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A $PbTiO_3$ Transmitting/P(VDF-TrFE) Receiving Wideband Ultrasonic Transducer in VHF Band

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Abstract

A new type of high frequency wideband ultrasonic transducer with a separation between a transmitter and a receiver was proposed and its characteristics were simulated using a PSpice model. The piezoelectric ceramic $PbTiO_3$ as a transmitter and the piezoelectric copolymer P(VDF-TrFE) as a receiver were used for high sensitivity and wide bandwidth, respectively. The characteristics of the focusing transducer with center frequency of approximately 35MHz fabricated in this study showed very wide bandwidth, which could give an axial spatial resolution better than 30 μm in B-mode image for biological tissues.

Keywords: *Ultrasonic transducer, $PbTiO_3$, P(VDF-TrFE), Co-polymer, VHF band*

I. Introduction

One of the ultimate purposes of the development of an ultrasonic diagnosis system is to improve the spatial resolution of images. Image quality is determined by the axial and the lateral spatial resolutions. The axial resolution, which is especially important in the B−scanned images, is determined by the frequency bandwidth of the ultrasonic transducer and the sound velocity in medium. To obtain a wide bandwidth for realizing the high resolution of a microscopic scale, a very high frequency (VHF) transducer higher than 30MHz should be used. Recently, VHF ultrasounds have employed for the medical diagnostic system or the UBM (Ultrasonic Backscatter Microscope) system in the fields of ophthalmology or dermatology[1−3]. However, the probes of those systems have the structure of backing/piezoelectric/matching layers, same as the conventional ultrasonic probes so far. The difference is only that the thickness of the piezoelectric layer and the matching layer are very thin so as to generate VHF ultrasonic waves.

In this study, in order to obtain a wide bandwidth which gives an axial resolution better than 30μm in the B−mode skin image, we have proposed a new structure of the VHF ultrasonic transducer which has a separation between a transmitter (Tx) and a receiver (Rx). It consists of four layers of transmitting piezoelectric/matching/ acoustic buffer/ receiving piezoelectric layers. In this structure, a piezoelectric ceramic $PbTiO_3$ and a piezoelectric copolymer P(VDF−TrFE) are used as a transmitter and a receiver for high sensitivity and wide bandwidth, respectively, and a fused quartz rod is used for the acoustic buffer. The characteristics of the transducer were simulated using PSpice, and a focusing transducer with center frequency approximate 35MHz was fabricated to confirm the effectiveness of the proposed structure of transducer.

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Table 1. Physical properties of materials(4).

Materials	ν_l (m/s)	ρ (kg/m³)	$\varepsilon/\varepsilon_0$	k_t	Z_a (Mrayl)
$PbTiO_3$	5050	7000	200	0.50	35.4
P(VDF-TrFE)	2400	1880	6	0.31	4.5
Fused Quartz	5960	2200	-	-	13.1
Al	6420	2700	-	-	17.3

II. Design and Fabrication of Transducer

2.1. Structure and Materials

Figure 1 shows the basic structure of the transducer with Tx/Rx separation proposed in this study. As shown in this figure, the transmitting transducer $PbTiO_3$ and the matching layer Al are bonded on a side of a fused quartz rod, and the receiving transducer P(VDF−TrFE) is bonded on the other side.

The physical properties of the materials used in the probe are shown in table 1. The acoustic waves generated from the $PbTiO_3$ transmitter propagate into the medium through the matching layer, the buffer rod and the P(VDF−TrFE), and the signals reflected from the targets existing in the interior of medium are received by the P(VDF−TrFE) receiver. When the wave transmits into medium, the P(VDF−TrFE) works as a matching layer between the fused quartz and the medium. Since the specific acoustic impedance, 4.5 Mrayls, of the P(VDF−TrFE) is quite similar to the geometric mean of the impedances of the fused quartz and the biological tissue, it becomes a good matching layer for them when the thickness is controlled with $\lambda/4$. In this structure, the length of the buffer rod should be decided by considering the signals from the targets which exist among the multi−reflections from both sides of the rod.

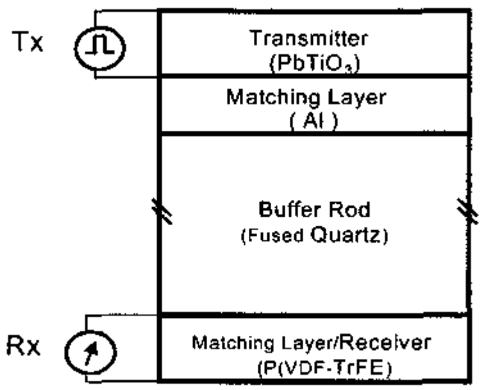


Fig. 1. Basic structure of the proposed transducer.

2.2. Design and Fabrication

Since we are considering biological tissue as a medium, the sound velocity can be estimated at approximately 1540 m/s. The time interval of 6.5μs is necessary for observing 5 mm thickness. Therefore, the fused quartz rod of 20mm length was used, which gives 6.7μs of time delay between interior multi−reflections.

The axial resolution is generally given by the following equation[2].

$$\delta_x = 2\nu \cdot \ln 2 \cdot \frac{1}{\pi \Delta f} \qquad (1)$$

(ν: sound velocity. *Δf: bandwith*)

Therefore, a bandwidth $\Delta f = 22.6$ MHz at least is needed in order to obtain a resolution better than 30μm. Generally, the fractional bandwidth of an ultrasonic probe is determined by the structure of its backing and matching layer, and higher frequency creates wider bandwidth in the same structure. For this reason, we have chosen approximately 35MHz as the center frequency of the transducer. The diameter of the $PbTiO_3$ and P (VDF−TrFE) transducers were set at 3mm for the good electric impedance matching with 50 Ω[5]. The diameter of the fused quartz rod 18mm was decided in order to avoid detection of the spurious noises by multi−reflection, scattering, and mode conversion in the inside. Figure 2 (a) and (b) show the structural dimensions and a photograph of the cased focusing probe. As seen in

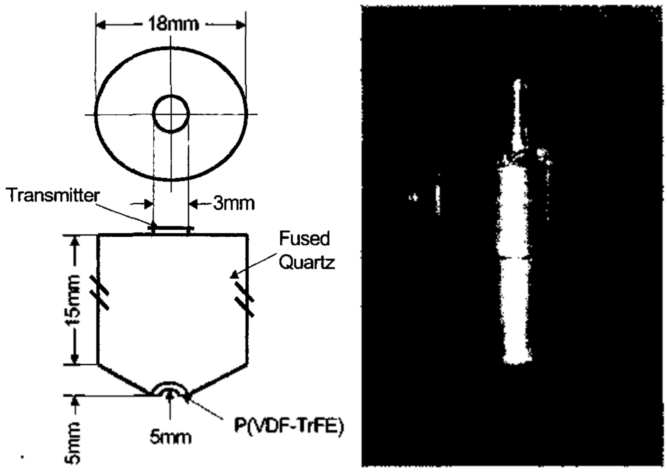


Fig. 2. Structure (a) and photography (b) of the fabricated focusing transducer.

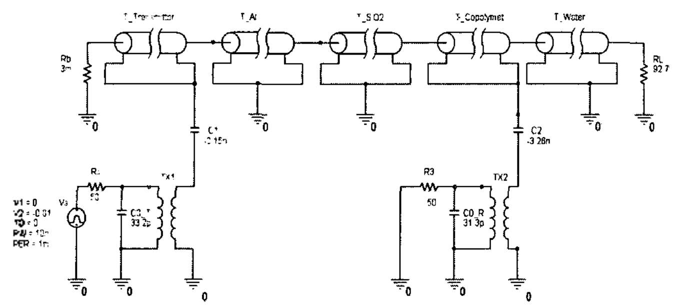


Fig. 3. PSpice model for simulation.

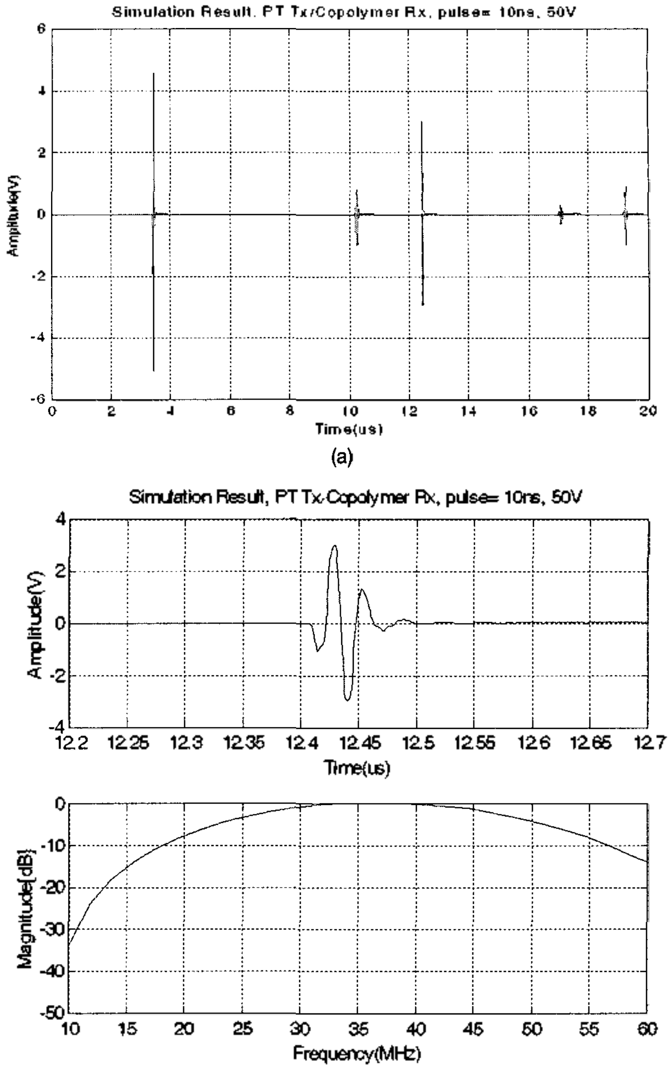


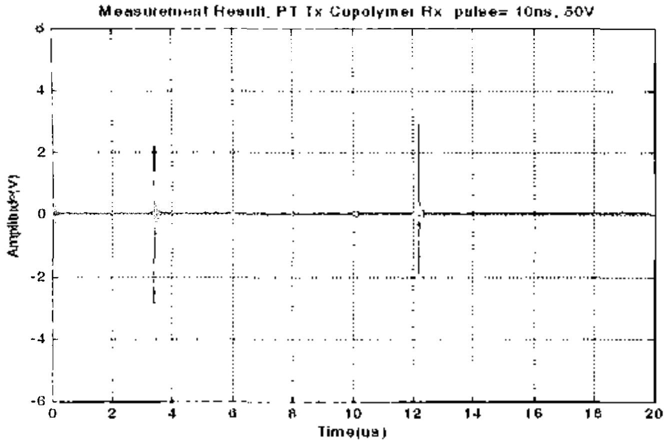
Fig. 4. Impulse response of the probe(simulation).
(a) pulse train (b) target signal

the photograph, the upper subminiature connector is for transmission and the other one on the side is for reception. In fabrication, the gold electrodes with 0.1μm thickness were sputtered on both sides of a thinly polished $PbTiO_3$ and diced circularly. The $PbTiO_3$ was bonded on one side of the quartz rod with Al foil of $\lambda/4$ thickness for center frequency using epoxy (EPOTEK 301). On the other side of the rod P(VDF−TrFE) film was fabricated by spin coating after fabrication of the bottom electrode on the concave surface of the rod. After upper electrode deposition, it was poled for 30 minutes at 90℃ in an electric field of 20V/μm. Finally, it was coated using parylene with about 1μm thickness for electrical insulation and mechanical protection.

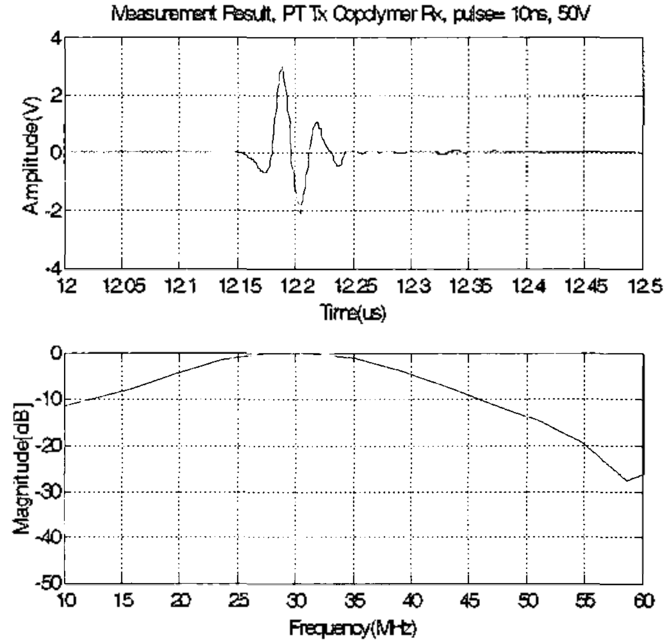
III. Characteristics Evaluation Using PSpice Model and Measurement

The characteristics of the transducer with the proposed structure were simulated using the PSpice model as shown in Fig.3[6,7]. In the model, parameters for every component were obtained by analogy of acoustical parameters with electrical ones for the electric transmission lines with 3mm diameter. In the simulation, we assumed a stainless steel plate (42 *Mrayl*) as the target, located in water at the focal position of the concave lens surface. Figure 4 (a) and (b), as the simulation results, show the received impulse responses at P(VDF−TrFE) when the electric square pulse with 50V amplitude and 10ns width was applied to the transducer.

In Fig. 4 (a) the third pulse is the signal reflected from the target which we want to obtain. The first pulse is the signal received directly from the $PbTiO_3$ transmitter. Others are interior multi−reflections of the rod or multi−reflection between the rod and the target. In the B−mode imaging by a transducer with the structure shown in Fig. 1, only signals that come between the first and the third pulses should be generally used. In this experiment, however, we used a concave transducer with 5mm radius. Therefore the signal reflected from target becomes the 3rd one. Figure 4 (b) shows the waveform and the power spectrum of the target signal. The center frequency is 37.1MHz and the -6dB bandwidth is about 32.3MHz (% bandwidth 87.1%). Figure 5 (a) and (b) show the measurement results corresponding to Fig.4. The 2nd pulse in the Fig. 5 (a) becomes very small because of the scattering on the concave surface, which is ignored in the simulation. The center frequency is 35.2MHz and the -6dB bandwidth is about 26.2MHz(% bandwidth 74.5%). The differences come mainly from the focusing effect and the attenuation in water which were ignored in the simulation. By the eq. (1), it is expected that these



(a)



(b)

Fig. 5. Impulse response of the probe(measurement), (a) pulse train (b) target signal

bandwidths will give the axial resolution 21㎛ (simulation) and 26㎛ (measurement), respectively.

IV. Conclusions

In this paper, a new type of high frequency wideband ultrasonic transducer consisting of PbTiO3 transmitter/Al matching layer/fused quartz buffer/P(VDF−TrFE) receiver was proposed, and its impulse response was simulated using the PSpice model. The characteristics of an approximately 35㎒ focusing transducer fabricated in this study were also measured. Conclusively, it is revealed that the proposed transducer has a very wide bandwidth which could give an axial spatial resolution better than 30㎛ in the B−mode image for biological tissues.

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