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High-frequency transducer for MR-guided FUS

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Introduction

High-intensity focused ultrasound is finding increasing therapeutic use. However, the frequencies at which it operates are typically limited to below 5 MHz, preventing research into therapy with ultrahigh spatial precision. A reason for this is that the design and fabrication of high-frequency biomedical ultrasound transducers to produce high intensities is an engineering challenge, especially for operating frequencies above 30 MHz, primarily because of the acoustic impedance mismatch and the high attenuation of water of 6dB/cm at 50 MHz leading to a low penetration depth. Commonly used materials such as PZT do not have the ability to produce a high enough intensity, due to de-poling or cracking. A potential application of high-intensity high-frequency ultrasound is non-invasive microsurgery.

Methods

To overcome these problems, we used Y-36o Lithium Niobate (LiNbO3). This crystal has a high Curie temperature and is much more difficult to de-pole at high-power inputs. In addition, Y-36o LiNbO3 has a resonant frequency of 3.3 MHz mm-1, thus allowing for much thicker elements at higher frequencies compared to PZT. A bowl transducer was manufactured using a total of 7 0.5-mm thick elements (4 hexagonal and 5 pentagonal) with a maximum width of 25 mm. The bowl had a curvature radius of 50 mm. The transducer was microballoon-backed in order to simplify the manufacturing process. The pentagonal elements were linked and driven by a 50-dB amplifier, whereas the hexagonal elements were linked and driven by a 55-dB amplifier. To test the available working frequency; single element transducers were manufactured with element thickness ranging from 500 μm to 200 μm, having working frequencies between 6.6 MHz and 20 MHz.

Results

The multi-element focused transducer generated a modulated sound field with an enveloped wavelength of 550 kHz at a frequency of 6.6 MHz with a maximum peak-to-peak pressure of 24.3 MPa; equivalent to mechanical index of 4.7. The modulation could be varied by changing the phase of either the pentagonal or hexagonal linked elements. The microballoon-backed transducers had a 5% reduced acoustic output compared to the air-backed transducer. Single-element transducers produced a maximum peak-to-peak pressure of 14 MPa at 6.3 MHz in the acoustic focus at 12 mm. These transducers were capable of producing over 6 MPa and 4 MPa at the 3rd and 5th harmonics, respectively, corresponding to frequencies of 21 MHz and 35 MHz.

Conclusion

We have established that manufacturing a high frequency, high intensity, multi-element, focused ultrasound transducer using $LiNbO_3$ is feasible. We have also shown it is possible to use the resonant frequency and up to the 5^{th} harmonic to achieve higher working frequencies.