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

M. Zapf1, K. Hoffmeier2, G. Schall1, S. Gebhard3, K.W.A. von Dongen3, H. Gemmeke1, A. Michaels3, N. V. Rulke1
1 Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
2 Institute of Material Science, TU Dresden, Dresden, Germany
3 IKTs, Fraunhofer Institute, Dresden, Germany
4 Laboratory of Acoustical Ultrasonics, Delft University of Technology, The Netherlands

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

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)

3. Evaluation and Results

A. Background

Transducers produced by dicing a fully polarized piezoelectric wafer
Four elements bonded together and work as a single transducer
Polyurethane (PU) as backing layer
Acoustic characteristics of rectangular transducers: 2.6 MHz center frequency, 1 MHz bandwidth and 36° opening angle at -3dB

B. Motivation

Region of Interest (ROI) needs to be increased for next generation USCT
Analysis shows that -3dB opening angle transducer should be increased to 60°

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 single PZT fibre (Fig. 4)

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)

B. Acoustic characteristics

3-axes characterization setup - Capable of generating arbitrary waveforms using waveform generator and arbitrary transducer 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) Chip length of 100 μs (Fig. 8 left) and 90 μs (Fig. 8 right) (iv) Semicircle pattern of radius 60 mm

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)

B. Motivation

Region of Interest (ROI) needs to be increased for next generation USCT
Analysis shows that -3dB opening angle transducer should be increased to 60°

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 single PZT fibre (Fig. 4)

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)

B. Acoustic characteristics

3-axes characterization setup - Capable of generating arbitrary waveforms using waveform generator and arbitrary transducer 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) Chip length of 100 μs (Fig. 8 left) and 90 μs (Fig. 8 right) (iv) Semicircle pattern of radius 60 mm

Table 1: Evaluation of acoustic characteristics of a rectangular and a circular working element of circular transducer

<table>
<thead>
<tr>
<th>Transducer Type</th>
<th>Frequency (MHz)</th>
<th>Max. Pressure (Pa)</th>
<th>3dB Opening Angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular transducer</td>
<td>2.00</td>
<td>259.8</td>
<td>35.91</td>
</tr>
<tr>
<td>Rectangular transducer</td>
<td>2.25</td>
<td>259.8</td>
<td>24.22</td>
</tr>
<tr>
<td>Circular transducer</td>
<td>2.00</td>
<td>49.9</td>
<td>57.30</td>
</tr>
<tr>
<td>Circular transducer</td>
<td>2.25</td>
<td>62.1</td>
<td>61.60</td>
</tr>
</tbody>
</table>

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

References


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

<table>
<thead>
<tr>
<th>Thickness (μm)</th>
<th>Impedance (kΩ)</th>
<th>Phase (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (kΩ)</td>
<td>Median (kΩ)</td>
</tr>
<tr>
<td>450</td>
<td>12.08</td>
<td>11.23</td>
</tr>
<tr>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>550</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1: Total of 171 ultrasound transducers are surrounded by 171 ultrasound transducers
Fig. 2: A new fabrication process of piezocomposite fibres
Fig. 3: Phased array containing 17 individual PZT fibres, backside or ground
Fig. 4: Phased array containing 17 individual PZT fibres, backside or ground
Fig. 5: Phased array containing 17 individual PZT fibres, backside or ground
Fig. 6: Phased array containing 17 individual PZT fibres, backside or ground
Fig. 7: An example of an electrical transducer of a circular transducer with an opening angle 20°
Fig. 8: An example of an electrical transducer of a circular transducer with an opening angle 20°