An Investigation into the Effects of Acoustical Coupling of Integrated Photonics Based Ultrasound Transducer (IPUT) Arrays

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Introduction

The signal-to-noise-ratio (SNR) is an important parameter for improving image quality of medical ultrasound. Increasing SNR allows for detection at larger penetration depths, which benefits difficult to image (e.g. large) patients.

The SNR is limited by:

- The pressure reduction during propagation due to diffraction, attenuation effects and low scattering strength of small scatterers,
- The peak pressure is limited by safety standards (MI)

Thus, fundamentally, the only way to increase SNR are more sensitive transducers.

The Integrated Photonic Ultrasound Transducer (IPUT) is a newly developed ultrasound transducer which combines a mechanical resonator (membrane) and photonic waveguides.

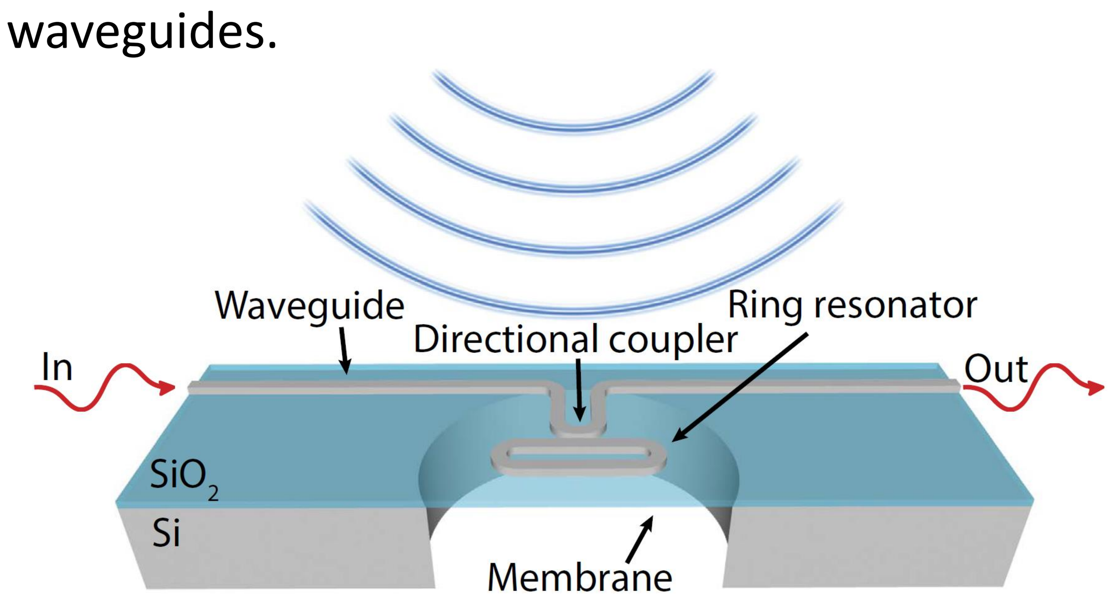


***Figure 1.** Schematic overview of a photonic waveguide integrated onto a membrane [1]*

The small IPUT size (<<0.5λx0.5λ) means multiple IPUTs can be cascaded within a single matrix array element to increase sensitivity.

However, the performance of closely packed IPUTs can be reduced by the less defined clamping of the membrane edges and by acoustical crosstalk.

Goal: To investigate the mechanical coupling between IPUTs to maximize IPUT element sensitivity and bandwidth.

Method

A 3D time-domain acousto-elastic FEM model (COMSOL) was developed to characterize the time response and transfer functions for a variety of IPUT array configurations:

- IPUT center frequency 2.4 MHz
- IPUT pitch: 1.1× to 5× the IPUT diameter
- IPUT radius 0.1 mm
- Membrane thickness: 3 um SiO2
- 40 um PMMA coating on top of the membrane
- Si wafer thickness 0.3 mm
- Backing layer around the Si wafer: 18 MRayl

The geometry consisted of 6 IPUTs in a hexagonal pattern, adjacent to water, with symmetry conditions on both chip edges to model an infinite number of IPUTs.

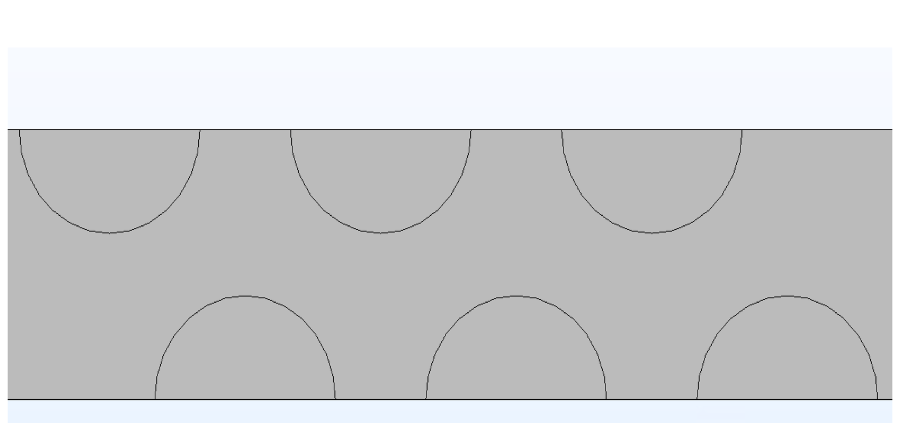


***Figure 2.** The top view of the hexagonal pattern*

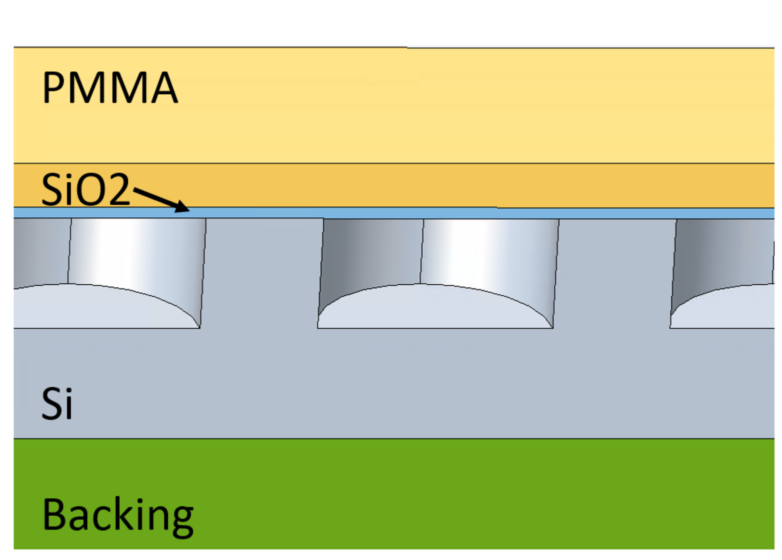


***Figure 3.** Side view in the solid domain*

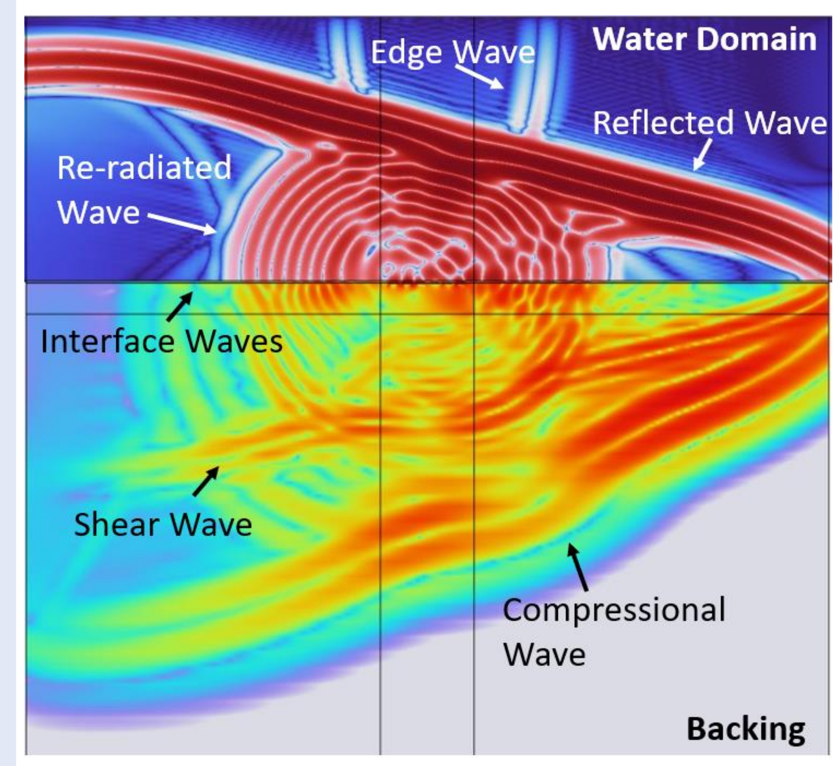
A compressional wave was excited under a 20 degree angle in the water domain.

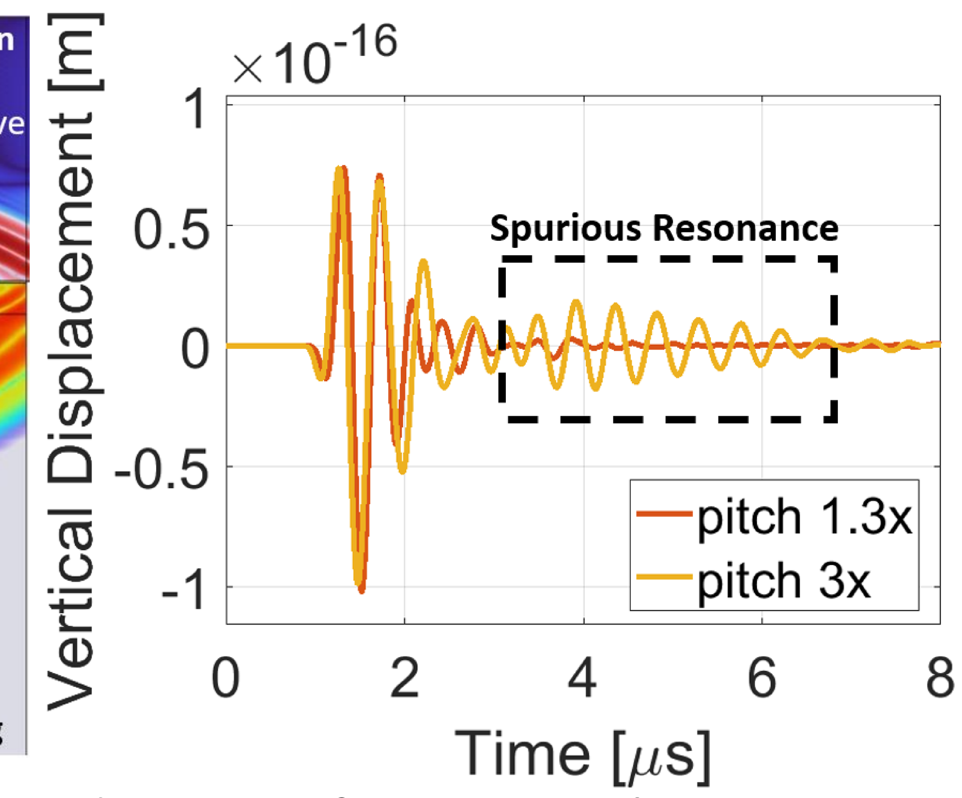
The IPUT response was obtained by extracting the vertical displacement and dividing this by the input pulse in the frequency domain.

Results

The relevant wave modes and types occurring in the system as modelled by the FEM:

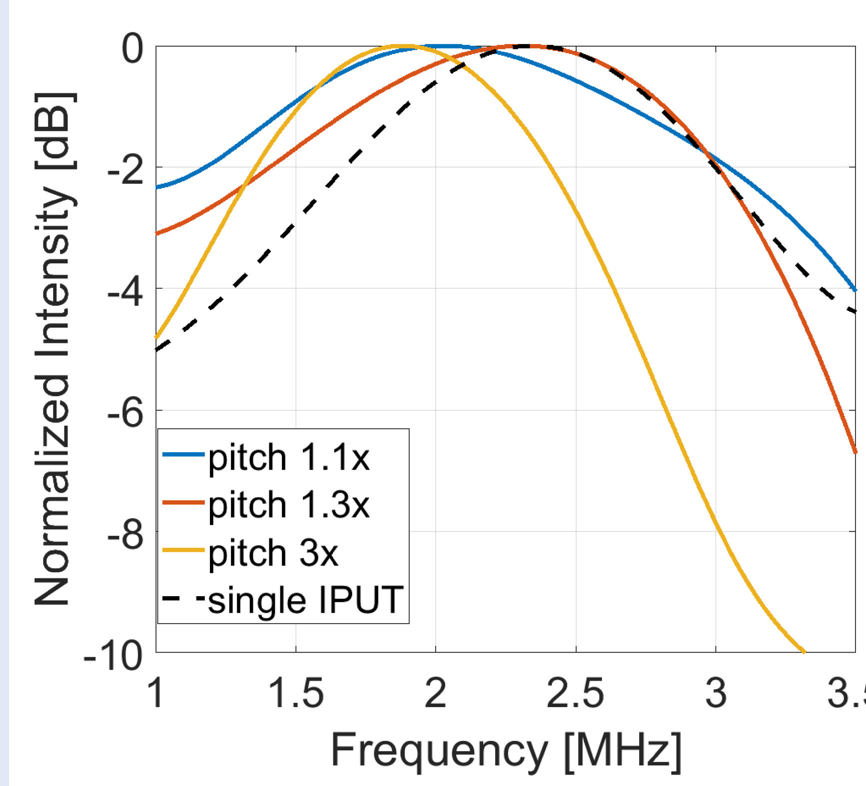
- In the solid domain: Compressional, shear and interface waves.
- In the water domain: the reflection of the incoming compressional wave, edge waves created by the limited aperture of the acoustic source in the simulation and re-radiated compressional waves from the IPUTs.

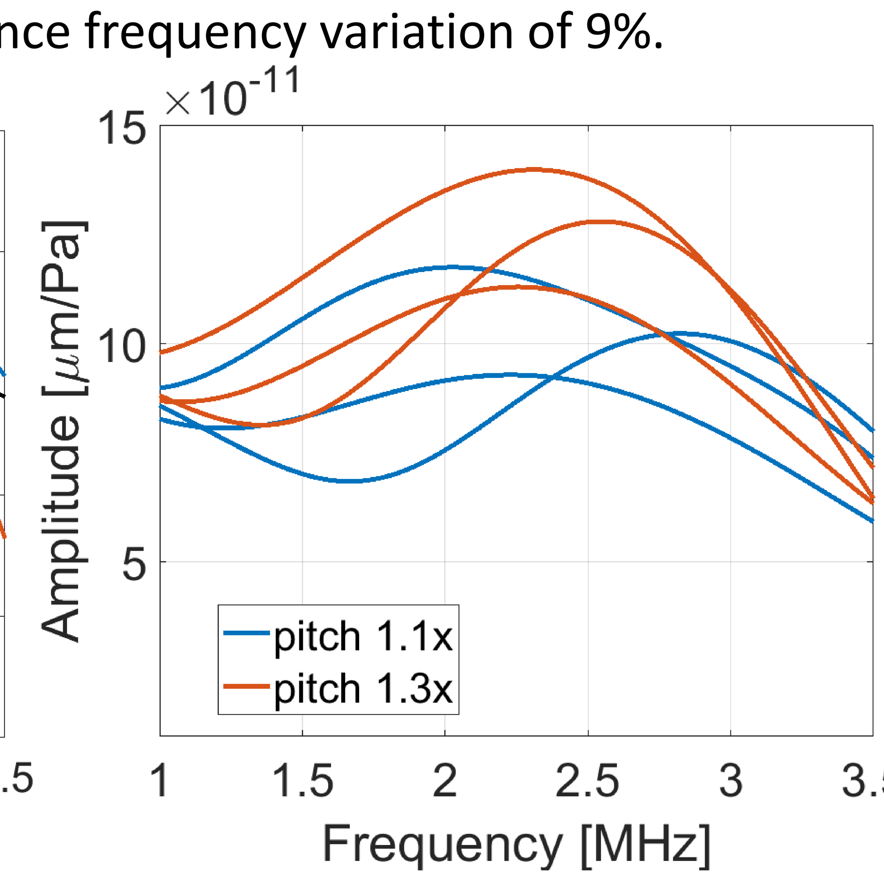




For pitches above λ_{water}, for an IPUT diameter of 200 um with a resonance frequency of 2.4 MHz, spurious resonances were predicted by the model. These resonances occur due to the re-radiated compressional waves reverberating between the IPUT structures.

For small IPUT pitches, the clamping of the IPUT membrane edges was affected by the lack of material near the edge, reducing the Q-factor. This also resulted in a larger variation of the individual IPUT responses in an acoustic element consisting of cascaded IPUTs. This negatively affects the total element sensitivity. The optimal pitch was 1.3x the IPUT diameter with a Q factor reduction of 20% and a resonance frequency variation of 9%.





Conclusion

The results showed that a pitch of 1.3× the IPUT diameter was optimal. This gave the best trade-off between IPUT grid density/unit area (highest sensitivity/unit area), Q-factor reduction (20%) and variation in resonance frequency (9%).

References

[1] Leinders, S., Westerveld, W., Pozo, J. *et al.* A sensitive optical micro-machined ultrasound sensor (OMUS) based on a silicon photonic ring resonator on an acoustical membrane. *Sci Rep* **5**, 14328 (2015).

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