EVALUATION OF PIEZO COMPOSITE BASED OMNIDIRECTIONAL SINGLE FIBRE TRANSDUCERS FOR 3D USCT

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1. Introduction

- Breast cancer - Most widespread cancer among women in the world
- 3D Ultrasound Computer Tomography (USCT) system developed for early breast cancer detection (Fig. 1)
- 2041 ultrasound transducers are used in a multistatic setup for 3-D imaging
- Reconstruction of images using Synthetic Aperture Focussing Technique (SAFT) algorithm
- Three imaging modalities - Reflection, Speed of Sound and Attenuation

Fig. 2 : 3D semi-ellipsoidal aperture whose walls are surrounded by 157 ultrasound transducers

Fig. 1 : 3D USCT with covers opened

A. Background

- Transducers produced by dicing a fully polarized piezoelectric wafers
- Four elements bonded together and work as a single transducer
- Polyurethane (PU) as backing layer
- Acoustic characteristics of rectangular transducers: 2.5 MHz center frequency, 1 MHz bandwidth and 36° opening angle at -3dB

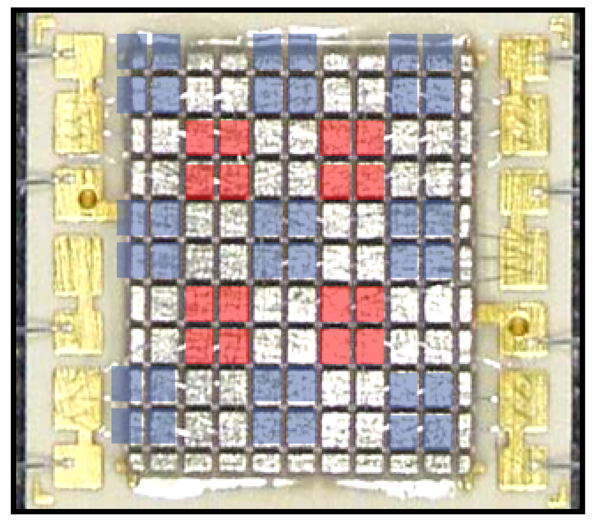

Fig. 3 : 5 mm piezoceramic wafer diced into rectangular elements. Four elements are bonded together and work as a single transducer (red and blue)

B. Motivation

- Region of Interest (ROI) needs to be increased for next generation USCT
- Analysis shows that -3dB opening angle of transducer should be increased to 60°
- **Goal:** New transducer design with an excellent reproducibility and increased opening angle while preserving center frequency and bandwidth

2. Approach

- Simulation shows that decrease in surface area leads to increase in opening angle
- An idea of circular instead of rectangular transducer was introduced
- Circular transducer design will result into additional pressure homogeneity
- Existing dice-and-filling is unable to produce circular shaped transducer
- An innovative technique is introduced based on a single PZT fibre (Fig. 4)

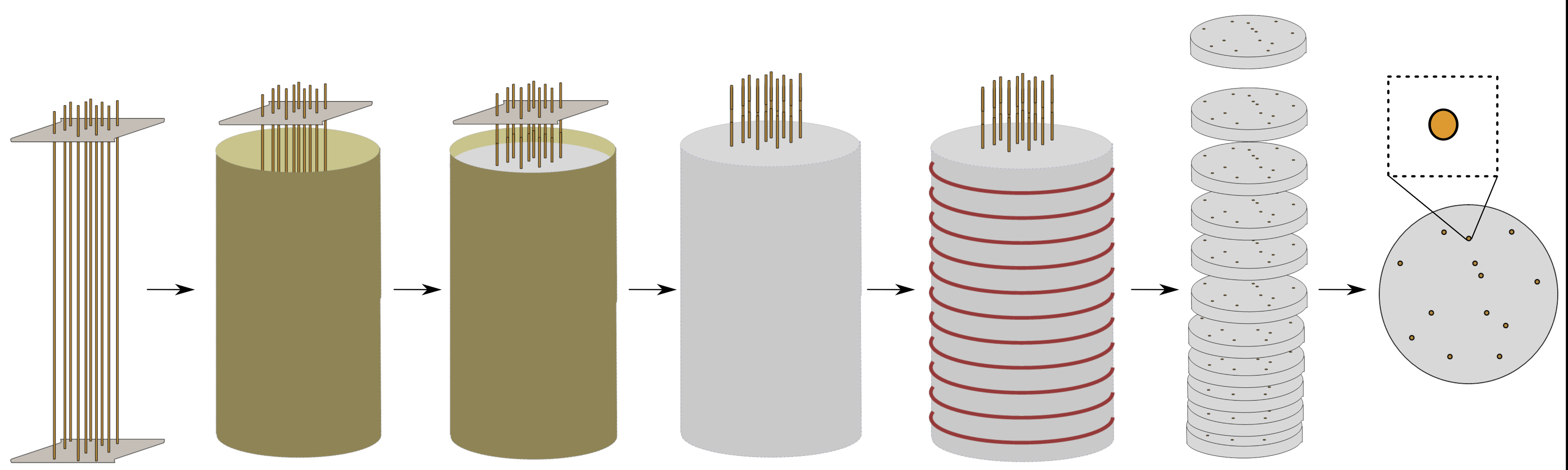

Fig. 4 : New fabrication process of piezocomposite fibres

A. Fabrication

1. Arrange PZT fibres in a required pattern
2. Place them in cylindrical container and fill with epoxy polymer
3. Allow it to cure for 2 days at 23°C
4. Dice the composite block into thin wafers of required thickness and then polarize
5. Conductive glue is used for connecting the PZT fibres with the contact pads (manual bonding)
6. Finally, the PZT fibres are placed in cylindrical housing (Fig. 6)

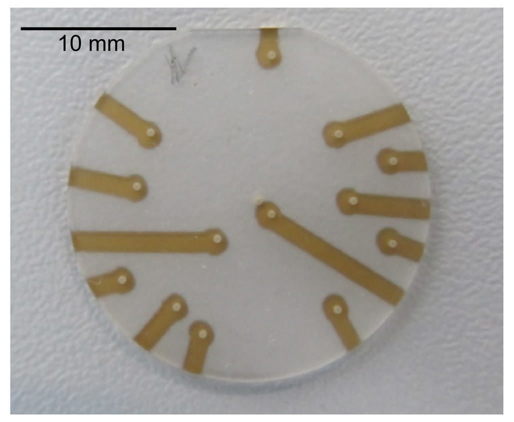

Fig. 5 : Piezoceramic containing 13 individual piezo fibres, backside is ground

Fig. 6 : Piezocomposites connected with contact pads in a cylindrical housing for acoustic measurement

3. Evaluation and Results

- Four different thickness of PZT fibres are produced - 450, 500, 550, 600 µm
- Evaluation of thickness and diameter shows good match and small deviation

A. Electrical characteristics

- **Expected impedance:** As surface area decreased by factor of 4, impedance should increase by factor of 4
- **Expected phase:** Approx. 0° phase at resonance frequency and deviates at other frequencies (Fig. 7)
- Statistical evaluation shows approx. 30% deviation from the mean impedance value and 7.3% deviation from the maximum phase value (Table-1)
- **Indication of working transducer:** Presence of series and parallel resonance (Fig. 7)
- **Non-working transducer:** Weakly distinct series and parallel resonance values

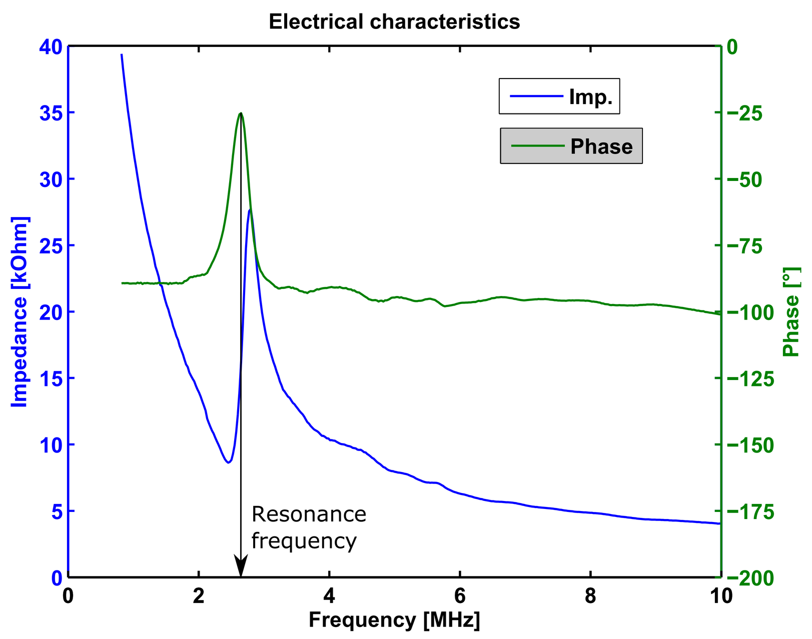

Fig. 7 : An example of an electrical characteristics of a circular transducer with impedance = 16.23 kΩ and phase = -25.3° at its resonance frequency = 2.65 MHz

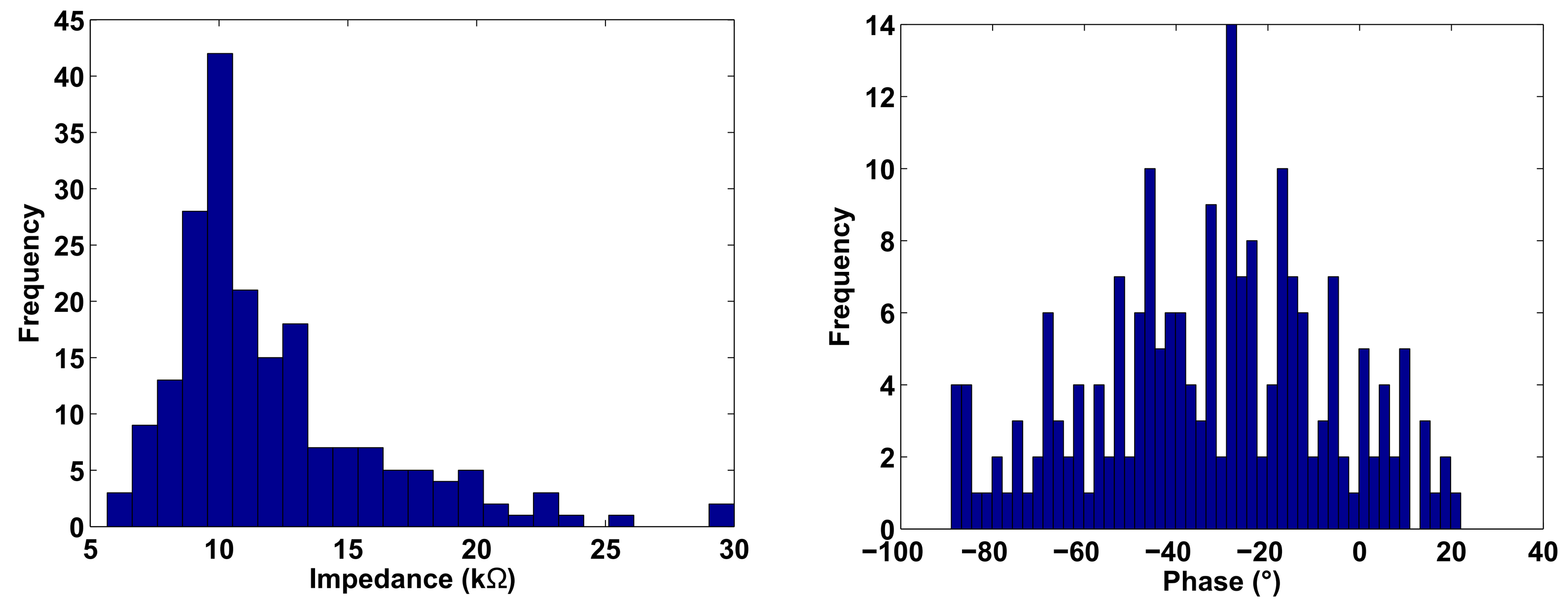

Fig. 7 : Histogram of electrical impedance (left) and phase (right) evaluated for the thicknesses (450, 500, 550, 600 µm) of the PZT fibres

Impedance			Phase		
Mean (kΩ)	Median (kΩ)	Std_dev (%) $= \left(\frac{\text{Std\_dev (k}\Omega)}{\text{Mean (k}\Omega)}\right)*100$	Mean (°)	Median (°)	Std_dev (%) $= \left(\frac{\text{Std\_dev (°)}}{360°}\right)*100$
12.08	11.23	30.71	-32.72	-30.90	7.3

Table 1 : Statistical Analysis of electrical impedance and phase of all the elements of PZT fibres with different thicknesses of 450, 500, 550, 600 µm where Std_dev = Standard deviation

B. Acoustic characteristics

- **3-axes characterization setup** - Capable of generating arbitrary waveforms using waveform generator and arbitrary patterns using hydrophone which can move in 3-axes
- **Input data** - (i) Excitation signal with multiple center frequency (0-5 MHz) (ii) Bandwidth of 0.25 MHz (iii) Chirplength of 100 µs (Fig. 8 left) and 80 µs (Fig. 8 right) (iv) Semicircle pattern of radius 60 mm

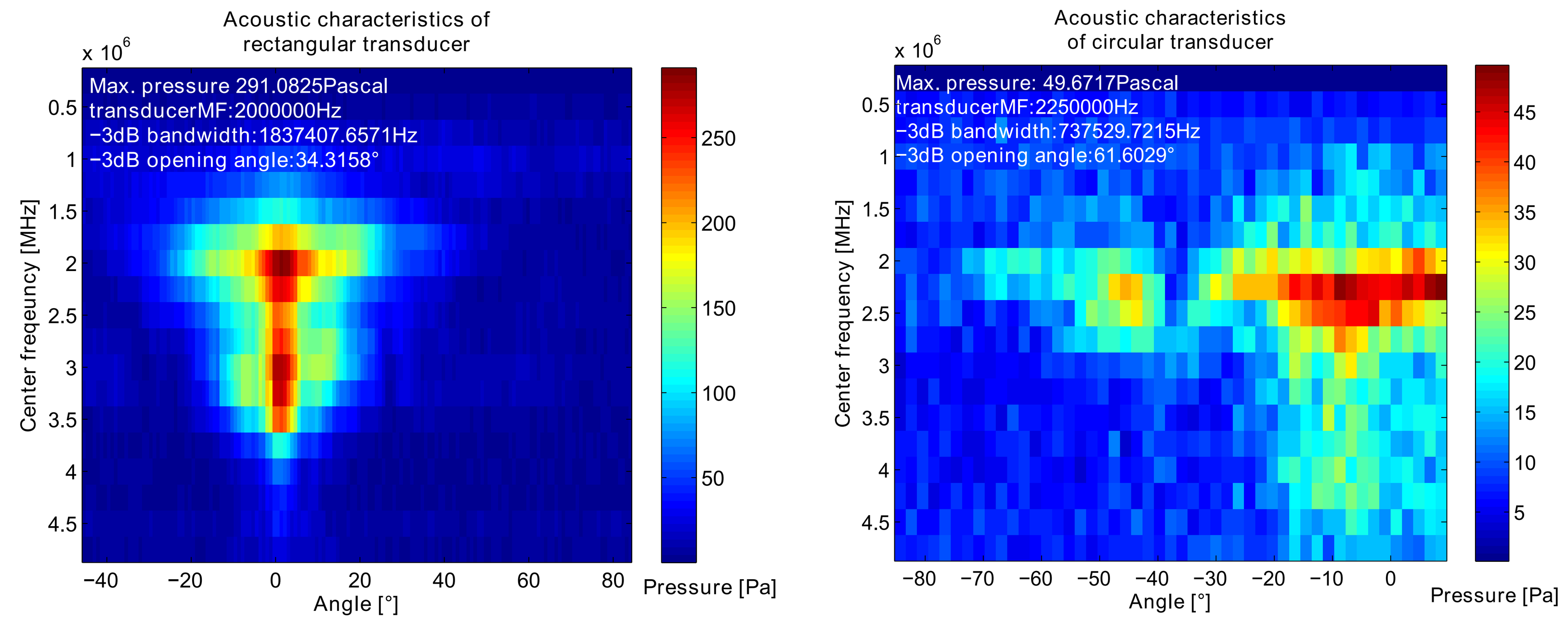

Fig. 8 : Acoustic characteristics of a rectangular transducer (left) and a circular transducer (right)

Example transducer	Frequency (MHz)	Maximum pressure (Pa)	-3dB opening angle (°)
Rectangular transducer (#79.4 (bonded 4 elements))	2.00	291.1	35.91
	2.25	259.8	24.22
Circular transducer (#36 (element-3))	2.00	49.9	57.38
	2.25	62.1	61.60

Table 2 : Evaluation of acoustic characteristics of one of the rectangular and the best working element of circular transducer after compensating the energy as the input excitation signal are of different lengths

Result of the analysis of two transducers mentioned in table-2

- Opening angle has been successfully increased to 60°
- As the surface area of circular transducer decreases by factor 4 as compared to the rectangular transducer, the sound pressure should also decrease by factor 4. For the selected element of transducer (Fig. 8 right), the expected sound pressure is obtained (Table-2)

4. Discussion and Conclusion

A. Discussion

- Some elements were broken resulting into very low sound pressure but the one chosen here has relatively expected sound pressure
- Large variability in electrical and acoustic characteristics of PZT fibres

B. Conclusion

- An innovative fabrication technique was introduced instead of conventional dice-and-filling method
- Reproducibility achieved in terms of disc thickness, shape and position of fibres
- Significant increase in opening angle to 60°
- Other characteristics like center frequency and bandwidth has been preserved

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