MR-Temperature maps of a HIFU CMUT

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Introduction: In the last decade, non-invasive and minimally invasive, high intensity focused ultrasound (HIFU) has gained popularity in the treatment of diseases such as uterine fibroids, cancer, and cardiac arrhythmias. HIFU therapy is often guided by magnetic resonance imaging (MRI), which provides anatomical images for guidance, temperature maps for treatment monitoring, and post-operative evaluation of tissues. While piezoelectric transducers have dominated MR-guided ultrasound therapies, capacitive micromachined ultrasonic transducers (CMUTs) show many competitive advantages including ease of fabrication, improved efficiency and performance, and minimal self-heating. In this paper, we will show the first results of an unfocused CMUT heating a gel phantom and monitored by MRI.

Methods:

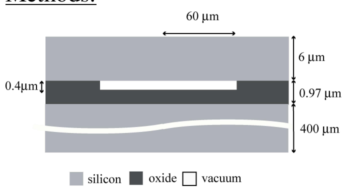

Fig. 1: Schematic of a HIFU CMUT cell

CMUTs (Fig. 1) were fabricated using the wafer-bonding process [1] with a highly conductive silicon membrane. This eliminates the need for metal on the surface of the cells and associated electromigration effects during high power operation. In addition, silicon is highly thermally conductive, which reduces self-heating. Finally, the silicon membranes are completely MR-compatible [2]. After creating 2.5 x 2.5mm transducers by placing cells in parallel, we attached the device to a printed circuit board and placed it inside the 3.0 T GE MR system. An oil film and a piece of polyethylene were used to electrically isolate the CMUT from the gel phantom, which was placed on top (Fig.

After tuning the CMUT with an air-core inductor, we applied a DC voltage of 172 V superimposed with a 2.5 MHz continuous wave (CW) sinusoidal signal that was 250 Vpp. The heating of the HIFU gel was monitored using a fast gradient echo sequence. Images were acquired in the coronal plane with a TR/TE of 17.4/13.5 ms for 7.5 minutes during which the ultrasound was turned on for 2.5 min. Subsequently, images were acquired in the sagittal plane with a TR/TE of 28.7/19.1 ms for 12.5 minutes while the ultrasound was applied for 5 min. Temperature maps were calculated from the phase difference of the heating and baseline images, using a thermal coefficient of 0.01 ppm/°C.

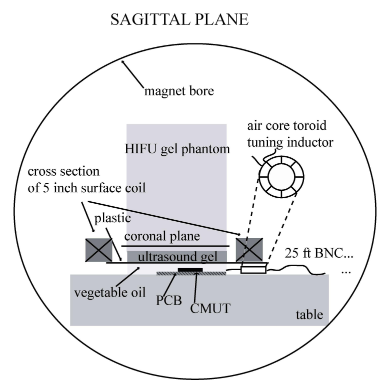

Fig. 2: Setup for MR-temperature monitoring of a HIFU CMUT

Results and Discussion: During operation of the HIFU CMUT, we measured an electrical to acoustical efficiency of 68%, which is competitive to piezoelectric transducers. With this efficiency, even a small unfocused transducer could produce a temperature rise of 14.6°C after 2.5 min at a distance of 3 mm from the transducer's surface, and 16.8°C at the surface of the transducers (Fig. 3).

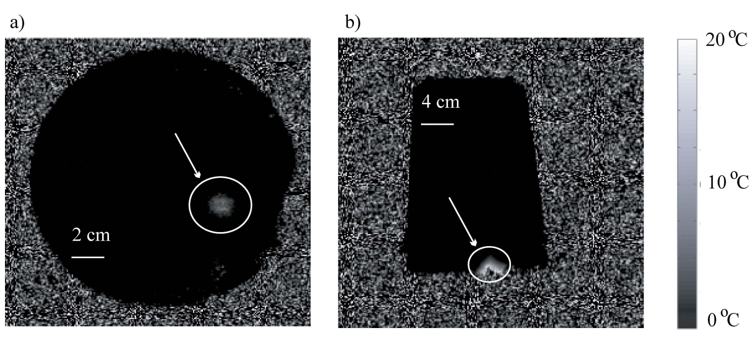

Fig. 3: MR-temperature maps of the coronal (a) and sagittal (b) plane, showing the time point with the greatest temperature rise during the application of ultrasound.

Conclusion: We have demonstrated that a HIFU CMUTs has the efficiency and power needed for therapeutic applications. In our experiments, even a small, unfocused device was able to heat a HIFU gel phantom by 16.8°C after 5 min of therapy. We have also shown that it is possible to monitor the therapy administered by CMUTs using MR-temperature maps with no noticeable effect on MR image quality. Future work includes the development of annular ring arrays that can be focused. With these, greater amounts of energy will be deposited in the tissue, increasing the speed and degree of heating; electronic steering of the focus will also be possible with the array.

References:
[1] Y. Huang, et al, Microelectromechanical Systems, 12(2), pp. 128-137.
[2] J.F. Schenck, Medical Physics, 23(6), pp. 815-850.