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Improved fabrication of focused single element P(VDF–TrFE) transducer for high frequency ultrasound applications

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ABSTRACT

We present an improved fabrication technique for the focused single element poly (vinylidene fluoride–trifluoroethylene) P(VDF–TrFE) transducer. In this work, a conductive epoxy for a backing layer was directly bonded to the 25 μm thick P(VDF–TrFE) film and thus made it easy to conform the aperture of the P(VDF–TrFE) transducer. Two prototype focused P(VDF–TrFE) transducers with disk- and ring-type aperture were fabricated and their performance was evaluated using the UBM (Ultrasound Biomicroscopy) system with a wire phantom. All transducers had a spherically focused aperture with a low f-number (focal depth/aperture size = 1). The center frequency of the disk-type P(VDF–TrFE) transducer was 23 MHz and −6 dB bandwidth was 102%. The ring-type P(VDF–TrFE) transducer had 20 MHz center frequency and −6 dB bandwidth of 103%. The measured pulse echo signal had reduced reverberation due to no additional adhesive layer between the P(VDF–TrFE) film and the backing layer. Hence, the proposed method is promising to fabricate a single element transducer using P(VDF–TrFE) film for high frequency applications.

1. Introduction

An ultrasound transducer with broad bandwidth and high sensitivity has been becoming important for diagnostic ultrasound imaging. Typically, the performance of the ultrasound transducer depends on the property of the piezoelectric material capable of converting the electrical energy into mechanical energy, and vice versa. A single crystal and a piezoceramic material such as a lead zirconate titanate (PZT) have been frequently used for conventional diagnostic transducers [1]. Although aforementioned piezoelectric materials have high electromechanical coupling coefficients, they are suffered from narrow bandwidth, high acoustic impedance, and difficult aperture conformation [1,2].

In 1969, Kawaii discovered high piezoelectricity in PVDF (polyvinylidene fluoride) providing broad bandwidth, low acoustic impedance, and excellent mechanical flexibility [3]. Although the electromechanical coefficient of PVDF was lower than piezoceramic materials, it has been successfully used for various ultrasound applications. More recently, the poly (vinylidene fluoride-trifluoroethylene) P(VDF–TrFE) called PVDF copolymer was developed [4–6]. Its higher electromechanical coefficient, lower electrical and mechanical loss compared to PVDF were allowed to make various types of P(VDF–TrFE) transducers including a linear or an annular array transducer [7–9]. The applications of P(VDF–TrFE) transducer have been expanded from hydrophone construction [10–14] to imaging of tissue microstructure such as dermatology, ophthalmology, biomicroscopy, and small animal applications because design parameters and operating conditions of the P(VDF–TrFE) transducer are suitable for high frequency range [15–20].

Although the P(VDF–TrFE) film is easy to handle, achieving focused aperture using P(VDF–TrFE) film is very challengeable. Most fabrication processes require an additional adhesive layer between P(VDF–TrFE) film and backing materials and thus may result in high amplitude of reverberation in pulse echo signals [21–23]. Recently, PVDF spin coating technique has been developed instead of P(VDF–TrFE) film, however, it needs special equipments and complicated process [24,25]. In this paper, we present an improved fabrication technique for the focused single element transducer by using P(VDF–TrFE) film and conductive epoxy. The disk- and ring-type P(VDF–TrFE) transducers with highly focused aperture were successfully built and their performance was evaluated.

2. Methods

2.1. Transducer fabrication

The fabrication procedure for a ring-type transducer is divided into two major stages: making a disk-type transducer and subsequently making a cylindrical hole in the center of the

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Table 1
Material properties for P(VDF–TrFE) [9,26].

Property	Value
Density (ρ)	1880 kg/m^3
Longitudinal wave velocity (v_l)	2280 m/s
Acoustic impedance (Z_A)	4.3 Mrayl
Piezoelectric strain constant (d_{31})	12 pC/N
Electromechanical coupling coefficient (k_t)	0.3
Relative dielectric permittivity ($\varepsilon^S/\varepsilon_0$)	5
Electrical loss tangent ($\tan\delta_e$)	0.12
Mechanical loss tangent ($\tan\delta_m$)	0.04

Table 2
Measured performance of the prototype P(VDF–TrFE) transducers.

	Disk-type	Ring-type
Center frequency (MHz)	23	20
−6 dB Bandwidth (%)	102	103
P(VDF–TrFE) thickness (μm)	25	25
Focal depth (mm)	9.4	13.5
Inner diameter (mm)	-	8
Outer diameter (mm)	9.4	13.5
F-number	1	1
Electrical impedance (Ohms)	120	70

aperture. As a piezoelectric material, we used 25 μm thick P(VDF–TrFE) film (Ktech Corporation, Albuquerque, NM) whose resonance frequency is 24 MHz at λ/4 resonance with a heavy backing layer [20]. For a conductive backing layer, silver epoxy (ESOLDER 3022, Von. Roll Isola, Inc., New Haven, CT) was directly added on P(VDF–TrFE) film with gold electrode. Note that the plasma cleaning job was done before adding silver epoxy for more stronger adhesion force between P(VDF–TrFE) film and the backing layer. After using the centrifuge machine and overnight curing, the P(VDF–TrFE)-backing stack was trimmed off by using the lathe machine in order to obtain the desired aperture size of 13.5 mm. Subsequently, it was assembled with a brass housing and filled with unloaded epoxy (EPOTEK 301, Epoxy Technology, Billerica, MA) for insulation between the housing and the electrode of the backing layer. After overnight curing, we can make a hole with 8 mm diameter using the lathe machine for the ring-type transducer. Another brass housing was inserted inside of the hole. In the case of a disk-type transducer, hole making process was omitted. For conformation of the focused aperture, the stainless steel ball with 27 mm diameter was mounted on the front side of the transducer and pressed focused at 70 °C in the oven during short time, i.e., less than 5 min. The electrode wire was used to connect the conductive backing layer and the SMA (Subminiature version A) type connector assembled with the housing. Finally, 0.5 μm thick gold/chrome electrode was sputtered on the front side of the transducer for ground electrode between P(VDF–TrFE) and the housing.

Table 1 describes the properties for P(VDF–TrFE) and Table 2 shows the measured performance of the prototype transducer. Fig. 1a and b shows the photography of the disk- and ring-type P(VDF–TrFE) transducers and Fig. 1c shows a cross-sectional schematic diagram of the ring-type P(VDF–TrFE) transducer. They have spherically focused aperture and no matching layer.

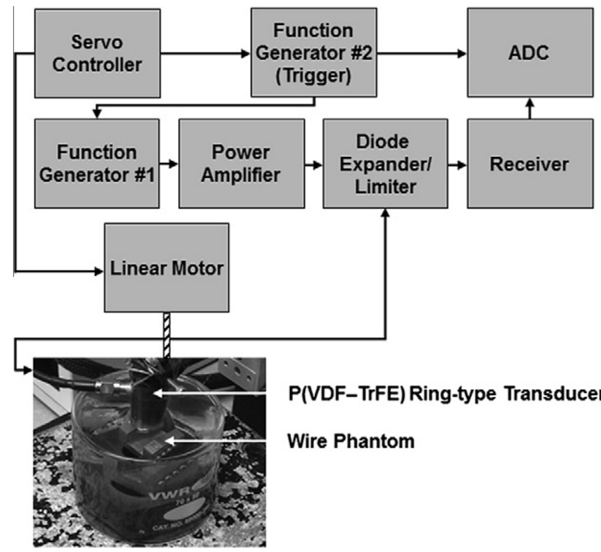

Fig. 2. Schematic diagram of the single-channel UBM system for high frequency 2D B-mode imaging of the single element transducer (ring-type transducer).

2.2. Experimental setup for B-mode imaging

Fig. 2 shows the schematic diagram of the single-channel UBM (Ultrasound biomicroscopy) system for high frequency 2-dimensional (2D) B-mode imaging. The B-mode images were obtained from the linear mechanical scanning and the target was a wire phantom with five wires. The diameter of each wire was 20 μm and made from tungsten. The UBM system was composed of several components. A linear motor controlled by a servo controller (LAR37, SMAC Inc., Carlsbad, CA, USA) and trigger generator (33250A, Agilent, Santa Clara, CA) was operated in swept mode in order to obtain multiple scanlines. For imaging, a function generator (33250A, Agilent, Santa Clara, CA) was connected to a power amplifier (325LA, ENI Co., Santa Clara, CA) with a 50 dB gain. A

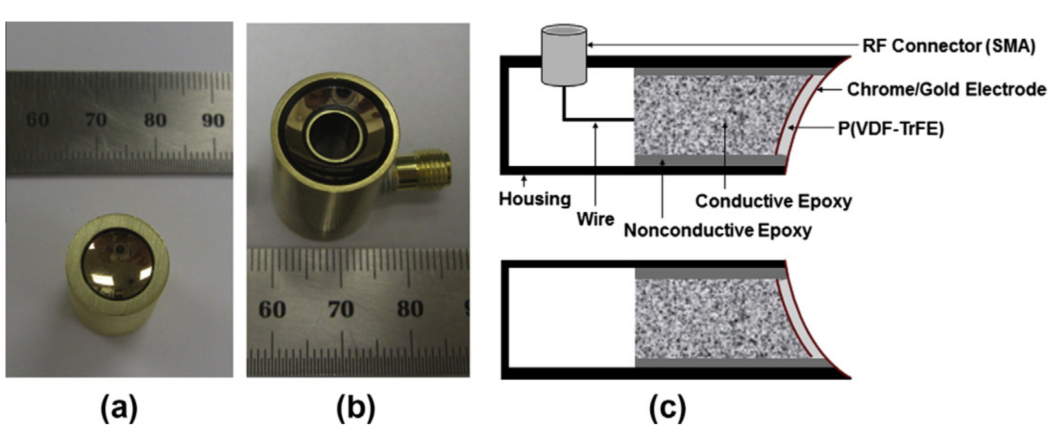

Fig. 1. Photographs of the prototype (a) disk- and (b) ring-type P(VDF–TrFE) transducers. (c) A cross sectional schematic diagram of the ring-type P(VDF–TrFE) transducer. Note that the photography (a) and (b) shows the aperture before chrome/gold sputtering for the ground electrode.