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A study on the energy concentration in human body using focused ultrasound.

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1. Introduction

Acoustic Targeted Drug Delivery (ATDD) is a method of stimulating the tissue beneath the surface of the skin by using a low intensity focused ultrasound [1].

A significant advantage of the ATDD device with the MEMS technology is that large transducer arrays can be implemented in a small area [2]. This enables the delivery of high acoustic power to the target area without generating high pressure on the surface of the transducer. Moreover, beamforming system with the MEMS technology for the ATDD doesn't suffer from the self-heating effect because MEMS transducer array is fabricated from high thermally-conductive silicon. As a result, it is suitable for applications that need long-term attachment of an ultrasound transducer on the skin.

In this study, we presented the design and measurement of an ultrasonic beamforming system using the MEMS based transducer array for the ATDD application.

2. Materials and Methods

The pressure is calculated with the Rayleigh-Sommerfeld integral for the simulation of individual transducers and large ultrasound phased array [3].

$$p(\mathbf{r},t) = j\rho c k e^{j\omega t}\int_{S'} u(\mathbf{r}')\frac{e^{-jkR}}{2\pi R}d\mathbf{S}' \qquad (1)$$

where ρ is the density of the water, c is the speed of sound, k is the wave number, and R is the distance from the center of the transducer to specific object of interest. The pressure field is computed via the superposition of complex pressure produced by the phased array transducer. Then, it returns the values of the emitted pulsed pressure waves with time at all positions of interest.

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Table I. Simulation and Experimental conditions

	Parameter Description	Setting
ω	Driving frequency	2.2MHz
u	Velocity amplitude of the surface	0.15 m/s
N	Number of elements per axis	15
	Diameter of element	100μm
	Kerf between adjacent elements	50μm

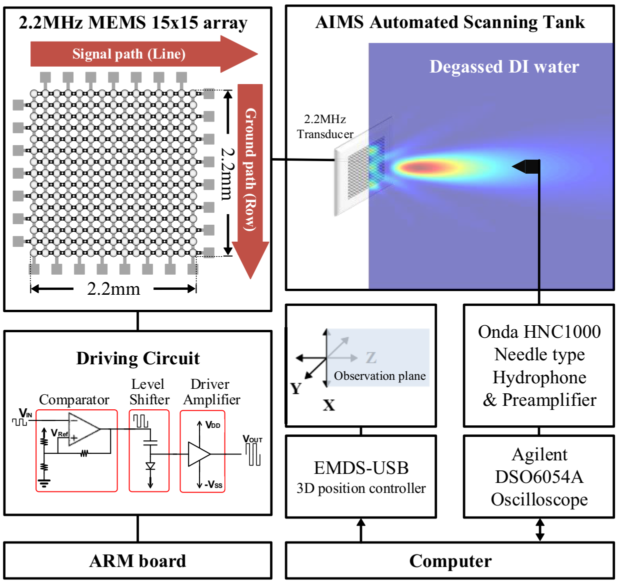
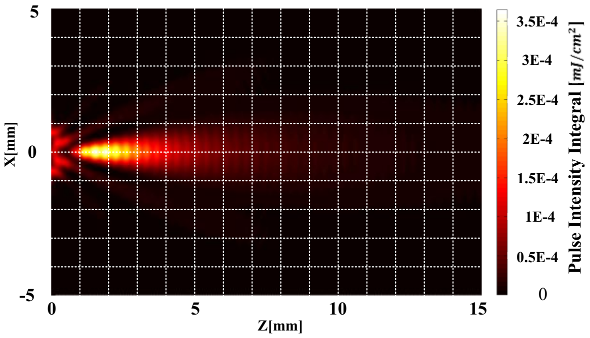


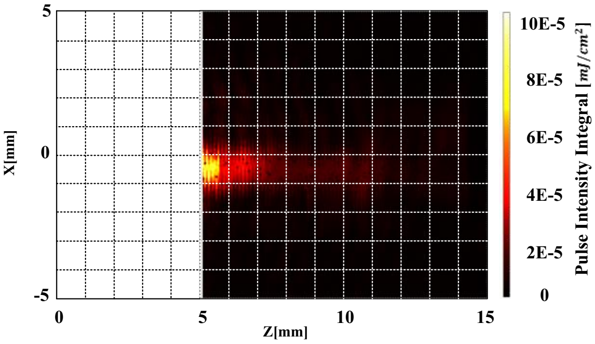
Fig. 1 A schematic diagram of the experimental setup for measurement using a pressure mapping system.

Fig. 1 shows the system configuration of the ultrasonic beamforming system. MEMS transducer transforms the electric power generated by the ARM board and amplified by the driver amplifier into ultrasonic power. Each signal path has a specific time delay, which is controlled by the ARM board. The driving amplifier circuit consisting of a comparator and driver amplifier converts digital signal to an analog signal having a high voltage. The acoustic performance of the transducer was evaluated with the precision acoustic measurement tank (AIMS) with degassed water using a calibrated needle-type hydrophone.

3. Results.



(a) Simulation



(b) Hydrophone Measurement

Fig. 2 Beam pattern of Pulse Intensity Integral

Fig. 2(a) shows the result of the simulated beam pattern of Pulse Intensity Integral (PII). The focal point was about 2 mm from the surface of the transducer with the z-axis direction. **Fig. 2(b)** shows the measured beam pattern at depth from 5 mm to 15 mm with the z-axis direction.

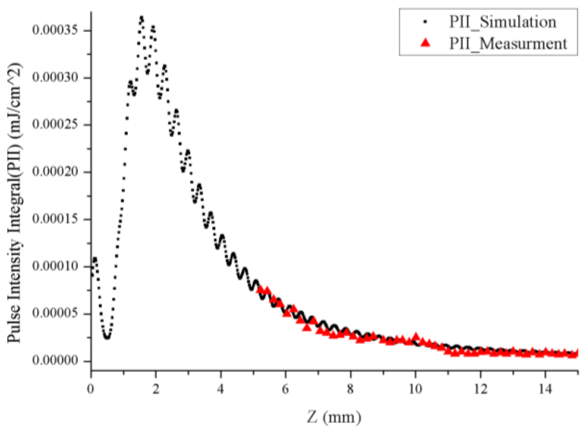


Fig. 3 Comparison of simulated and measured values of Pulse Intensity Integral for the MEMS transducer

Fig. 3 shows the comparison of the simulated and measured value of PII at depths ranging from 5 mm to 15mm below the transducer surface. The simulated and the measured I_{spta} at 7 mm are 96.72 mW/ cm^2 and 94.08 mW/ cm^2 respectively. The focused beam pattern can be estimated from the simulation results because the measured values show a great agreement with the simulation results presented in **Fig.3**.

The acoustic focal region (AFR), the region bounded by the intensity contour lying 3 dB below the peak intensity, was located at 2mm from the surface of the transducer with the z-axis direction. At the AFR, simulated I_{spta} is the largest value of 739 mW/cm^2. The dimensions of the AFR are 1.7 mm along the beam axis and 0.8 mm in the transverse direction.

I_{spta} ranging from 0.05 to 0.8 W/ cm^2 increases the cell membrane permeability as already observed in the literature [4]. Therefore, focused ultrasound using beamforming system with the MEMS transducer array could be used for the ATDD.

4. Conclusion and future work

This paper has presented the design and measurement of an ultrasonic beamforming system using the MEMS transducer for the ATDD application. The beamforming is achieved by adopting the time difference between each signal path. ARM processor which has a high operating frequency to satisfy the resolution of the time delay is used. A small AFR dimension (0.8 mm×1.7 mm) and an intensity value of I_{spta} (739 mW/cm^2) by are achieved using the MEMS transducer.

The simulation and measurement results proved to be a perfect alternative for the ATDD.

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