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A circular array transducer for photoacoustic imaging by using piezoelectric single crystal PMN-PZT

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1. Introduction

Recently, photoacoustic (PA) imaging has attracted many interests in various fields.[1-3)] For the imaging, a sample of target is usually excited by a pulse laser and the conserved energy generates PA waves due to thermoelastic expansion. There are many reports about ultrasound transducers for detection of the PA signals and most of the transducers consist of single-element. The center frequency about 1~10 MHz is generally used in the conventional systems of PA tomography or microscopy for biological tissues such as small animals.[1,4)] In those systems, the piezoelectric polymer PVDF or the piezoelectric composite is used for wide bandwidth. However, the receiving sensitivity is still not enough to detect weak PA signals.

The single crystal PMN-PZT has very high electromechanical coupling and piezoelectric constants with high permittivity and low dielectric loss.[5)] It could be used to make the ultrasound transducer having wide bandwidth and good sensitivity which are desired for the PA imaging. In this study, a circular array transducer with high sensitivity and wide bandwidth (1~15 MHz) was designed and fabricated by using the PMN-PZT. The electro-acoustic characteristics of every element and the obtained ultrasound (US) and PA signals by it were compared with those by a commercial PVDF hydrophone.

2. Experiment

Figure 1 depicts a schematic diagram of the PA tomography system set up in this study. The circular array transducer, part (a) of the figure, consists of 120 needle hydrophones as piezoelectric elements. The structure of one element is shown in Fig. 2. A 0.31 mm thick and 0.5×0.5 mm^2 area PMN-PZT plate (Ceracomp Co. Ltd.) which has piezoelectric coupling coefficient $k_{33} \approx 0.92$ and $\varepsilon_{33}^{S} \approx 1030$ was bonded with a copper (Cu) wire (Φ≈0.7 mm) using a conductive sliver epoxy (EPO-TEK H20). The wire was coated by Teflon and inserted into a

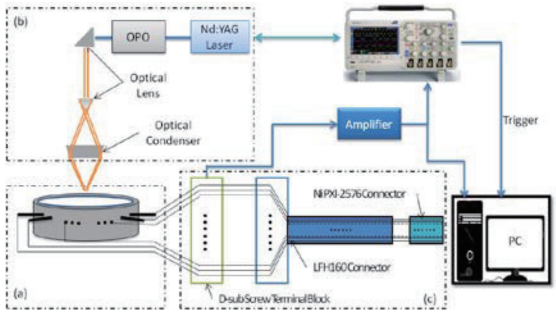

Fig. 1 Schematic diagram of PA tomography system.

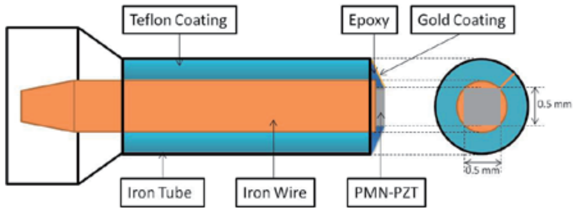

Fig. 2 The structure of the PMN-PZT needle point hydrophone.

stainless steel tube. Non-conductive epoxy (EPO-TEK 301) filled around the PMN-PZT for insulation and watertight. The upside electrode were connected to the tube by a gold line which was made by a sputtering system. All the hydrophones were fixed on the wall of a cylindrical acrylic chamber of which size is 52 mm in diameter and 15 mm in depth. The 120 horizontal channels for insertion of the hydrophones pointed to the center of the chamber and the angle between every two neighbor hydrophones was 3°.

A Q-switched Nd:YAG (Surelite II, Continuum) laser and a tunable OPO laser (Surelite OPO Plus), shown part (b) of Fig. 1, delivered 5 ns pulses at 10 Hz with wavelength in the range from 680 to 2500 nm. The ring-shaped light pattern was generated by a spherical conical lens and focused on the central point in the chamber of the transducer by using a PMMA optical condenser.

All elements of the transducer were connected to a switch module (PXI-2576, NI) through a connector and blocked cables (LFH160, NI). The obtained data was stored by a personal computer.

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3. Results and discussion

For comparison, the receiving impulse responses for three kinds of hydrophones which are available in 1~20 MHz frequency range were simulated as shown in Fig. 3. Two of them were assumed that the piezoelectric element of PMN-PZT plate or a PVDF film (52 μm, Kynar) was simply attached on a backer of Cu rod. The other had two matching layers (1st matching: 4.99 MRayls, 2nd matching: 2.0 MRayls) with λ/4 thickness as well as the same structure of the PMN-PZT hydrophone.

As shown in Fig. 3, the PMN-PZT hydrophone with two matching layers has higher sensitivity and wider bandwidth than others. The -6 dB bandwidth was about 12.3 MHz, which was wider than the other two (9.4 and 9.0 MHz, respectively).

The receiving characteristics of the fabricated hydrophone were measured and compared with a PVDF needle hydrophone (Φ≈0.2 mm, Precision Acoustics LTD). The US signal was offered by a 5-MHz transducer (A332S, Olympus NDT) which was excited by an impulsive signal (100 V). Figure 4 shows the received US signals of the PMN-PZT and PVDF hydrophones. The shapes of two signals are similar, but the amplitude of the signal by PMN-PZT hydrophone is about 3.9 times larger than the other. Figure 5 shows the variation of sensitivity for all elements of the array transducer. The sensitivity deviation was less than 2.5 dB from the average value.

To generate PA signal, the alumina plate was excited by the laser. Then the generated PA signal

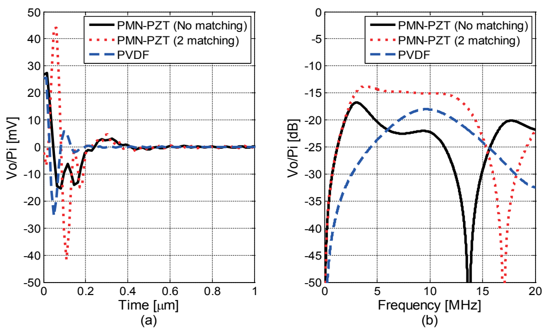

Fig. 3 The simulated receiving impulse response of three kinds of hydrophones.

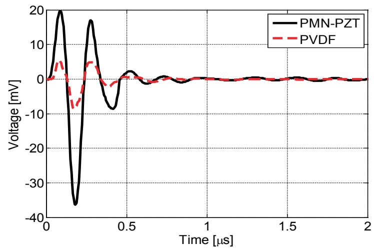

Fig. 4 US signals received by the PMN-PZT and the PVDF hydrophones.

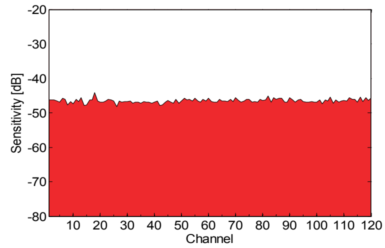

Fig. 5 Variation of sensitivity of 120 elements of the PMN-PZT transducer.

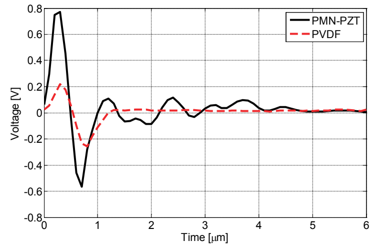

Fig.6 PA signals received by the PMN-PZT and the PVDF hydrophones.

was detected by the PMN-PZT transducer and the PVDF needle hydrophone. Figure 6 shows the typical waveforms of received PA signals. It was found that the PMN-PZT transducer shows higher sensitivity (V_{pp}≈1.3 V) than the PVDF hydrophone (V_{pp}≈0.5 V).

4. Summary

For application in a PA tomography system, a circular array PMN-PZT transducer with 120 elements was designed and fabricated. The receiving impulse responses of three kinds of hydrophones were simulated for comparison. The results showed that PMN-PZT has high sensitivity and wide bandwidth in frequency range from 1~10 MHz. The measured US and PA signals by the transducer were compared with those by a commercial PVDF hydrophone. Conclusively, it was shown that the fabricated PMN-PZT transducer is suitable for PA imaging.

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