PERFORMANCE OF ULTRASONIC TRANSDUCERS MADE FROM COMPOSITE PIEZOELECTRIC MATERIALS

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ABSTRACT

Single element transducers and linear arrays made from composite piezoelectric materials were characterized for application in medical ultrasonic imaging. The composite transducers showed a compact temporal response and high sensitivity over a broad frequency range. Prototype linear arrays with elements defined by an electrode pattern alone exhibited low acoustic cross talk between neighboring elements and overall performance equivalent to that of state of the art diced arrays.

I. Introduction

Improved piezoelectric materials for use in medical ultrasonic transducers have been the subject of several studies in recent years [1-6]. Conventional materials, such as PZT ceramics, have good electromechanical properties, however they must be acoustically matched to tissue in order to efficiently transmit and receive over a broad frequency band. The application of these ceramics in linear arrays impose an additional complexity. Elements must be diced to promote acoustic isolation between them; moreover each element must be further subdiced into several subelements to suppress coupling to unwanted lateral modes. Recently, modified lead-titanate ceramics with extremely low planar electromechanical coupling factor have been proposed to circumvent the need for subdicing array elements [2-4].

Elimination of dicing altogether and much better acoustic match to tissue has been achieved with piezoelectric polymers such as polyvinylidene difluoride (PVDF) and its copolymers [5,6]. However, the performance of such transducers is presently limited by the low electromechanical coupling factor and the large dielectric loss of the polymers.

In the preceding paper [7] we have shown that composite materials, consisting of a piezoelectric ceramic and a passive polymer, combine the desired properties of high electromechanical coupling coefficient and low acoustic impedance. The composite structure studied consists of a grid of parallel PZT rods embedded in an epoxy matrix. To reach the low megahertz range of interest to medical ultrasonics, we have made composites whose lateral spatial scale is below 100 microns in both the ceramic and polymer phases. In this paper we describe the performance of such composites in device configurations: prototype single element transducers and linear arrays.

II. Single Element Transducers

Single element transducers (center frequency 2 - 5 MHz) were fabricaterd using circular disks (19 mm diameter) of composite in which Spurr epoxy holds together a grid of parallel PZT rods (Nittany 500) oriented perpendicular to the disk face. For the samples discussed in this paper, the PZT rods had lateral dimensions of 75x75 microns with 75 micron spacing between the rods. Prior to the fabrication of the composite disks into transducers, the complex electrical impedance of the free disks was measured as a function of frequency in order to determine the effective electromechanical properties of the composite material. On the average, these measurements yielded effective coupling factor $k_t = 0.55$, sound velocity $v^D = 3300$ m/s, clamped dielectric constant $\varepsilon^S = 200$, and mechanical quality factor $Q_m = 20$. The same measurement was repeated with one face of the composite disk immersed in water. A fit of these data to the theoretical impedance of the loaded disk [7], predicted by the Mason's model, yields an average acoustic impedance of 7.5 MRayls for the composite-samples. These results are in good agreement with the data reported in the preceding paper for composite materials with 200 - 300 micron scale in the 500 kHz range. The reduced acoustic impedance achieved with the composite materials eases the technological problems in acoustic matching to tissue. First, the impedance step bridged by the matching is smaller so the allowable tolerances in the thickness and the acoustic impedance of the matching layer are broader. Second, the appropriate acoustic impedance for the matching layer is brought into a range where a variety of homogenous materials are readily available.

The performance of the composite transducers will be demonstrated with an air-backed 2 MHz transducer provided with a quarter wavelength matching layer of the same Spurr epoxy used in the composite (Z = 2.4 MRayls). The sensitivity of the

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transducer was characterized by measuring the round trip insertion loss [8]. The transducer was placed in a water tank at a distance of 0.5 cm from a steel block and was driven with an HP3314 sinewave generator. Electrical matching of the transducer to the source was accomplished with a series inductance and adjustment of the output resistance of the source to the resistance of the transducer near the resonance. The generator was adjusted to transmit tone bursts with an amplitude V_t of 5 volts and duration of about 15 cycles into a load equal to the source resistance. The insertion loss was determined from the amplitude, V_r, of the echo signal generated across the same load, as $20\log(V_r/V_t) + 0.6$ dB, where the 0.6 dB accounts for the imperfect reflection of the steel block. The results shown in Figure 1 indicate a high sensitivity (minimum insertion loss 3.8 dB) over a broad bandwidth (6 dB fractional bandwidth 50%). A larger fractional bandwidth of 60% with a higher minimum insertion loss of 6.5 dB were obtained with a 3 MHz transducer provided with a light backing (Z = 1.4 MRayls). This high sensitvity confirms the expectations based on the composite electromechanical properties.

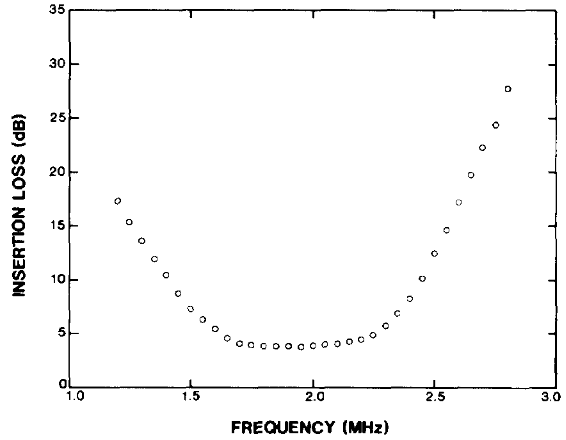

Figure 1. Two way insertion loss versus frequency measured in a 2 MHz composite transducer.

The impulse response characteristics of the transducer were measured using a Metrotek pulser-receiver system. The transducer was placed in a water tank opposite a steel block and driven with a Metrotek MP203 pulser. When loaded with a 50 ohm resistor, the pulser produced voltage spikes whose amplitude spectrum was flat to within ±1 dB up to 10 MHz. A Metrotek MR101 receiver amplifier in conjuction with a stepless gate (Metrotek MG701) passed the first reflected echo onto an HP3585 spectrum analyzer and a Tektronix 7904 oscilloscope. An optimized electrical network was used to match the transducer to the drive electronics [9]. Figure 2 shows the temporal pulse-echo response of the composite transducer. The pulse lengths at the -20 dB and -40 dB levels are 1.5 and 3.6 microseconds, corresponding to 3.0 and 7.2 periods, respectively. This compact temporal response confirms the expectation provided by the properties of the composite materials.

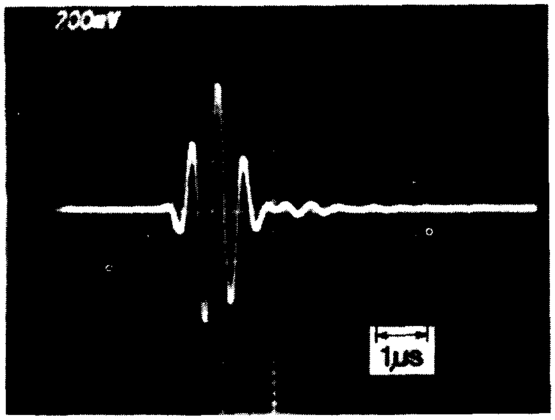

Figure 2. Time domain impulse response of a 2 MHz composite transducer.

III. Linear Arrays

Linear arrays have been fabricated from composite material (center frequency 2 - 5 MHz) by patterning the electrodes without dicing the array elements. Trial arrays were formed on 19 mm composite disks by scribing the metallization over one face of the disks, the other face remaining uniformly metalized acted as a ground electrode. We illustrate the results of cross coupling measurements using a 2 MHz array scribed onto the back of the same single element transducer characterized above. The array, diagrammed in Figure 3,

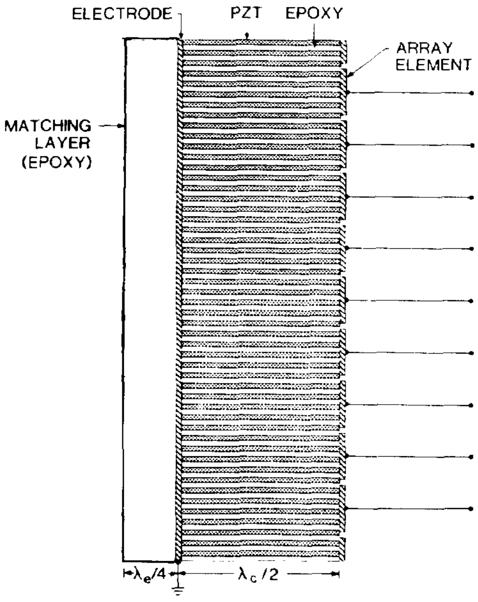

Figure 3. Schematic cross-section of a composite linear array with elements defined by the electrode pattern alone.

included 10 elements of 1 mm width, 16 mm length, and period of 1.05 mm.

Electrical measurements of cross talk were performed by exciting one element of an array with a single cycle sine wave (peak to peak amplitude V_e = 10 V) and measuring the peak to peak amplitude, V_c, of the open circuit voltage signal generated on adjacent elements. Cross coupling coefficients were calculated as $20\log(V_c/V_e)$. The data summarized in Table I show exceptionally low mechanical cross coupling when the array is radiating into water.

Table I. Electrical and Mechanical cross coupling measured in a 2 MHz composite array radiating into air and into water.

Neighboring Element	CROSS COUPLING (dB)		
	Electrical	Mechanical	
	Air & Water	Air	Water
1st	-28		
2nd	-45	-45	-48.5
3rd	-58	-50	-54
4th	-55	-53	-56.5

This result was further confirmed by measuring the far field radiation pattern generated by the excitation of a single element in the array. Figure 4 shows the radiation pattern measured when a single element was excited with a 2 MHz tone burst. The solid and dashed curves in this figure describe the theoretical beam patterns for isolated rectangular piston radiators of width 1.1 mm and 1 mm, respectively, in a soft baffle [10]. A comparison of the experimental data and the calculated curves shows that the equivalent element width due to cross coupling is only 10% larger than the geometrical width of the element. These measurements provide convincing evidence that a high degree of acoustic isolation can be achieved in composite arrays without dicing the composite material.

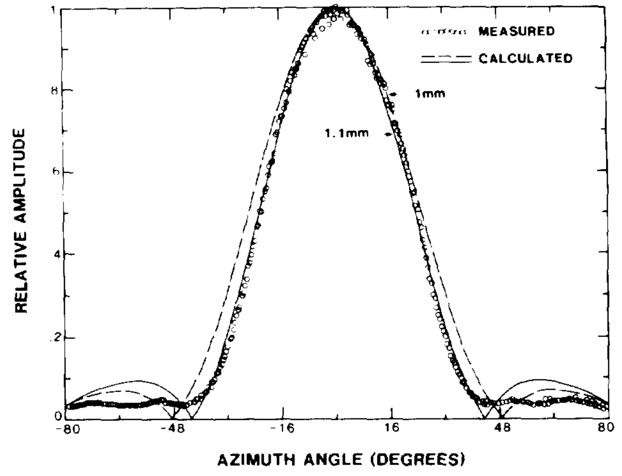

Figure 4. Measured radiation pattern from a single element (width 1 mm) in a composite array. Solid and Dashed curves are calculated for isolated elements of width 1mm and 1.1 mm, respectively.

IV. Acoustic Images

A prototype linear array with a center frequency of 4.5 MHz was fabricated to test the quality of acoustic images produced by undiced composite arrays. The array was provided with a mechanical lens to focus the beam in the direction perpendicular to the electronic lens. Figure 5 shows an image of Ecobloc foam generated with the composite array. Comparison of this image with that produced by a conventional diced PZT array shows that the two are equivalent. Thus the low cross talk and the good impulse response characteristics of the composite array produce the expected high image quality. The fabrication and performance of composite linear arrays will be described in more detail elsewhere.

Figure 5. Image of Ecobloc foam taken with a composite array.

V. Conclusions

Transducers made from composite piezoelectric materials are well suited for application in medical ultrasonic imaging. A simple design of composite transducers with a single matching layer yields a compact temporal response and high sensitivity over a broad frequency range. Application of composite materials in transducer arrays is of particular interest. A high degree of acoustic isolation between neighboring elements can be achieved in composites without dicing the array elements. The performance of composite linear arrays with elements defined by an electrode pattern alone is equivalent to that of state of the art diced arrays.

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