Single crystal Piezoelectric Composite Ultrasound Needle Transducer Development

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Abstract

In this study, single lead magnesium niobite-lead titanate crystal (PMN-PT) / epoxy 1-3 composites were applied for high-frequency ultrasound needle transducers, guiding the puncture path during the thoracic regional anesthesia. Specifically, PMN-PT/ epoxy 1-3 composites with center frequency of 20 MHz were designed and fabricated using the dice-and-fill method. After Computer Numerical Control (CNC) processing, the materials were made into a needle transducer and set up on the tip of the 18-gauge puncture needle. Comparison of PMN-PT and PMN-PT/ epoxy 1-3 composites performance, the amplitude of both were about 4-5 V and the former's bandwidth was about 30-40 %. Then, the bandwidth of the latter was promoted to 40-50 %. The results of porcine lung in vitro experiment showed that the PMN-PT/ epoxy 1-3 composites needle transducers can more clearly distinguish the upper and lower interfaces of the parietal pleura rather than the PMN-PT needle transducers. The results indicated that significant improvements in resolution can be achieved in pleura tracing using the PMN-PT/ epoxy 1-3 composites needle transducer.

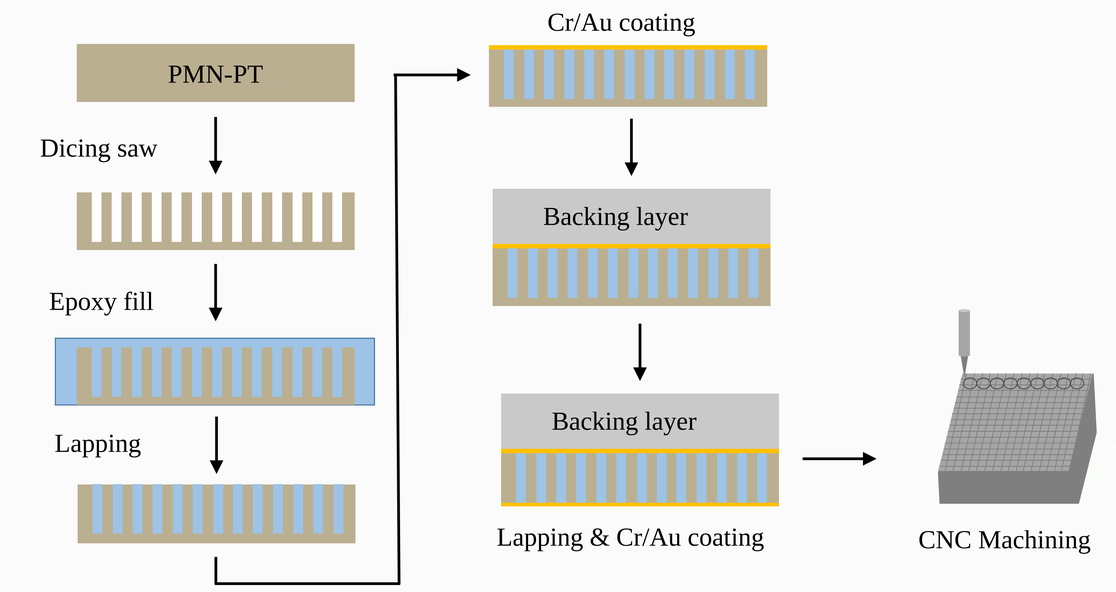
Keywords: PMN-PT single crystal, 1-3 Piezocomposites, Ultrasound transducers

Introduction

Regional anesthesia is achieved through anesthesia puncture assisted by an ultrasound imaging system in clinic. However, blurred image recognition of puncture needle tip and inaccurate identification of the tissues may lead to the risks of pleural injury, pneumothorax, etc. The previous studies, our team designed the intra-needle ultrasound (INUS) system; The transducer fit into an 18-guage puncture needle, and emitted ultrasound signals to identify the tissue during puncturing.

The previous studies have shown the PMN–PT/ epoxy 1–3 composite transducer have a larger promotion in performances than PMN-PT transducer, including electromechanical coupling properties (Kt value) and reduce the acoustic impedance. Therefore, we aimed to miniaturize the PMN-PT/ Epoxy1-3 Composite material and applied to the INUS transducer to improve its efficiency.

Materials and Methods



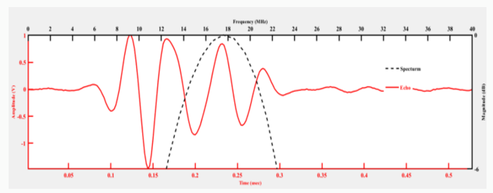
Results

Table 1. Performance comparisons of PMN-PT/ epoxy 1-3 Composite and PMN-PT transducers. The asterisks indicated significant differences between the FW and SW groups. Values are means ± S.E.M. (n=18, $p<0.05$, by student's *t*-test).

Piezoelectric materials	Vp-p(V)	Bandwidth(%)	Kt	Axial Resolution(mm)
PMN-PT/ epoxy 1-3Composite	3.4 ± 1.4	42.9 ± 6.6 *	0.66	0.1 *
PMN-PT	3.6 ± 1	31.5 ± 5.7	0.65	0.16

*Significant at 5% level.

A. (a)



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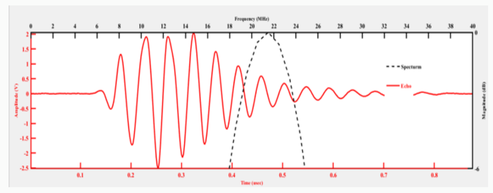

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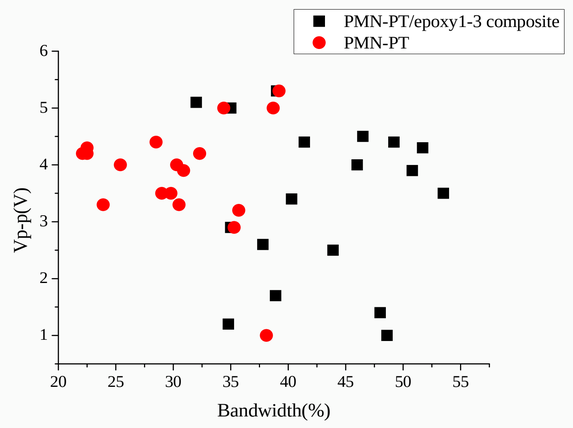
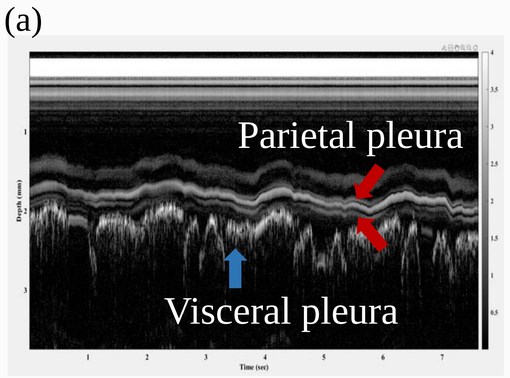


Fig. 1. A. Pulse-echo measurements and respective frequency spectra of different materials-based ultrasound needle transducers. (a) PMN-PT/ epoxy 1–3 composite, (b) PMN-PT. **B.** Amplitude and Bandwidth Scatter plot of PMN-PT/ epoxy 1-3 Composite and PMN-PT transducers.

(a)



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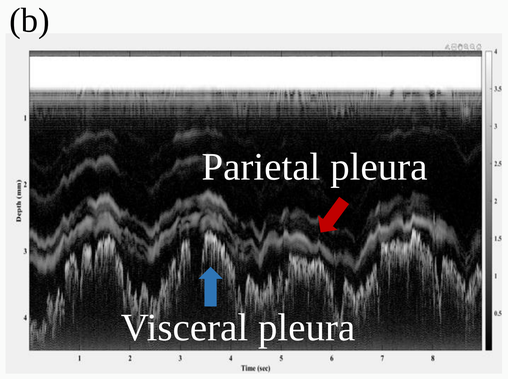

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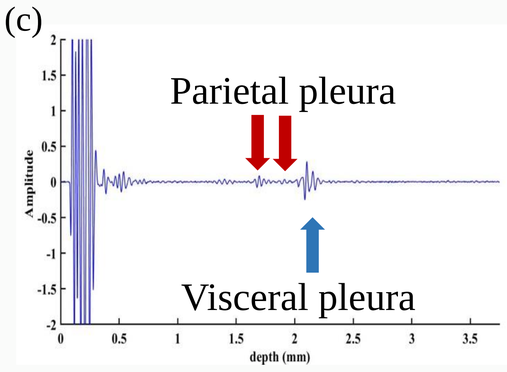

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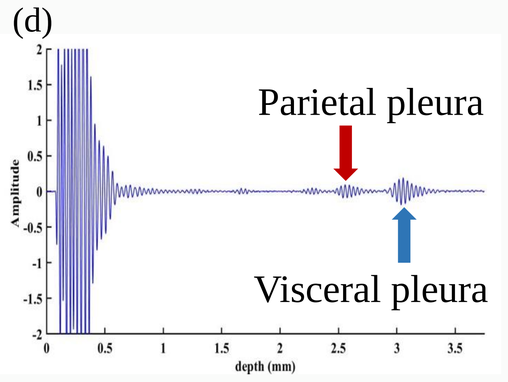
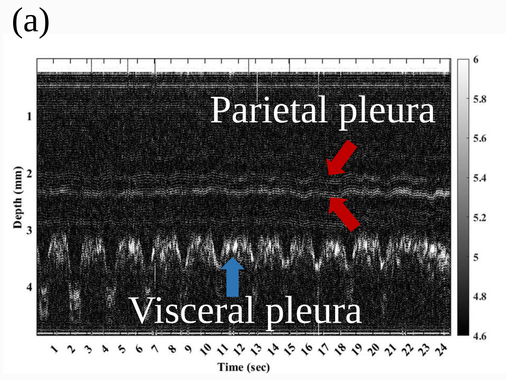


Figure 2. The ultrasound M-mode images and RF-mode of different materials-based ultrasound needle transducers in porcine lung in vitro experiment. (a, c) PMN-PT/ epoxy 1–3 composite, (b, d) PMN-PT.

(a)



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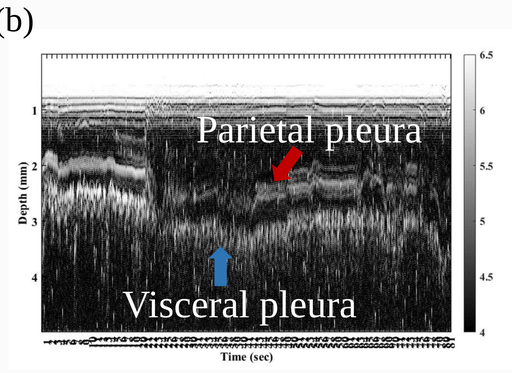

Figure 3. The ultrasound M-mode images of different materials-based ultrasound needle transducers in porcine in vivo experiment. (a) PMN-PT/ epoxy 1–3 composite, (b) PMN-PT.

Summary

- The bandwidth of PMN-PT/ epoxy 1–3 composite was significantly higher than PMN-PT, and the axial resolution of the former was significantly better than the latter. However, the amplitude and Kt of both were not have significant difference.
- No matter in porcine lung in vitro experiment or porcine in vivo experiment, the PMN-PT/ epoxy 1–3 composite transducers could clearly distinguish the interfaces of parietal pleura, having superior axial resolution. On the other way, interfaces of parietal pleura were blurred and indistinguishable by using PMN-PT based transducer.

Acknowledgement

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