# Gradient index phononic crystals for acoustic power transfer applications

**Ahmed Allam**, Karim Sabra, and Alper Erturk
*Smart Structures & Dynamical Systems Laboratory, G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332*
*a.allam@gatech.edu, karim.sabra@me.gatech.edu, alper.erturk@me.gatech.edu*

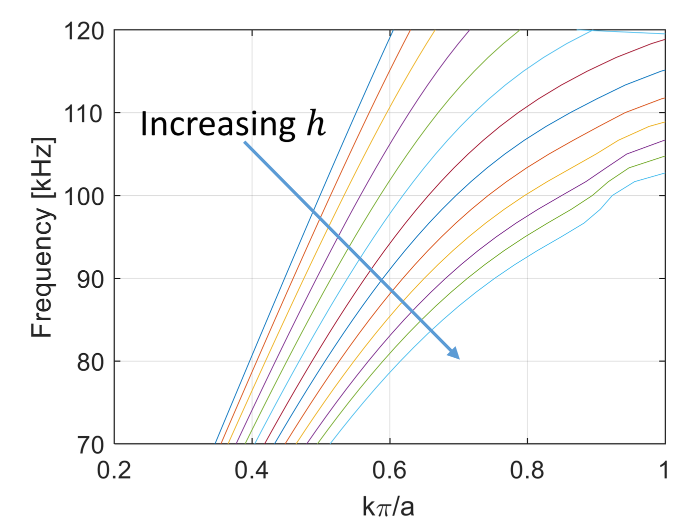
## Objectives and motivation

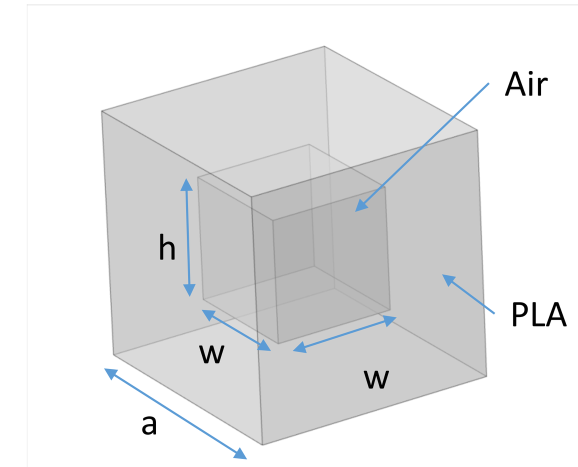
- A novel gradient index phononic structure is developed to control the propagation of ultrasonic waves for applications spanning from acoustic power transfer to sensing underwater.
- We propose a plastic hollow 3D printed simple structure as a basis for manipulating acoustic waves in aqueous media.
- The unit cell design relies on the substantial impedance mismatch between air and water to control the refractive index.

## Unit cell design and analysis

- A coupled (acoustic-structural interaction) finite-element model of the heterogeneous unit cell was used to estimate the dispersion by assuming Floquet boundary conditions.
- The slope of the dispersion curve at the design frequency and hence the phase velocity is mainly controlled by volume of air inclusion in the cell
- Increasing the air filling fraction slows down the acoustic waves incident on the cell
- Strong control over the slope of the dispersion plot is achieved at frequencies immediately below the Bragg scattering.
- This allows for strongly varying the index of the medium through a gradual change in the cell structure.

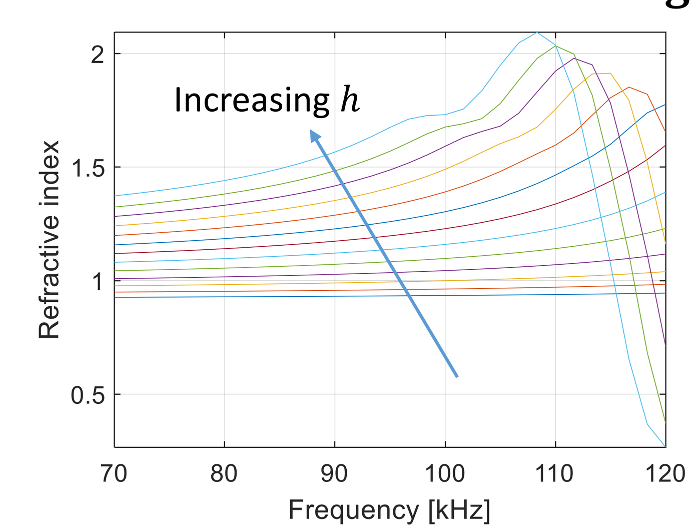
**Dispersion**

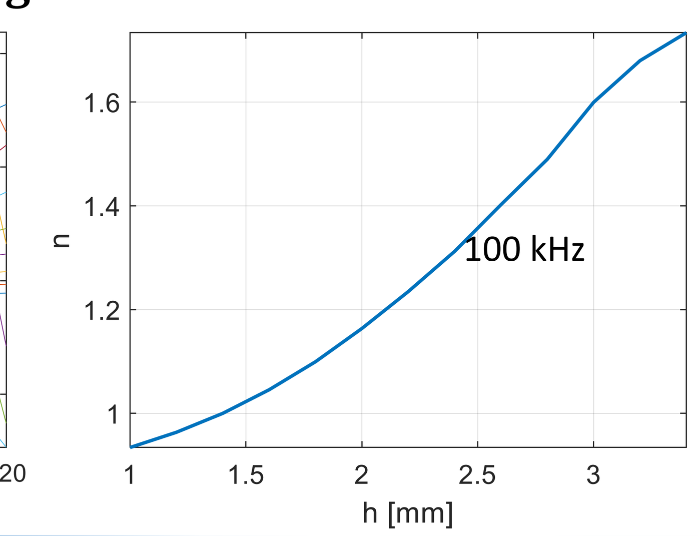



- Cell Dimensions
  - Fixed: $a = 4\text{mm},\ w = 2.6\text{mm}$
  - Variable: $h$

**Effect of inclusion height on the refractive index**



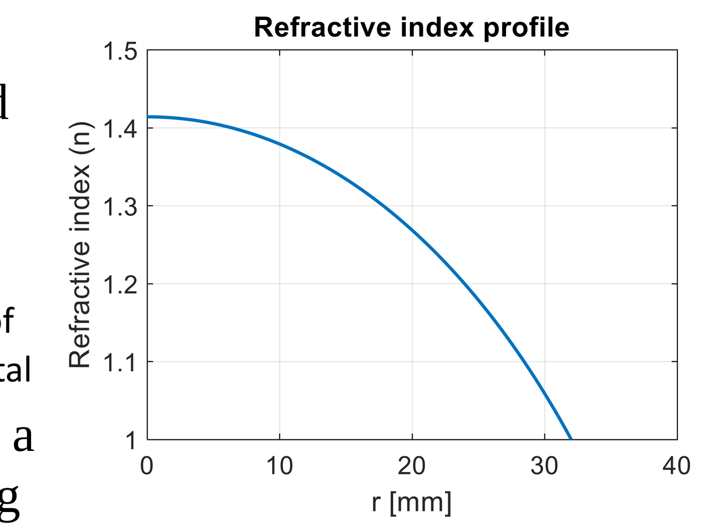




## 3D Printed Luneburg Lens

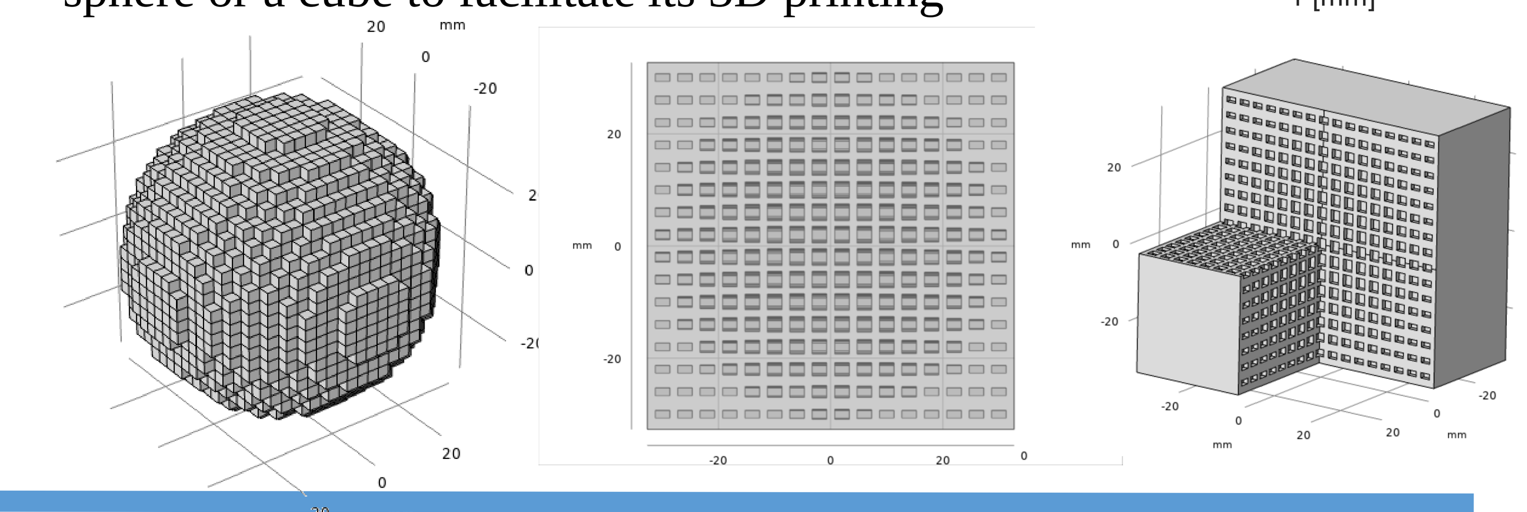
- Luneburg Lens can be constructed according to the refractive index profile:

$$n(r) = \sqrt{2 - \frac{r^2}{R^2}}, \qquad n = \frac{c_w}{c_{eff}}$$

$c_w$: Speed of sound in water
$c_{eff}$: Effective speed of sound in the crystal



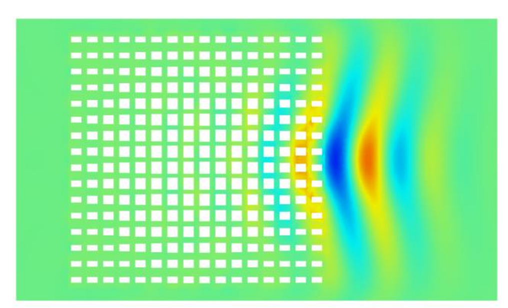

- The lens can be constructed in the form of a sphere or a cube to facilitate its 3D printing



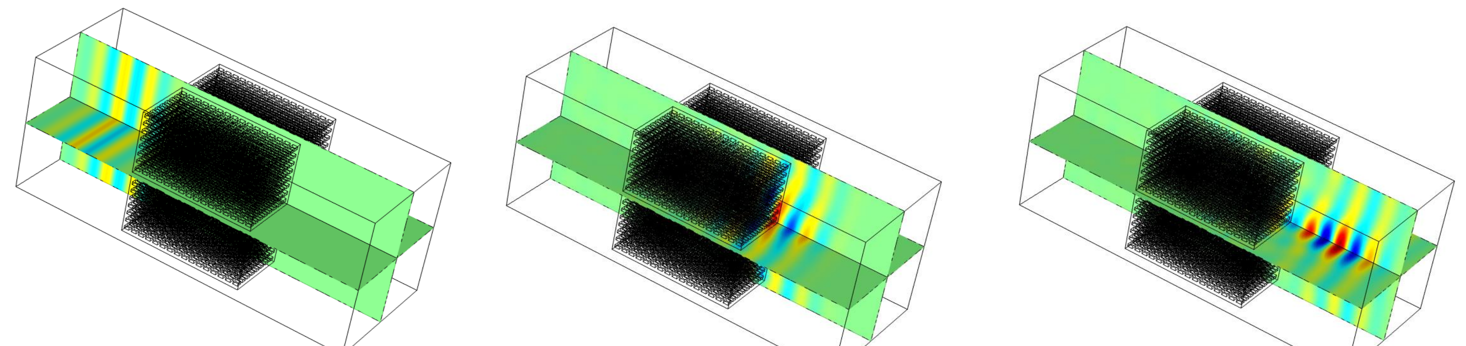
## Numerical simulations

- A 3D coupled (acoustic-structure interaction) finite-element model was used to conduct time domain and steady state frequency domain analyses of an incident plane wave on the designed Luneburg lens.

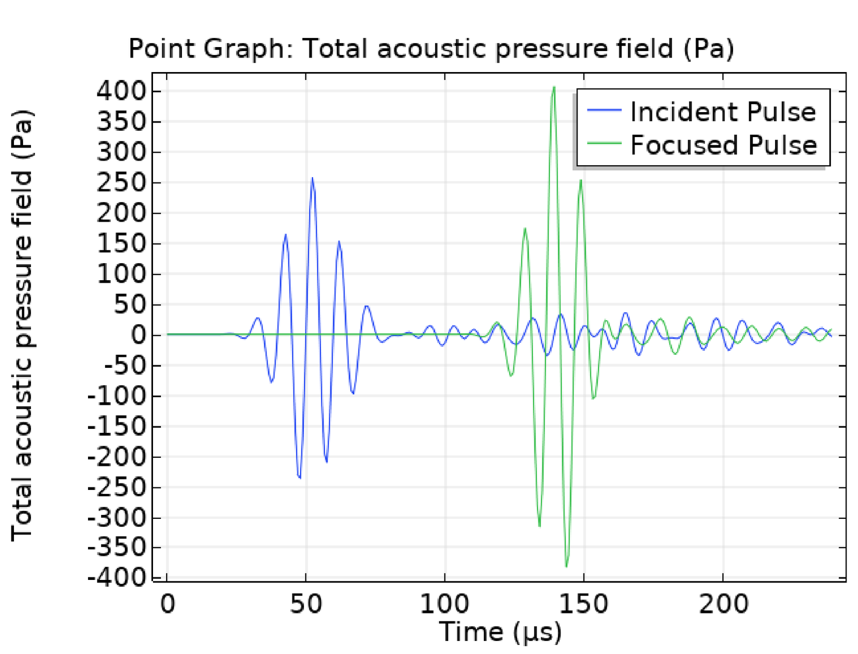
**Sectional view**



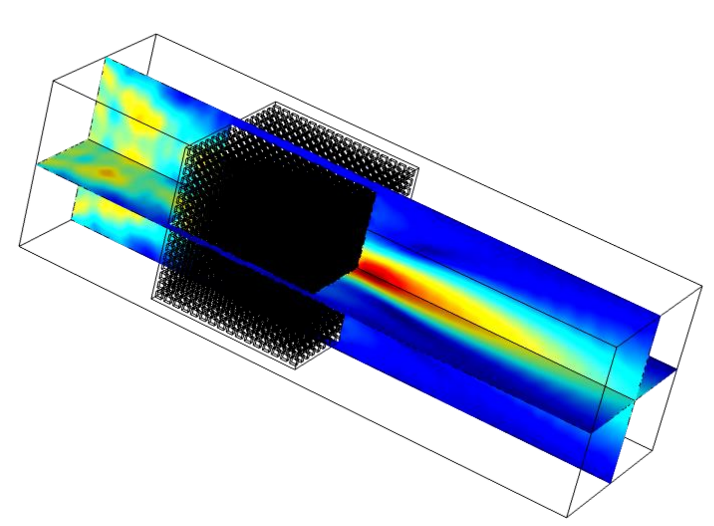
**Time lapse of an incident plane wave through the Lens**



**Simulated Focusing power**



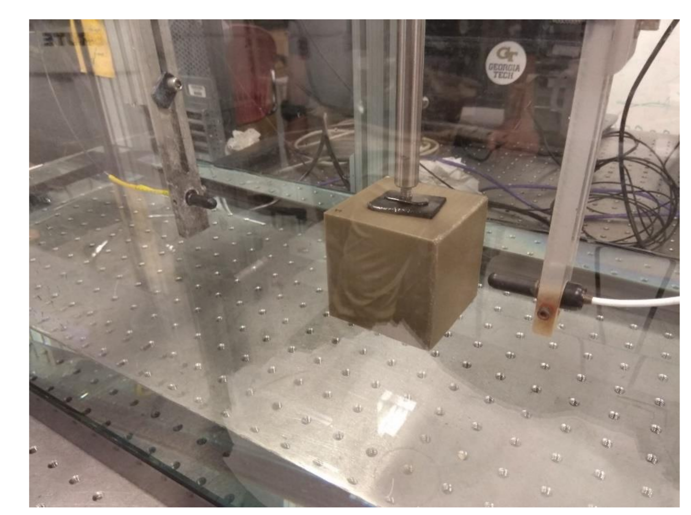

**Steady state RMS pressure field**



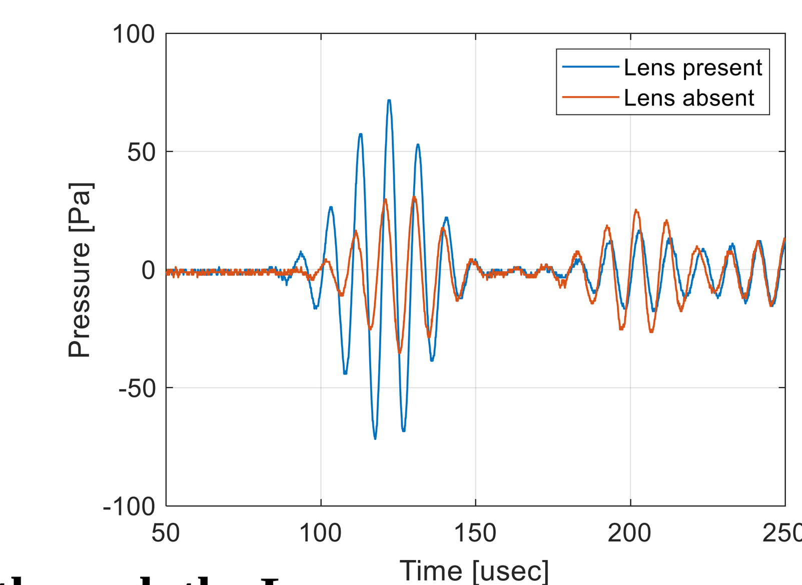
## Experiments

- A proof of concept lens was designed and printed on a basic desktop FDM 3D printer.
- The pressure field of the lens was scanned using a hydrophone mounted on a 3D positioning system.
- Another hydrophone was used as a point source projector to generate approximate plane waves in the far field.

**Experimental setup**

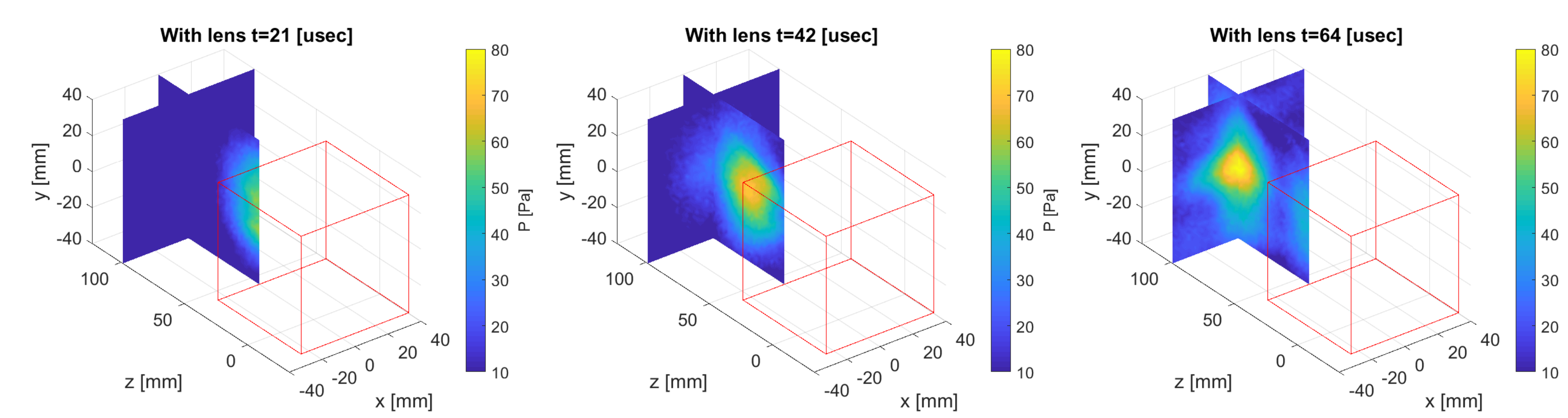


**Measured Focusing power**

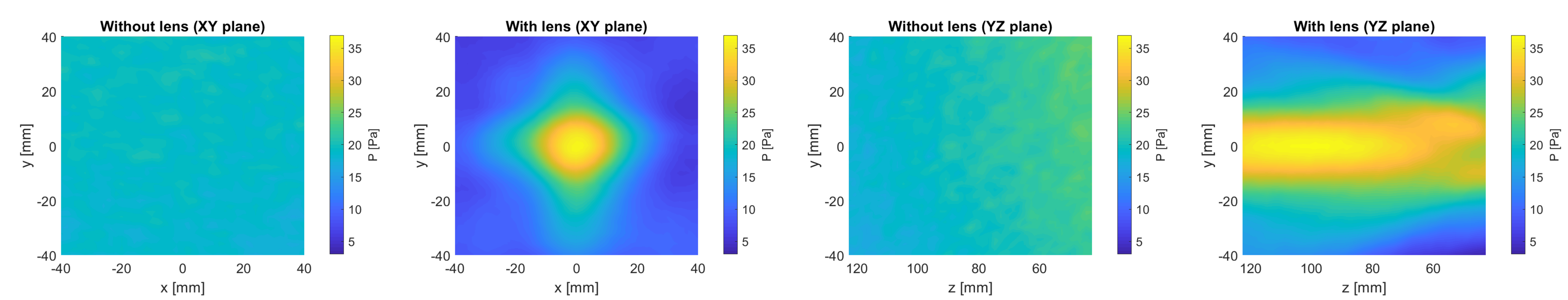



- An incident Gaussian pressure pulse of center frequency 100 kHz and 30kHz is generated and used to interrogate the lens.
- Preliminary results show that the focal length is around $3\lambda$ (56mm) and a power output gain of 4 at the focus of the lens.

**Time lapse of an incident plane wave through the Lens**




**Scanned RMS pressure in the focal and propagation planes**




## Conclusions

- A novel design for a phononic crystal made from air inclusions in 3D printed PLA is proposed and analyzed numerically via FEM.
- The air inclusions size controls the refractive index of the material with respect to water with values ranging from 0.9-1.8 across a wide frequency range.
- A 3D printed Luneburg lens made from the suggested crystal has been designed, simulated and experimentally validated.
- The fabricated lens is capable of focusing aqueous ultrasonic waves with minimum power reflection.
- A power output gain of 4 was achieved using the experimental prototype of the lens.
- Applications of interest span from wireless acoustic power transfer to underwater sensing

## Acknowledgement

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