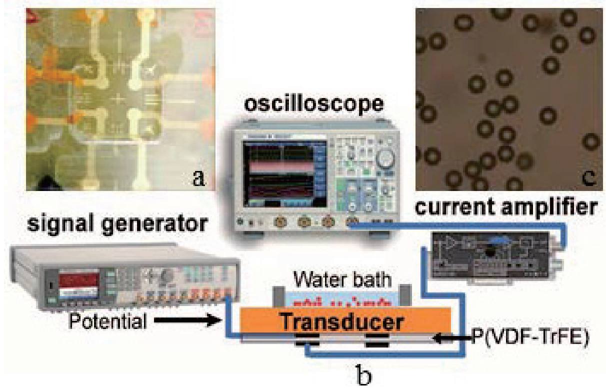

Fig. 1. Experimental setup. (a) Optical image of a transducer panel containing 4 transducers with glass plate chamber. (b) Experiment setup used to characterize the acoustical properties. (c) Optical image of polymer microspheres (~15µm).

The polymer microparticles of diameters between 5 to 25 µm (Duke scientific) were used to investigate the capabilities of transducer. The diluted microparticles suspension were pipetted into a small acrylic chamber on top of the PEI backing as shown in the Fig. 1(b). As the specific density of microparticles were 1.05 g/cm^3 and its size relatively large (> 5µm), the particles were allowed to settle down on top of the PEI substrate before experiments. An optical image of the settled sample is shown in the inset **Fig 1 (c)**.

The acoustical reflection (AR) at PEI/water boundary for five different sizes micro particle with diameters ranging from 5 to 25µm together with a reference measurement (no particles) is shown in the **Fig. 2(a)**. The experimental data shows an extension trailing waveform for the microparticles solution compare to the reference. The extension of the AR is limited, indicating that the most of the particles are located at the PEI surface. Since the transducer surface is parallel to the PEI surface, the spatial distance to all microspheres will be almost constant, yielding a coherent backscattering.

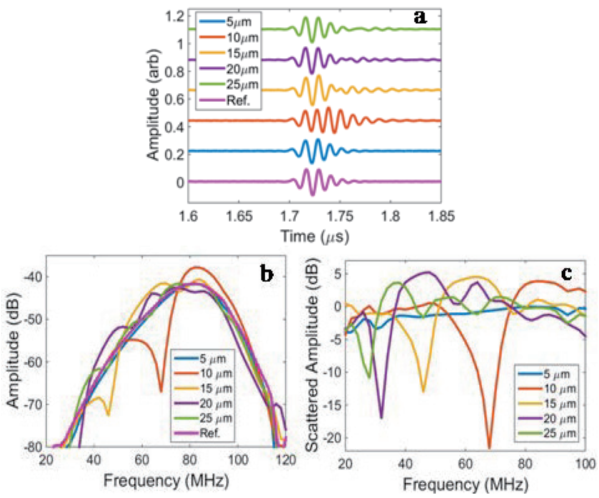

Fig. 2. Acoustic reflections for the reference signal (no particle) and for microspheres with five different sizes. (a) Time domain reflections obtained from the experiment using 1 wt% concentration, (b) corresponding spectra, and (c) spectra after subtracting the reference spectrum

The frequency spectra of the five microparticle solutions and the reference spectrum are shown in the **Fig. 2(b)**. Here, the peak frequency of the reference spectrum, which corresponds to the central frequency, is located around 80 MHz. With an increase in the particle size there is an increase absorption in the frequencies, both in terms of local absorption in bands (giving a number of local extreme points), and more global absorption for high frequencies. The number of the absorption peaks also increased with increase in the particle size.

The band was also visualized by subtracting the reference spectrum from the particle spectra as shown in **Fig. 2(c)**. From the figure, the scattering contribution from the microspheres and the number of local extreme points can more easily be identified. These extreme values are strongly correlated to resonances and anti-resonances of standing wave features in the microspheres.

3. Conclusion

Unfocused high frequency P(VDF-TrFE) copolymer ultrasonic transducers is fabricated and employed to evaluate the scattering from polymer microparticles. The high frequency ultrasonic transducer offers large flexibility due to a direct coupling to an external glass or polymer materials device under test (DUT). The suggested high frequency ultrasonic transducer offers large flexibility due to a direct coupling to an external glass or polymer materials DUT. Here, we detected microspheres of diameter 5 to 25µm by introducing particles directly on the PEI substrate, the counter side of the transducer aperture. The amplitudes of the back scattering signals were found to be dependent on the particles sizes with corresponding spectra yielding a number of local minima and maxima. In addition, the frequency locations of these extreme values are strongly correlated to the particle sizes. The transducers can be integrated with the advance micro-fluidic systems and will find applications for lab-on-a-chip detection and analysis of microparticles and biological cells.

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