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Adjustable acoustic pattern controlled by "Acoustic mirrors"

Zhaoxi Li, Chunlong Fei*, Di Li, Dong-dong Chen, Qifa Zhou
School of Microelectronics
Xidian University
Xi'an, China
*clfei@xidian.edu.cn

***Abstract*—The controlled coupling of acoustic field is widely used in medical treatment, neuromodulation, particle manipulation, and biological imaging. Nowadays, phased arrays and acoustic lenses of design structures are two ways of controlling the ultrasound field. However, the disadvantages of the two methods are that phased arrays are complex in structure by adjusting parameters of each array element and acoustic lenses have limited flexibility when the design is complete. We designed report a new way for acoustic pattern control by using adjustable "Acoustic mirror". The principle is that two symmetric mirrors change the propagation of the sound generated by piezoelectric material and achieve interference enhancement in the target area. The 2D "Acoustic mirror" model is implemented in COMSOL and actual model build by 3D printed technology verify the simulation result. The acoustic intensity generated by piezoelectric material at various lateral and longitudinal locations along the focus can be precisely controlled by two adjustable mirrors. The focal depth varies from 39mm to 140mm while the angel of the mirror changes from 30° to 40°. Moreover, the focal position can be adjusted in a fan area with a center angle of 60°.The "Acoustic mirror" shows good control of sound field of ultrasonic transducer, which is simple and flexible. It suggests a new method for ultrasonic field control which may have broad application in the future.**

Keywords—ultrasonic field control, 3D printed technology, finite element simulation, Acoustic mirror

I. INTRODUCTION

Ultrasonic wave can induce various effects such as radiation force, thermal effects and cavitation. It has many biological and medical applications including biological imagine, particle manipulation, high intensity focused ultrasound(HIFU)[1] and nerve regulation[2]. Better control of the ultrasound beam is of paramount importance for various applications for example the correction of transracial focused ultrasound aberrations is a relevant issue for enhancing various non-invasive medical treatments[3].

Now here are two main ways to focus sound waves. The first method is the phased array. It can form high-energy beam spot areas at the target point acoustic because beams with small side lobes and strong directivity can be formed through adjusting parameters such as spacing, the delay time, and emission frequency of each array element[4]. However, phased arrays are complex in structure by adjusting parameters of each array element. The second method is the acoustic lens[5-6]. By using special materials and design structures, the acoustic wave bends when it passes through the lens, thus achieving a higher intensity at the target point. The disadvantage of acoustic lenses have limited flexibility when the design is complete.

We report a n a new way for acoustic pattern control by using adjustable "Acoustic mirror", through accurately adjusting the angle between the mirror and the piezoelectric element, we can adjust the propagation of the ultrasound conveniently, thus, achieve interference enhancement at the area of interest. Principle of reflection and interference were used to design the structure and situation of the mirror. A 2D model was implemented in FEM to evaluate the performance and a prototype was built through 3D printing technology to verify the design. It suggests a simple way for acoustic pattern control which can have broad application in the future..

II. RESULT

A. Numerical studies and theoretical analysis of "acoustic mirrors" model

Fig.1 shows the 2D model and schematic of "acoustic mirrors". The sound field of ultrasound source(1MHz PZT4) is in the middle of two rotatable acoustic mirrors which are fixed on the midperpendicular of source. It is assumed here that the piezoelectric material produces sound waves that are uniform plane waves. As show in Fig.1(a-b) the focal depth was obtained from reflection theory and Interference effect , and changes from 58.5mm to 145.2mm when the rotation angle of each mirror from 35° to 40°. Furthermore, the focus area also changes in the longitudinal direction when the angle of two mirrors is different in Fig.1(c). This theoretically gives a approximately sound field calculation model controlled by "acoustic mirror". Fig.1 shows the 2D model and schematic of "acoustic mirrors". The sound field of ultrasound source(1MHz PZT4) is in the middle of two rotatable acoustic mirrors which are fixed on the midperpendicular of source. It is assumed here that the piezoelectric material produces sound waves that are uniform plane waves. As show in Fig.1(a-b) the focal depth was obtained from reflection theory and Interference effect , and changes from 58.5mm to 145.2mm when the rotation angle of each mirror from 35° to 40°. Furthermore, the focus area also changes in the longitudinal direction when the angle of

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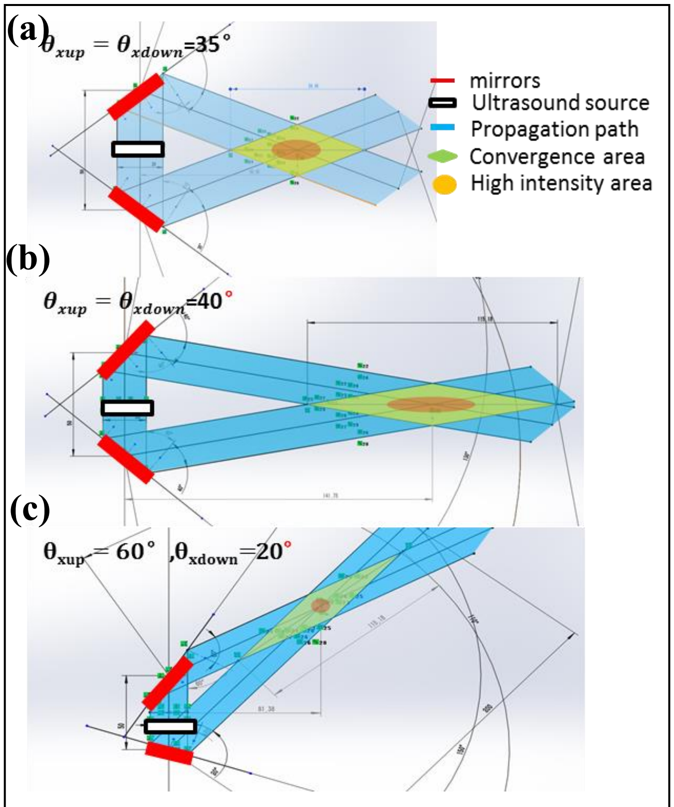

Fig.1 The 2D model and schematic of “acoustic mirrors” when the angle of acoustic mirror is dfferent from 35° and 40°

B. FEM of sound flied controlled by “Acoustic mirrors”.

Fig.2.(a) shows the intensity maps of the pressure fields generated by piezoelectric material(1MHz PZT) which is excited by 1MHz continued sin electrical signal. Specifically ,θ_1 and θ_2 represent the rotation angle of two mirrors. Fig.2.(a) indicate that as the angle of opening increases, the focus position and focus area will also become deeper and longer. It shows that the focus position will also be changed perpendicular to the depth direction when the two angles are different. The position of the focus and the length of the focus area are important features that characterize the focused sound field. As show in Fig.2.(b), the position of the focus will be change from 48mm to 153mm(distance to the center of piezoelectric material) as the angle of the mirror increases from 30° to 40°.The length of focus shows the same trend as the above when the angle increases the same value. Simulation result is got by COMSOL Multiphysics and show agree with the calculation mentioned above part A.

C. Experiments on “Acoustic mirrors” device.

The normalized intensity maps of the pressure fields from the acoustic mirror device with different angle of mirror are shown in Figs.3 (a)-3(d).

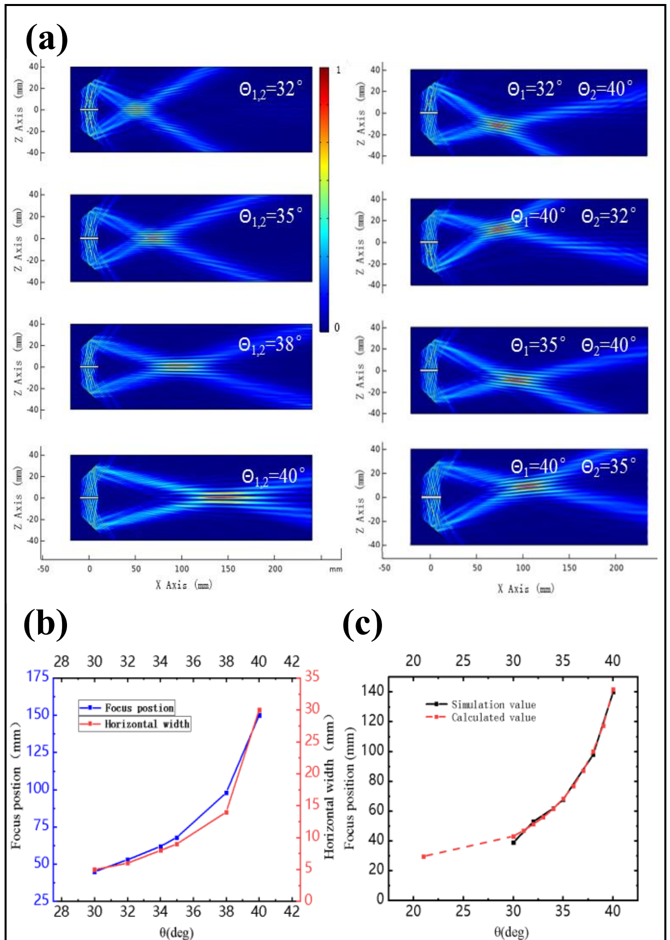

Fig.2 (a)Acoustic intensity obtained with two mirrors at the same angel(lift) and at the different angel(right) exited by 1MHz continued signal.(b)At different angles, the position of the maximum sound pressure and the sound pressure range will be changed.(c)The compareation of calculated and simulated value of the position of the maximum sound pressure(depth)

It measured the cross-sectional distribution of the sound field which was generated by circular piezoelectrical material (PZT-4) excited with pulse signal (PRF=200Hz, Voltage=300V, Energy per pulse=113.8uJ) and reflected by mirrors (Copper). In the Z-axis direction, five cross-sections(50mm×100mm) were selected for hydrophone scanning with a step of 1mm. In both cases (A: rotated angle= B: rotated angle=), the focusing effect is very evident and the sound field distribution has significant differences which were reflect by the focal length and focal area. Based on the maximum of the sound pressure, we divided the cross-sectional acoustic intensity distribution maps into three types: before convergence, convergence, after convergence. convergence in two situations of different angle(30° and 40°), the range of focal area decrease and also showing the same trend as above Part A and Part B.

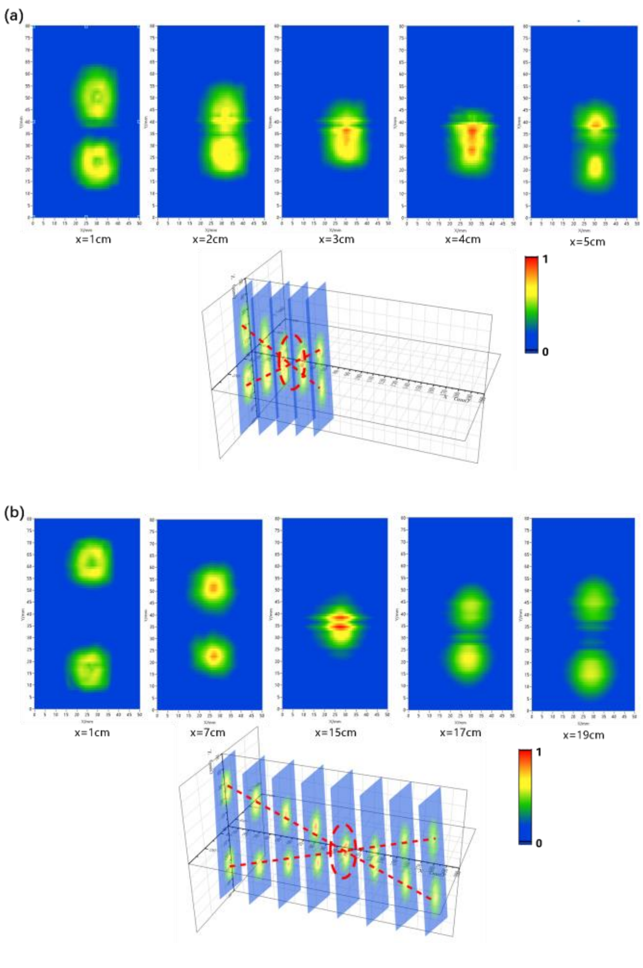

Fig.3 the normalized intensity maps of the pressure fields from the acoustic mirror device and 3D distribution of the sound field when the angle of two acoustic mirrors is 30°(a) and 40°(b).

III. Discussion and Conclusion

We report a "acoustic mirrors" method for controlling acoustic pressure patterns by mechanical rotating. A 3D-printed model with two mirrors is used to support a circle 1 MHz piezoelectric martial(PZT-4) excited by broadband pulse. The simulation results demonstrated that the focus position lateral changed from 50 mm to 148 mm when the angle of each reflector was rotated from 32 to 40 degrees. Furthermore, the focal position can be adjusted in a fan area with a center angle of 60°. When the angles of the two reflectors are different, the focus area also changes in the longitudinal direction. These results demonstrated that acoustic intensity generated by piezoelectric material at various lateral and longitudinal locations along the focus can be precisely controlled by two adjustable mirrors. This phenomenon has been confirmed by specific experiments using needle hydrophone test. It suggests a new method for ultrasonic field control which may have broad application in the future.

IV. Methods

A. bvbFabrication of the Fresnel lens-focused ultrasonic transducer

The 1 MHz ultrasonic source was built using PZT-4 as piezoelectric material, and Epoxy (Tec 301) as backing layer. The diameter of the PZT-4 is 25 mm. The acoustic mirror backet was design by Soildwork that was 3D-printed using a Fused Deposition Molding (FDM) printer (Pihawl,CN) with a print-layer thickness of 25 μm using PLA(VeroClear Resin: speed of sound, c=2424m/s, density, ρ=1180 kg/m^3, acoustic impedance, Z=2.86). Two polished copper pieces(speed of sound, c=4700m/s, density, ρ=8900kg/m^3, acoustic impedance, Z=4.18) as the acoustic mirrors are mounted on the bracket. The mirror device is connected to two cylinders as an axis to rotate from 0° in the horizontal direction to 90°. In this way, acoustic mirror rotate at different angles, which results in waveguide so as to enable focusing and change foucs position.

B. Experimental setup and measurements

Acoustic pressure maps were acquired using a 3D ultrasonic sound field distribution measurement system using LabVIEW software. The "acoustic mirror" device and a needle hydrophone (SN2839, NH1000, Precision Acoustics, Dorchester, UK) were placed opposite each other in degassed and Deionized water. The device was driven at the center frequency using Ultrasonic pulse signal generator (5073PR, OLYMPUS, USA). The voltage applied to the transducer was 30 V. Signals from the hydrophone were captured by a digital oscilloscope (DSOX3024A, Agilent, USA), then plotted in pseudo-color using LabVIEW coded imagine.

C. Numerical calculations

Simulations of acoustic wave propagation in water media and with "acoustic mirrors" structures were carried by using a finite-element analysis software (COMSOL Multiphysics 5.4, Sweden, Stockholm).

The COMSOL simulation sets the thickness and dimeter of the PZT ceramic to be 2 mm and 25 mm with the corresponding center frequency of 1 MHz. Both ends of the piezoelectric material are set as fixed constraints. The initial states of the two acoustic mirrors are horizontal and set to a 0-degree angle which defined as the angle formed by extension of the mirror and the piezoelectric material. The simulated variable is defined as the angle at which the mirror rotates along the center, and calculates different sound field distributions at different rotation angles of acoustic mirror. During the simulation process, the piezoelectric material was connected in series to a 50 Ω resistor and excited with a sinusoidal signal: an excitation frequency of 1 MHz, and a driving voltage of 200V peak-to-peak. The materials used for the COMSOL simulation are listed in Table I.

Table I. Materials used for the COMSOL simulation

Material	Function	c (m/s)	ρ (kg/m^3)	Z (MRayl)
PZT-4	Piezoelectrics	4600	7500	34.5
copper	Acoustic mirrors	4700	8900	4.18
Water	Front load	1500	1000	1.50

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