Thin Film PZT-Based PMUT Arrays for 1D Microparticle Manipulation & Imaging Applications

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Background, Motivation and Objective

There is growing interest in being able to deterministically manipulate microscale objects, particularly via acoustophoresis, due to possibility of application to biological specimens. Many bulk transducers have been used to demonstrate acoustic tweezing, but the limited number of array elements limits the controllability. In this work, piezoelectric micromachined ultrasound transducers (PMUTs) were tested for their suitability for photoacoustic imaging and particle manipulation applications, due to the relative simplicity of making 1 and 2D arrays.

Statement of Contribution/Methods

Phase pure, {001} oriented $PbZr_{0.52}Ti_{0.48}O_3$ films were via sol-gel process on Pt-coated SOI substrates with ~0.1 µm SiO_2 thickness as the elastic layer. Standard micromachining approaches were utilized to create released structures in the 6 – 8 MHz frequency range. Electrical characterization was done via hysteresis and permittivity measurements. Laser doppler vibrometry was used to determine resonant frequency and diaphragm deflection after the PMUT structure was released. Underwater characterization was conducted with a hydrophone to obtain pressure outputs and bandwidth.

Results/Discussion

Fabricated PMUTs with a 60 µm diaphragm diameter had a resonant frequency of ~ 8 MHz and a bandwidth of 62.5%. The in-air deflection was found to be > 100 nm at 5 V_{pp} unipolar excitation; this was dampened to ~ 10 nm underwater. For a single element with 20 diaphragms, ~ 9.5 kPa was achieved at 7.5 mm distance. For a device with an array of 20 elements, with each element having 40 diaphragms, the elements displayed high electrical uniformity in terms of performance for each element (permittivity: 1487 ± 8 at 95% confidence interval, loss tangent < 5%, output pressures = 18 – 25 kPa).
Particle manipulation of 4 µm silica beads with PMUTs was demonstrated with 5 V_{pp} unipolar excitation. Moreover, deterministic control of particles via acoustophoresis in 1D direction without the assistance of microfluidic flow was demonstrated. By turning adjacent elements on or off, the silica beads were trapped and manipulated from one element to another. Multiple trapping of beads per array element was also achieved. In addition, as driving frequency increased, bead patterns formed that correspond to higher mode shapes. Levitation planes were generated at greater than 30 MHz driving frequencies, and were detected as high as 60 MHz. It is noteworthy that bead movement was seen well outside the 6dB transducer bandwidth. PMUTs were also tested in both ultrasound imaging and photoacoustic imaging methods. Pitch-catch imaging on high acoustic contrast targets was demonstrated by using a single element with 20 diaphragms, imaging of millimeter scale targets could be achieved without the need for beam focusing. Using photoacoustic imaging, strong signal could be achieved with 0.7 mm pencil lead targets through ~ 5 mm of chicken tissue, as well as a single follicle of hair (~200 µm).