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A micro transducer based on contour-extensional vibration mode

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***Abstract*—The contour-extensional vibration mode is of practical importance in piezoelectric transformer. However, compare with conventional thickness mode transducer, it is difficult to be designed and realized. This paper reports a new type micro piezoelectric transducer based on contour-extensional mode with theoretical simulation analyses and experiments support. A 2.5MHz transducer prototype with dimensions 2*0.6*1 mm is designed by FEM and compared by experiment. The fabricated transducer is judged by performance parameters of measured the impedance curve, received acoustic pulse maximum waveform and acoustic intensity distribution. The main advantages of using contour-extensional are that can get the higher electromechanical coupling and solve miniaturization issues of thickness direction. The contour-extensional transducer has the targeted application in vivo thrombolytic therapy and ultrasound-guide of pedicle screws.**

Keywords—micro piezoelectric transducer, contour-extensional vibration mode, FEM

I. INTRODUCTION

Piezoelectric transducers serves as the core components for medical ultrasound images. Considering miniaturization issues, a lower frequency(1~3MHz) and smaller thickness(less than 1mm) is intensely demanded for interventional thrombolysis and ultrasound-guide of pedicle screws in vivo [1,2]. The modern medicine put forward the low frequency and minimized transducer. The thickness mode corresponds to a resonant vibration that is commonly employed in actual applications. For instance, the 3203HD(CTS Corp. USA) serves as the most common piezoelectric material of transducers, whose thickness mode constant is 2.02 MHz•mm. The classical transducer is constituted not only piezoelectric layer, but also matcher layer and backing layer(thicker than piezoelectric layer). The desired transducer thickness less than 1mm is really hard to be realized by thickness mode. There is also other potential application vibration mode such as contour-extensional[3,4], thickness-shear[5], thickness-twist[6]and so on, which are successfully used in piezoelectric transformers and resonators. The fundamental contour-extensional vibration mode is of practical importance in piezoelectric transformer because of high direct electromechanical coupling k_p.

From an energy efficiency point of view, 1-3 piezoelectric composites were proven to be useful materials for medical ultrasonic and underwater transducer applications. One of the most important reason is piezocomposites have higher direct electromechanical coupling k_{33} than their conventional piezoceramics k_t[7] for most piezoelectric material. Based on similar principles, the planar electromechanical coefficient k_p is higher than k_{31} and k_t, which is close to k_{33} for common PZT-4, PZT-5A and PZT-5H. For frequently-used piezoelectric material 3203HD of PZT-5H， it owns good piezoelectric coefficients, high electromechanical coupling, high dielectric constant, and low cost for fabricating a small element transducer. The k_p is approximately equal to k_{33}(PZT5H Material Technical date, CTS Corp.). The contour-extensional mode[8] of thin rectangular plates was lucubrated by many researchers[9,10] and was universal used to be power transfer4. The mode is effected by width and length with the planar coupling coefficient k_p. Of interest to this study is the contour-extensional vibration based thick rectangular plate model. The frequency number is simplified about 1.5 MHz•mm for our chosen court-extensional mode, which can effectively avoid limitation of thickness direction. The main advantages of using contour-extensional are that can get the higher electromechanical coupling and solve miniaturization issues of thickness direction. However, compare with conventional thickness mode transducer, it is more difficult to be designed and realized.

II. DESIGN OF THE MICRO TRANSDUCER

A. Finite element analysis

Based on the above advantages and requirements, we designed a 2.5 MHz contour-extensional mode transducer. The transducer with dimensions 2*0.6*1 mm is typically structured with matching layer(86μm), piezoelectric layer(253μm) and backing layer(700μm) according with traditional thickness mode transducer acoustic transmission requirement as showing in fig.1(a). The simulation mode of the contour coupled transducer is set up by finite element method (FEM) in fig. 1(b). The vibration mode of contour-extensional is represented the expansion and shrinkage process of the whole vibration showing in fig. 1(c). The vibration mode is part of family Ⅱ dilation-type of contour mode, which has been deeply analyzed by Richard Holland[8]. The design of contour transducer consults the

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experience of thickness transducer because of the same acoustic wave transfer path demand. Acoustic pressure of thickness direction(z direction) is calculated and the result is shown in fig. 1(d). As shown in simulated analysis result, the acoustic pressure distribution is reasonable and effective.

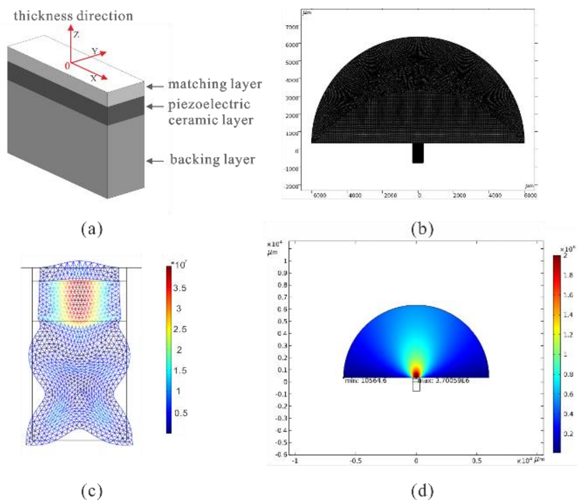

Fig. 1. The contour-extensional piezoelectric transducer model analysis，(a) the typically structured transducer with matching layer, piezoelectric layer and backing layer, (b) finite analysis model meshing, (c) contour-extensional vibration mode, (d) calculated acoustic pressure of thickness direction.

B. Experiment

A 2.5 MHz transducer prototype is fabricated for verify the simulated design and the impedance curve is measured to prove the design's feasibility. Fig. 2 shows impedance amplitudes curves from 1 MHz to 10 MHz, which are obtained by comparing the experimental result with the FEM. The line with circle and rhombus symbols indicate the experimental and the FEM simulation result, respectively. The difference between the FEM and experimental result is few in the contour resonance frequency. The thickness mode for 253μm piezoelectric ceramic should be about 8MHz, which is can be observed but not very obviously in the curve, the proper reason is transducer's shape restrains the thickness mode to some degree.

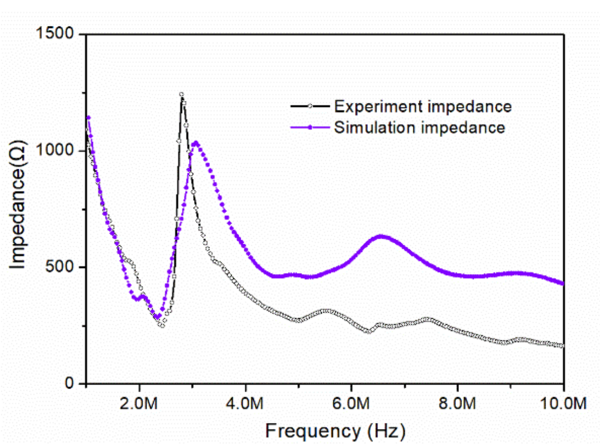

Fig. 2. The electrical impedance amplitude curve of the piezoelectric transducer by comparison the experimental result with the finite element method.

III. Result of Experiment

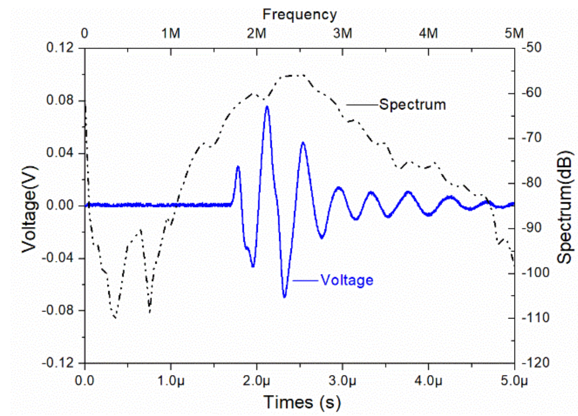

Fig. 3 The received acoustic pulse maximum waveform by hydrophone method

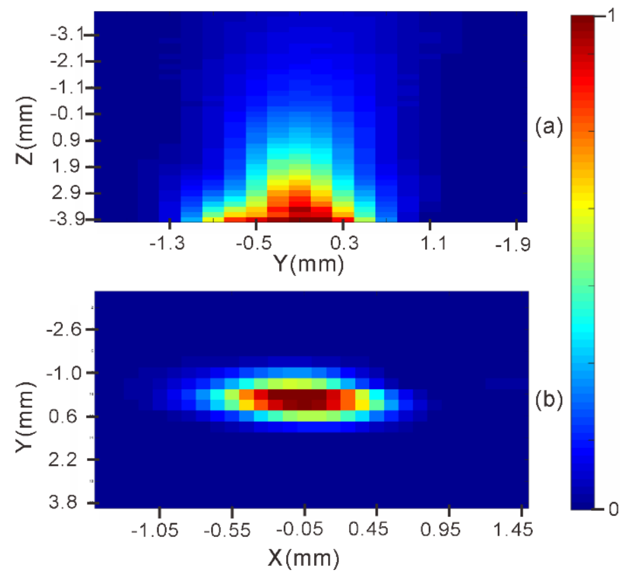

Fig. 4 Measured acoustic intensity distribution, (a)YZ plan, (b) XY plan

The received acoustic pulse waveform and acoustic intensity distribution are used to characterize the transducer's performance. Firstly, the acoustic distribution was measured by a 3D scanning system UMS III (Precision Acoustics Ltd., Dorchester, UK) with a PA 1mm hydrophone (0.1~20 MHz). For avoiding the collision and conforming to obtain as much complete information as possible, the distance of hydrophone and transducer was beginning at 1 mm for the recorded data. The received acoustic pulse maximum waveform is obtained by hydrophone method shown in fig. 3. The center frequency was 2.5 MHz and the −6 dB bandwidth of the transducer was about 46.3%. The received main pulse waveform is three cycles, and it indicates the transducer will have good performance in application. Secondly, the acoustic intensity distribution of this fabricated transducer along YZ and XY was measured as shown in fig.4(a) and fig.4(b), separately. The hydrophone measurement step size was 0.2 mm. The thickness, length and width of transducer is corresponding to Z, Y and X axis. The measured YZ plane and XY plane are similar with the normal thickness transducer. There is also side lobe existed. For low frequency 2.8MHz, the transducer has an small aperture of 2mm ×0.6mm which is similar as a point vibration source. The acoustic distribution result of experiment and the finite element analysis also reveal the point vibration trend.

IV. CONCLUTION

A contour-extensional mode transducer is proposed in this paper. Then a 2.5 MHz transducer prototype is fabricated to realize and verify the finite element analysis. Impedance curve and hydrophone method experiment was used to characterize the transducer's performance. Both finite element simulations and experiment result show that the contour-extensional can be excited in good performance with proper transducer sizes. The transducer with dimensions 2*0.6*1 mm is 2.5 MHz and the −6 dB bandwidth of was about 46.3%. It was found compare with traditional thickness mode transducer low frequency and thin thickness size is effective to the contour-extensional transducer. The contour-extensional transducer has the potential apply with multi-directional emission ultrasound for thrombolytic therapy. The micro piezoelectric transducers will be integrated into the minimally invasive needles and catheters for medical diagnostic or thrombolytic therapy. The new type transducer's theory design and the optimized method with matching and backing layer should be study in the future work.

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