A Transducer with Inversion Layer Technique for Expanded Lesion Size in HIFU Surgery

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***Abstract*—In High Intensity Focused Ultrasound (HIFU) surgery, benign or malignant tumors can be treated through the thermal and mechanical effects of the focused ultrasound. However, the overall HIFU treatment time is relatively long compared with the open surgery because the irradiation area of the ultrasound beam is very small. In this paper, we present a dual-concentric HIFU transducer with inversion layer technique to extend the focal region in the axial direction. The performance of the proposed technique was demonstrated by Finite Element Analysis (FEA) simulation, and the lesion size was increased by 97% compared with the conventional single element transducer based on the extended -6 dB Depth of Focus (DOF). Therefore, the proposed HIFU transducer can be one of the useful ways to shorten the total treatment time of the HIFU surgery.**

Keywords-finite element analysis; dual-concentric HIFU transducer; high intensity focused ultrasound; inversion layer; phase inversion.

I. INTRODUCTION

In High Intensity Focused Ultrasound (HIFU) surgery, one of the main disadvantages is relatively long treatment time, mainly due to the small therapeutic area per sonication [1]. In order to solve this problem, some researchers have developed specially designed HIFU transducers, such as toric or split-aperture transducers [2][3]. However, they can mainly expand the lesion size in the lateral direction rather than the axial direction. In this paper, we propose a dual-concentric HIFU transducer with inversion layer technique that can increase lesion size in the axial direction to treat a deeply located target. The performance of the proposed technique was demonstrated by Finite Element Analysis (FEA) using PZFlex tool (OnScale, Cupertino, CA, USA) [4].

The rest of the paper is structured as follows. In Section II and Section III, the principle of the proposed technique and the simulation results are explained, respectively. The conclusions are drawn in Section IV.

II. METHODS

The proposed HIFU transducer consists of disc-type and ring-type elements with the confocal point. Each element is driven by two input signals with opposite phases, i.e., 0° and 180°. In this case, the axial beam pattern with a deep valley can be generated [5]. To complement that deep notch point, multi-frequency ultrasound generated by the inversion layer technique was employed [6]. In other words, a dual-concentric transducer using inversion layer technique can achieve a relatively uniform -6 dB Depth of Focus (DOF). Note that DOF is closely related to the lesion size. In the FEA simulation, PZT4 (Lead Zirconate Titanate) and unloaded epoxy were used for piezoelectric material and kerf filler, respectively. To implement inversion layer technique, two piezoelectric layers with opposite poling direction were employed as shown in Figure 1(b). A conventional single element transducer in Figure 1(a) was also designed to compare the performance of the proposed transducer. The outer diameter of the ring-type element was 31.4 mm, the inner diameter of the disc-type element was 22 mm, and a kerf width was 0.2 mm. The aperture had a concave shape, and the focal length was 35 mm. There was no backing layer to maximize the transmitted energy, and water was chosen as the medium.

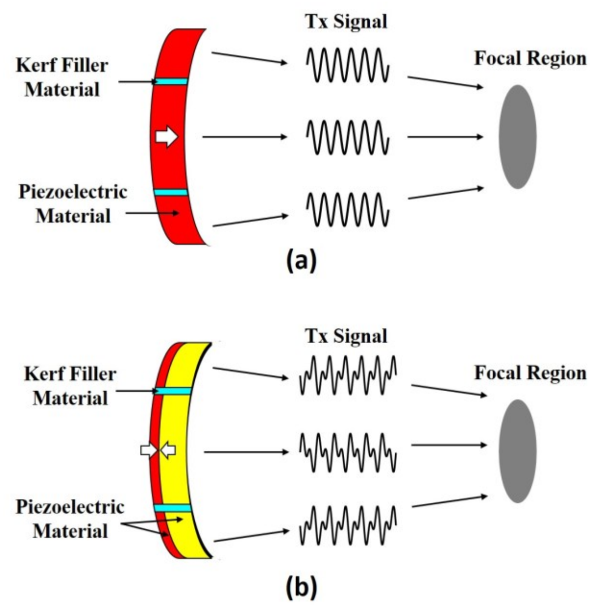

Figure 1. Schematic diagrams of (a) the conventional single element transducer and (b) the proposed transducer. Note that a white arrow indicates polling direction of piezoelectric material.

III. RESULTS

The simulation results of electrical impedance are shown in Figure 2(a) and (b). The conventional single element transducer in Figure 2(a) had single-resonance peak at 3

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MHz frequency, and the proposed transducer in Figure 2(b) had dual-resonance peaks at 3 MHz and 6 MHz at the same time. This phenomenon may reduce transmitted power, but it can be compensated by adjusting driving voltage of the input signal. In the sound field simulation, the conventional single element transducer had -6 dB DOF of 5.97 mm as shown in Figure 3(a), while the proposed transducer in Figure 3(b) had -6 dB DOF of 11.74 mm, which is 97% improved compared with the conventional single element transducer. The -6 dB lateral beamwidths of the conventional single element transducer and the proposed transducer were 0.79 mm and 0.72 mm, respectively. The lateral beamwidth of the proposed transducer was slightly reduced (7.7%) compared with the conventional single element transducer. Note that -6 dB lateral beamwidths were obtained based on beam projection scheme while the -6 dB DOF was acquired at maximum pressure in the axial direction.

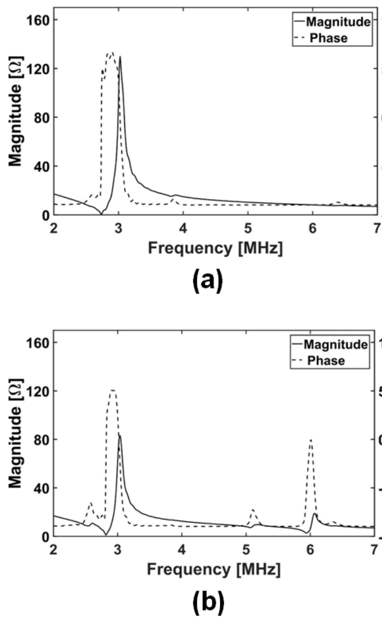

Figure 2. Electrical impedance simulation results: (a) the conventional single element transducer and (b) the proposed transducer (inner disc-type element).

IV. CONCLUSION

In this paper, we propose the dual-concentric HIFU transducer with the inversion layer technique to extend the focal length (i.e., -6 dB DOF). The proposed method can axially increase the focal length related to the lesion size by 97% compared with the conventional single element transducer and thus shorten the total treatment time of the HIFU surgery.

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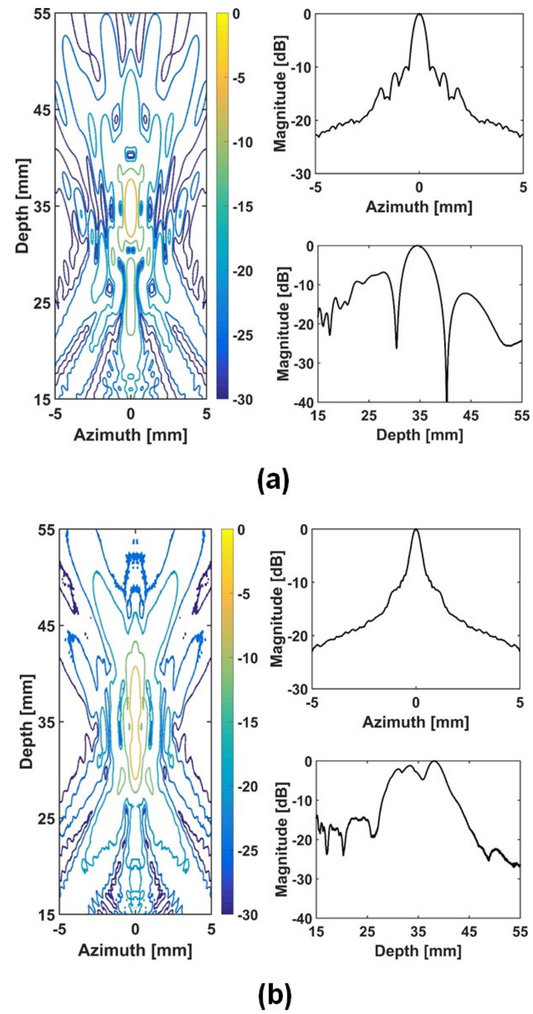

Figure 3. Sound field simulation results including 2D sound field, lateral beam pattern, and axial beam pattern: (a) the conventional single element transducer and (b) the proposed transducer.

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