Characteristics of a $PbTiO_3$ Transmitting/P(VDF-TrFE) Receiving 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 the PSpice model. The piezoelectric ceramic PbTiO3 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 a center frequency approximately 40㎒ focusing transducer fabricated in this study showed very wide bandwidth which could give an axial spatial resolution better than 30um in the B-mode image for biological tissues.

I. Introduction

One of the ultimate purposes of development of an ultrasonic diagnosis system is in the improvement of spatial resolution of the image. It's because the 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 decided by the frequency bandwidth of the ultrasonic transducer and the sound velocity of the medium. To obtain a wide bandwidth for realizing high resolution with microscopic scale, a very high frequency(VHF) transducer should be basically used. Recently, the VHF ultrasounds higher than several tens ㎒ has been employing in the medical diagnostic system or the UBM(Ultrasonic Backscatter Microscope) system for 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 only difference is that the thickness of the piezoelectric and the matching layer are very thin so as to generate very high frequency ultrasonic waves.

In this study, in order to obtain a good axial resolution better than 30㎛ 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 the PSpice model, and a center frequency approximately 40㎒ focusing transducer has fabricated to confirm the effectiveness of the proposed transducer.

II. Design and Fabrication of Transducer

II-1. Structure and Materials

Figure 1 shows the basic structure of the transducer with Tx/Rx separation proposed in this study. As shown in the figure, the transmitting transducer PbTiO3 and the matching layer Al are bonded on a side of fused quartz rod and the receiving transducer P(VDF-TrFE) is bonded on the other side of it.

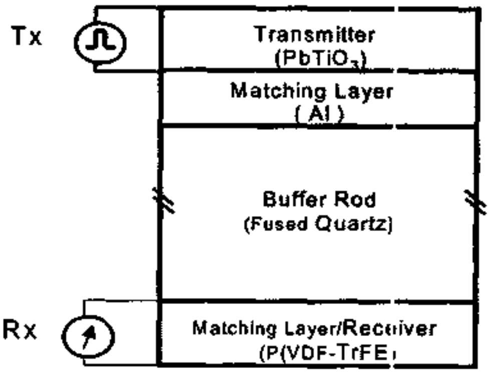


Fig. 1. Basic structure of the proposed transducer.

Table 1. Physical properties of materials [4].

Materials	v_l (m/s)	ρ (kg/m³)	ϵ/ϵ_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

The physical properties of the materials used in the probe are shown in table 1. The acoustic waves generated from the PbTiO3 transmitter propagate into the medium through the matching layer, buffer rod and P(VDF-TrFE), and the signals reflected from the target existing inside of the 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. Because the specific acoustic impedance 4.5 Mrayls of the P(VDF-TrFE) is quite similar to the geometric mean of the ones of the fused quartz and the biological tissue, it becomes a good matching layer between them if the thickness is controlled with λ/4. In this structure, the length of the buffer rod should be decided by considering of the signals from targets to be existed among the multi-reflections from both sides of the rod.

II-2. Design and Fabrication

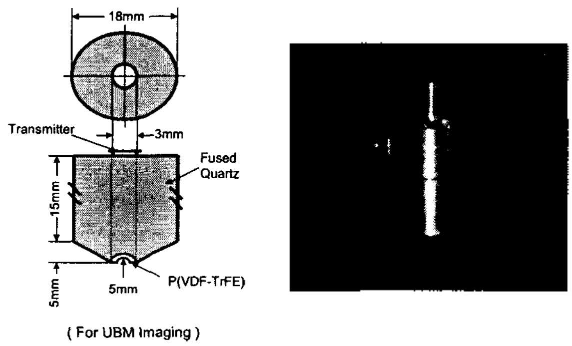
Since we are considering biological tissue as medium, especially human skin, the sound velocity can be estimated by 1540m/s approximately, and the time interval of 6.5μs is needed for observing 5mm thickness. Therefore, the fused quartz rod of 20mm length which gives 6.7μs of time delay between interior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

On the other hand, the axial resolution is given by the following equation [2].

$$\delta_x = 2\nu \cdot ln2 \cdot \frac{1}{\pi \Delta f} \qquad \text{-------------- (1)}$$

(ν: sound velocity. Δf : *bandwith*)

Therefore, the bandwidth $\Delta f = 22.6MHz$ at least is needed in order to obtain the resolution better than 30μm. Generally, the fractional bandwidth of an ultrasonic probe is determined by the structure of its backing and matching layer, and the higher frequency gives the wider bandwidth in the same structure. Therefore, we have chosen the center frequency of the transducer to be made is approximately 40MHz. And, the diameter of the $PbTiO_3$ and P(VDF-TrFE) transducers were decided by 3mm for good electric impedance matching with 50Ω[5]. The diameter of the fused quartz rod 18mm was decided to avoid detection of the spurious noises by multi-reflection, scattering and mode conversion inside of it. Figure 2(a) and (b) show the structural dimension and the photograph of the focusing probe in a case. In the photograph, the upper SMA terminal is for transmitting and the other is for receiving. In fabrication, the gold electrodes with 0.1㎛ thickness were sputtered on both sides of a thinly polished $PbTiO_3$ and diced in circular. The $PbTiO_3$ was bonded on one side of the quartz rod with Al foil of λ/4 thickness using epoxy(EPOTEK 301). On the other side of the rod P(VDF-TrFE) film was fabricated by a spin coating after the bottom electrode fabrication on the concave surface of the rod. After the upper electrode deposition, it was poled for 30 minutes at 90℃ in the electric field of 20V/㎛. Finally, it is coated using parylene with about 1㎛ thickness for electrical insulation and mechanical protection.



(a) (b)

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

III. Characteristics Evaluation Using PSpice Model and Measurement

The characteristics of the transducer with the proposed structure was simulated using the PSpice model as shown in Fig. 3[6]. In the model, all parameters for every component were obtained by analogy of acoustical parameters with electrical ones for transmission lines with 3㎜ diameter. In the simulation, we assumed a stainless steel plate(42*Mrayl*), as target, existed in water at the focal position of the concave lens

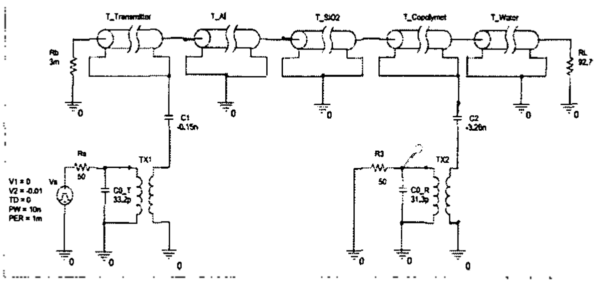
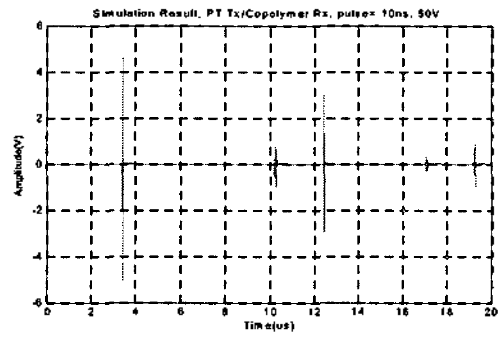
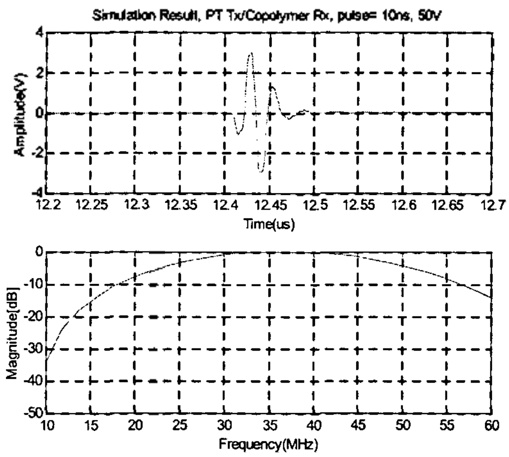


Fig. 3. PSpice model for simulation.



(a)



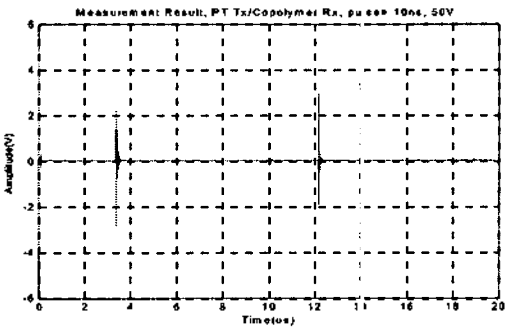
(b)

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

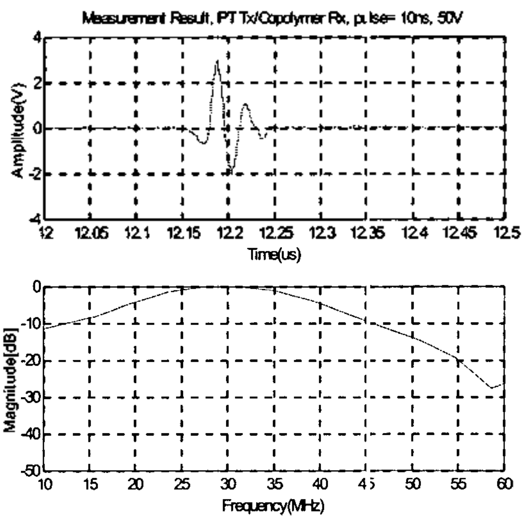
surface. Figure 4(a) and (b), as the simulation results, show the P(VDF-TrFE) received impulse responses when the electric square pulse of 50V amplitude and 10ns width is applied to the transducer.

In Fig. 4(a) the second 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 and others are interior multi-reflection of the rod or multi-reflection between the rod and target. In the B-mode imaging, the only signals that come between the first and the third pulses should be used. Figure 4(b) shows the waveform and its power spectrum of the target signal. The center frequency is 37.1㎒ and −6dB bandwidth is about 32.3㎒(% bandwidth 87.1%).

Figure 5(a) and (b) show the measurement results corresponding to Fig.4. The center frequency is 35.2㎒ and −6dB bandwidth is about 26.2㎒(% bandwidth 74.5%). The differences comes mainly from the focusing effect and the attenuation in water. By the eq.(1), it is expected that these bandwidths can give the axial resolution 21㎛(simulation) and 26㎛(measurement), respectively.



(a)



(b)

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

IV. Conclusions

In this paper, a new type of high frequency wideband ultrasonic transducer consists of $PbTiO_3$ transmitter/Al matching layer/fused quartz buffer/P(VDF-TrFE) receiver was proposed and its impulse response was simulated using the PSpice model. And, the characteristics of a approximately 40 ㎒ focusing transducer fabricated in this study were measured. Conclusively, it is revealed that the proposed transducer has very wide bandwidth which could give an axial spatial resolution better than 30*um* in the B-mode image for biological tissues.

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