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Controlling underwater sound propagation using 3D-printed phononic crystals

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ASA ACOUSTICAL SOCIETY OF AMERICA

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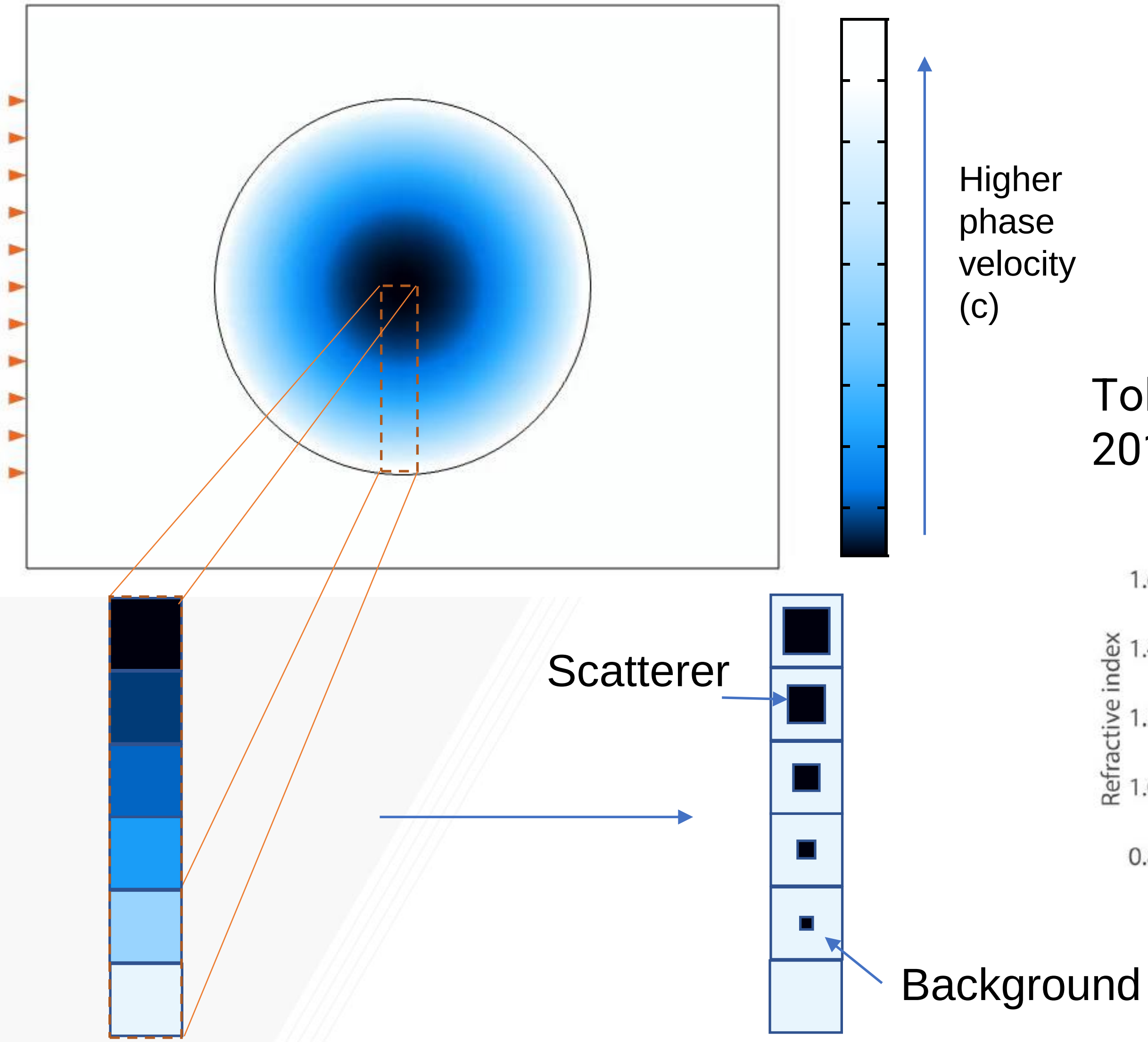
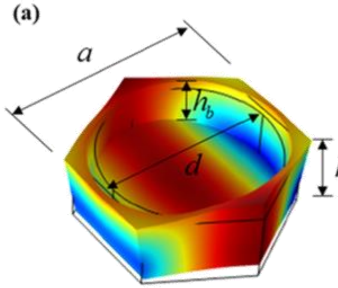
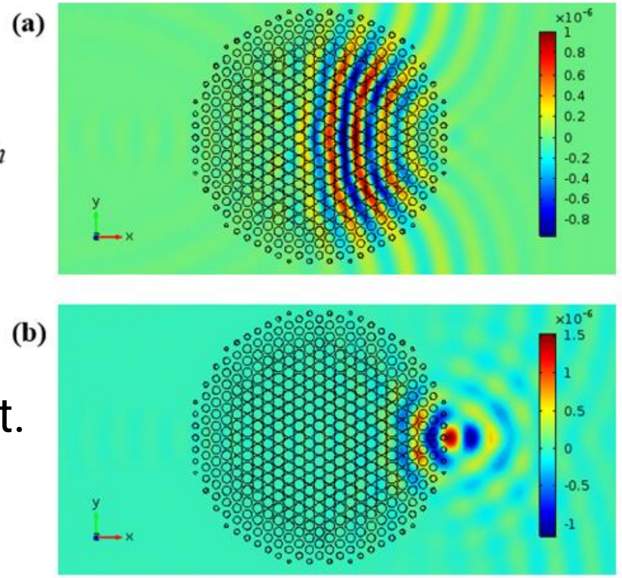
Background







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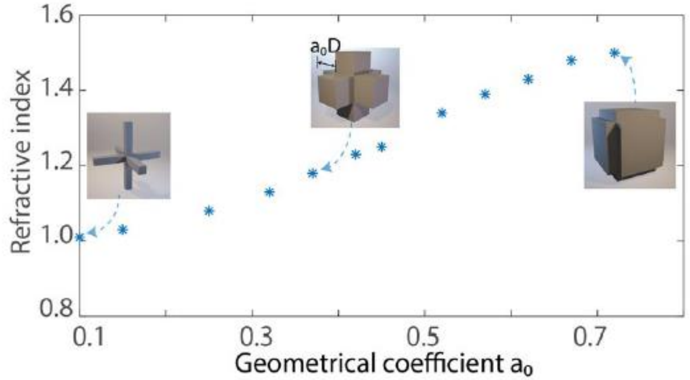
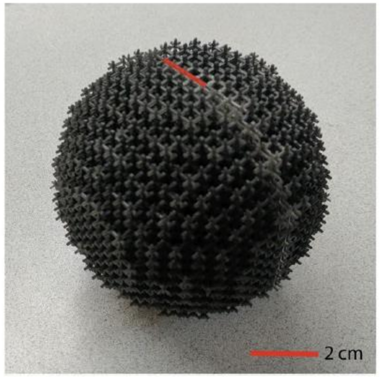
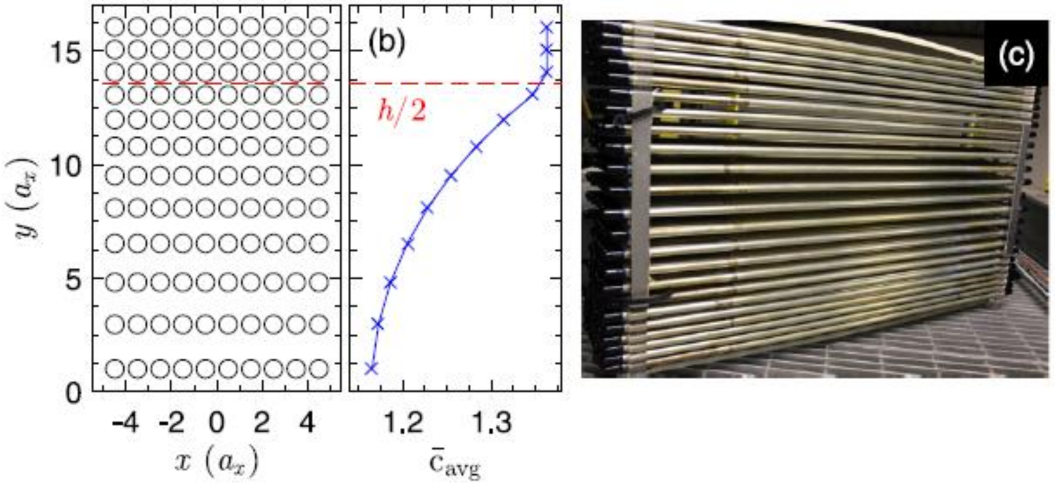




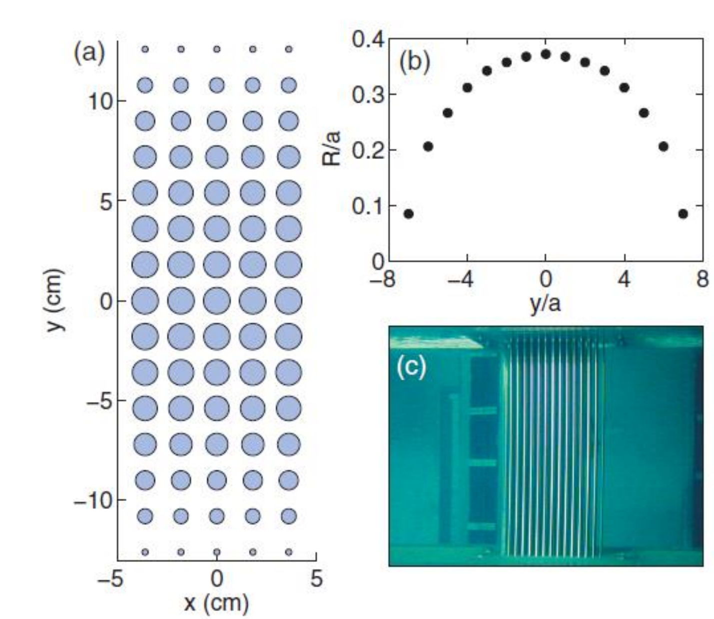
Xie, Y. *et al*. *Sci. Rep*. **8**, 16188 (2018).

Underwater implementations

- Use heavy metallic scatterers
- Limited to 2.5D designs
- Difficult to extend to 3D designs due to manufacturing limitations



Martin, T. P. *et al. Phys. Rev. Applied* **4**, 034003 (2015).



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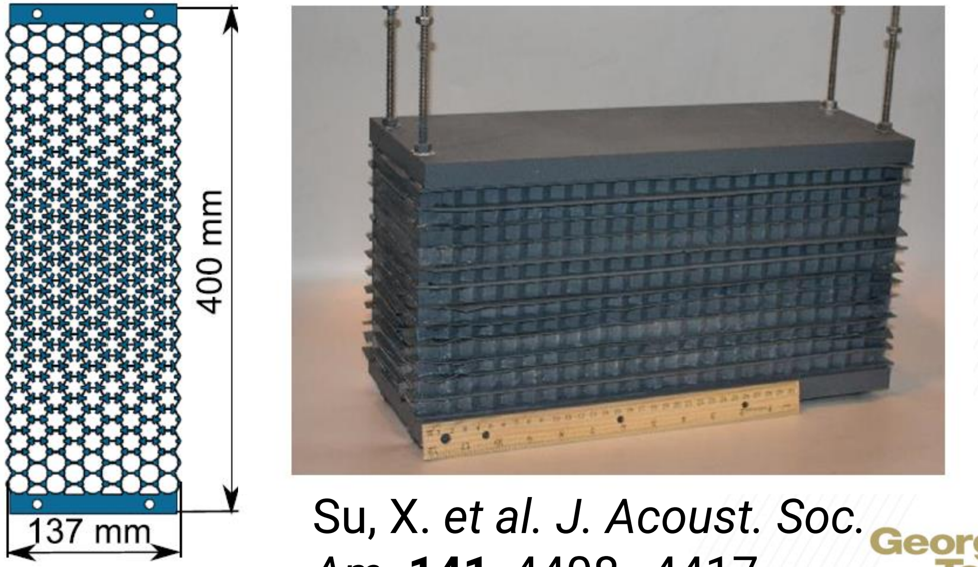

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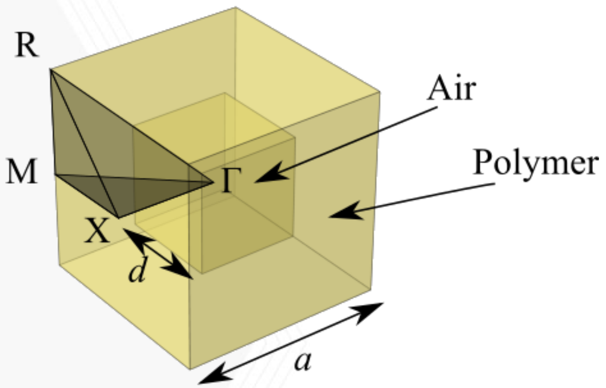
Objectives

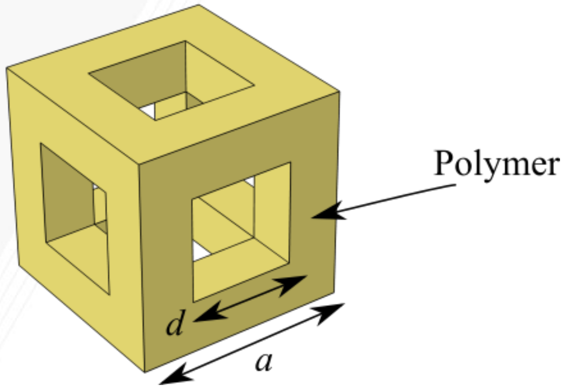
- Design a 3D gradient index phononic crystal capable of achieving a large variation in the effective refractive index compared to water.
- Use this phononic crystal to design a 3D Luneburg lens for focusing underwater acoustic waves.
- Use common 3D printing techniques to manufacture the lens.

Unit cell design

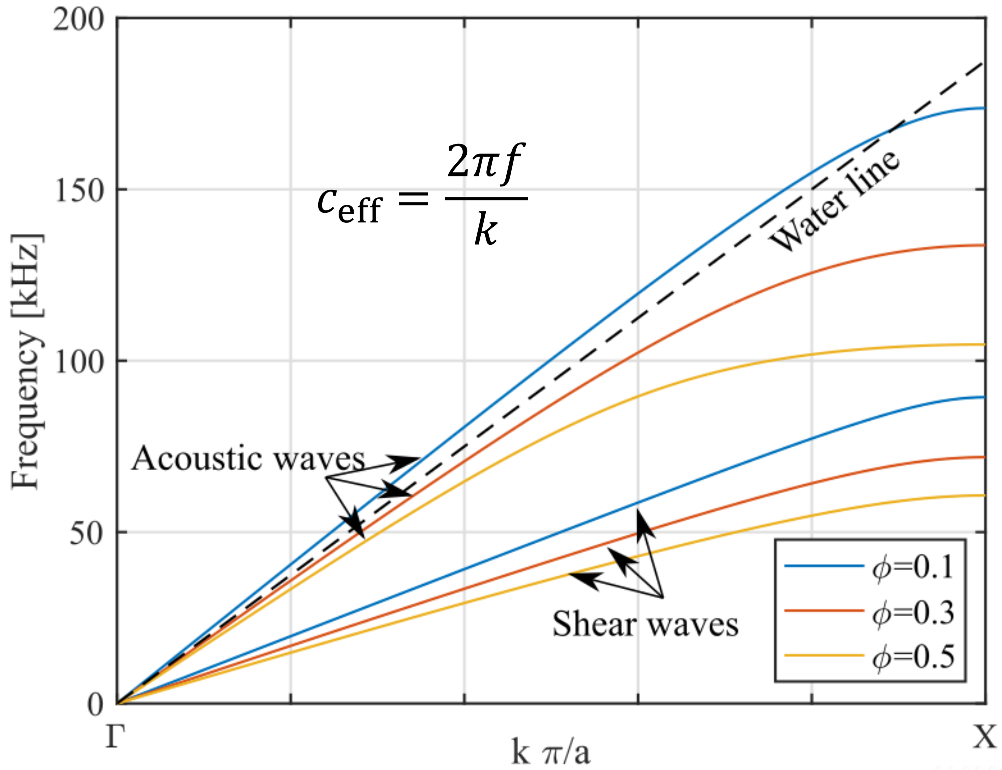
Cell design 1:

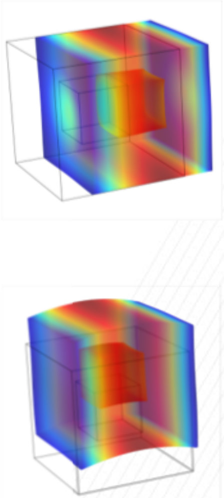


Cell design 2:



- Using a Comsol finite-element model of the unit cell is used to estimate the dispersion.





ϕ: volume filling fraction

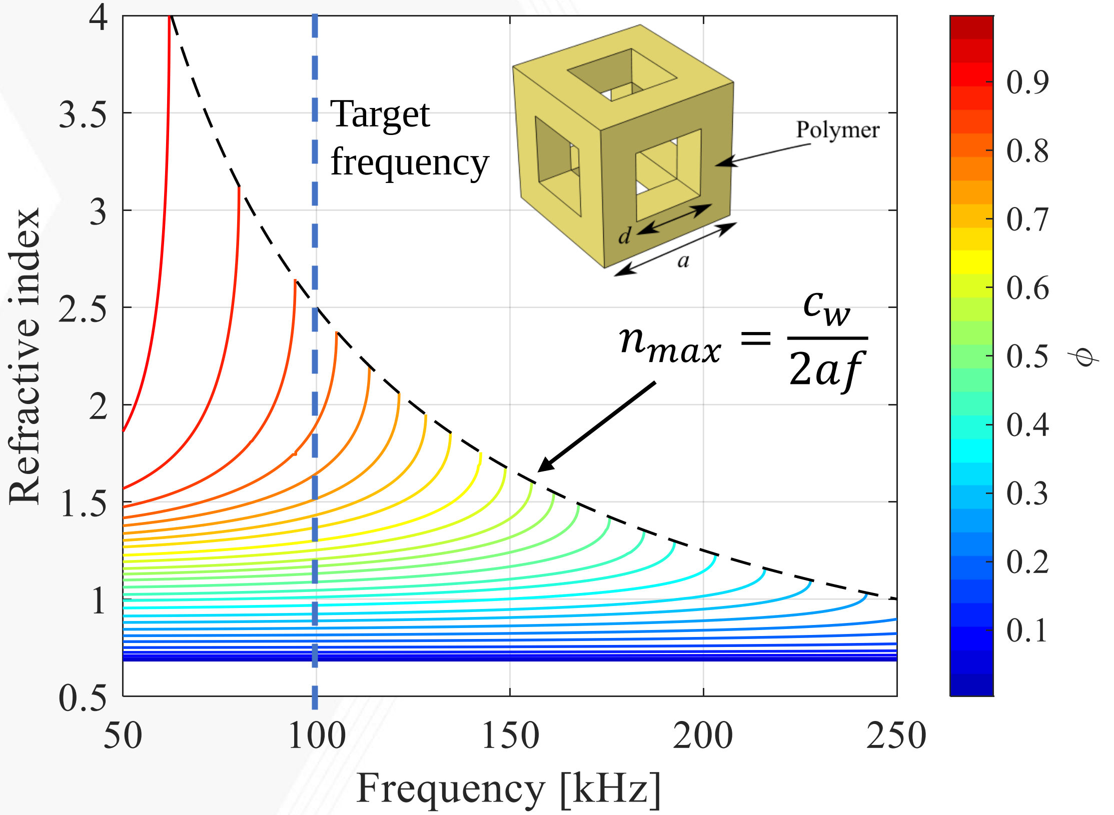
Effect of inclusion height on the refractive index

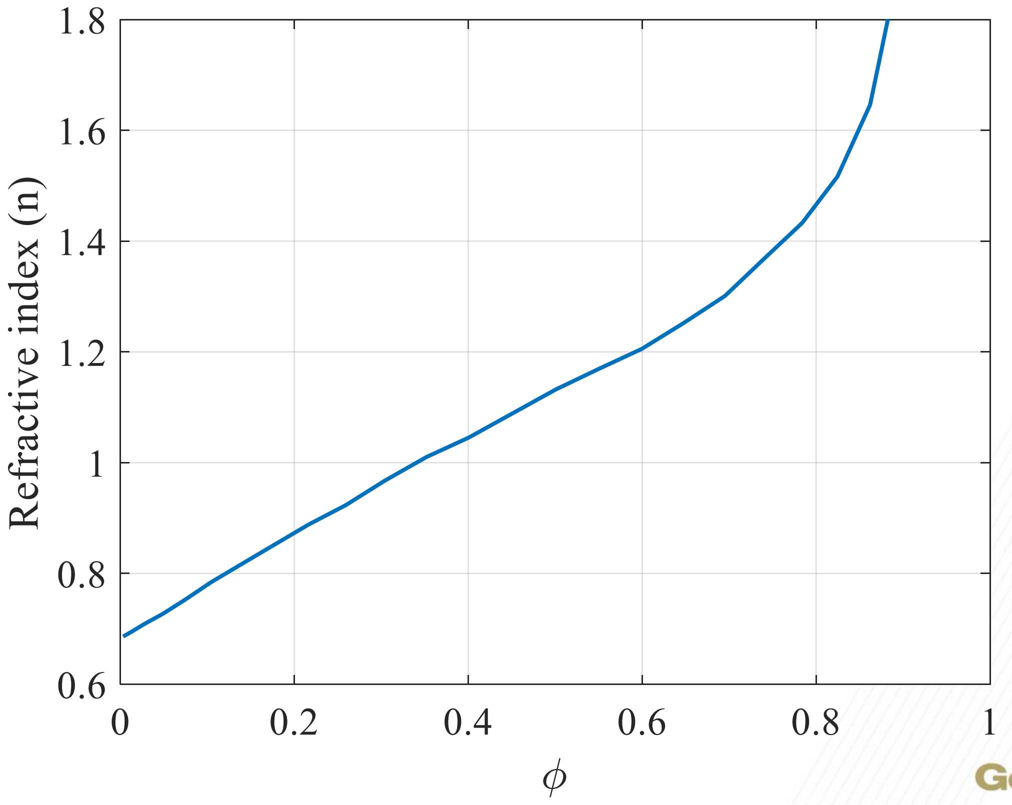
- The refractive index of the material (n) is given by:

c_w: Speed of sound in water

c_{eff}: Effective wave speed in the crystal

$$n = \frac{c_w}{c_{eff}}$$





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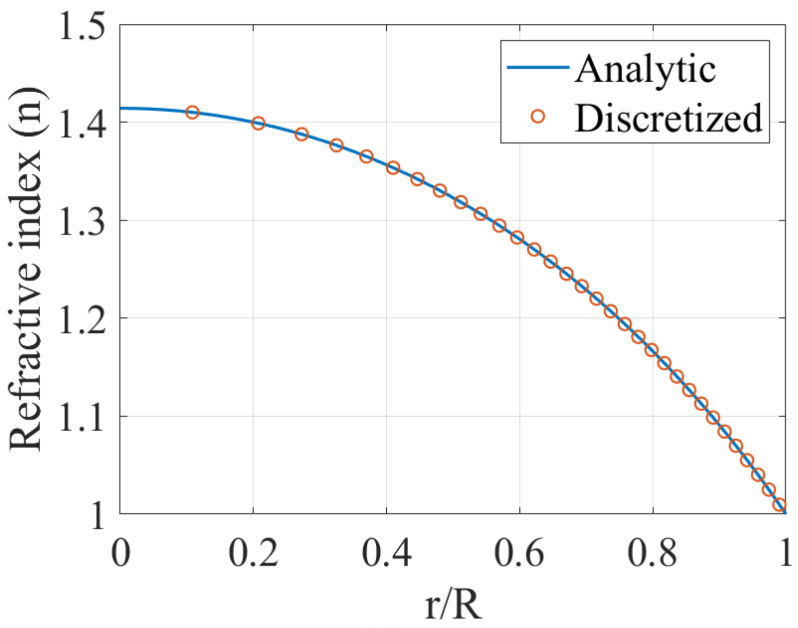
Luneburg lens in 3D

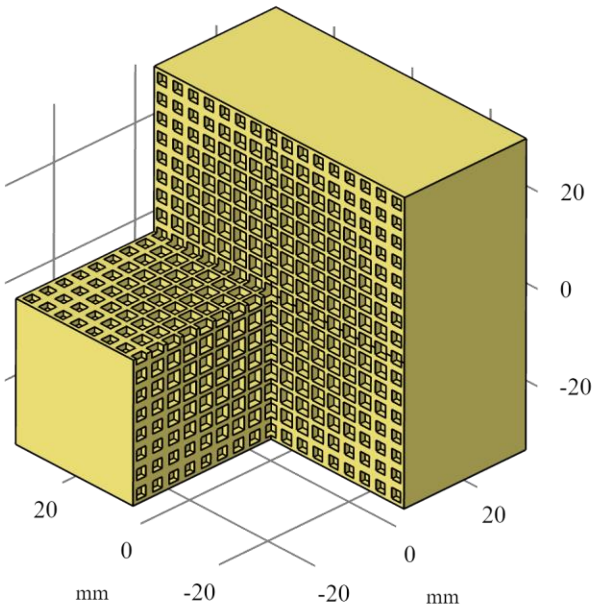
- Luneburg Lens can be constructed by varying the refractive index of the material gradually in space according to the profile:

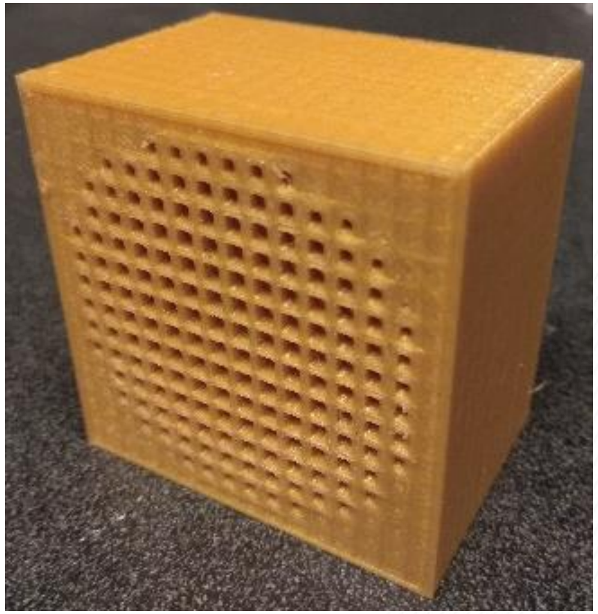
$$n(r) = \sqrt{1 - \frac{r^2}{R^2}}$$

r: position in space

R: radius of the lens

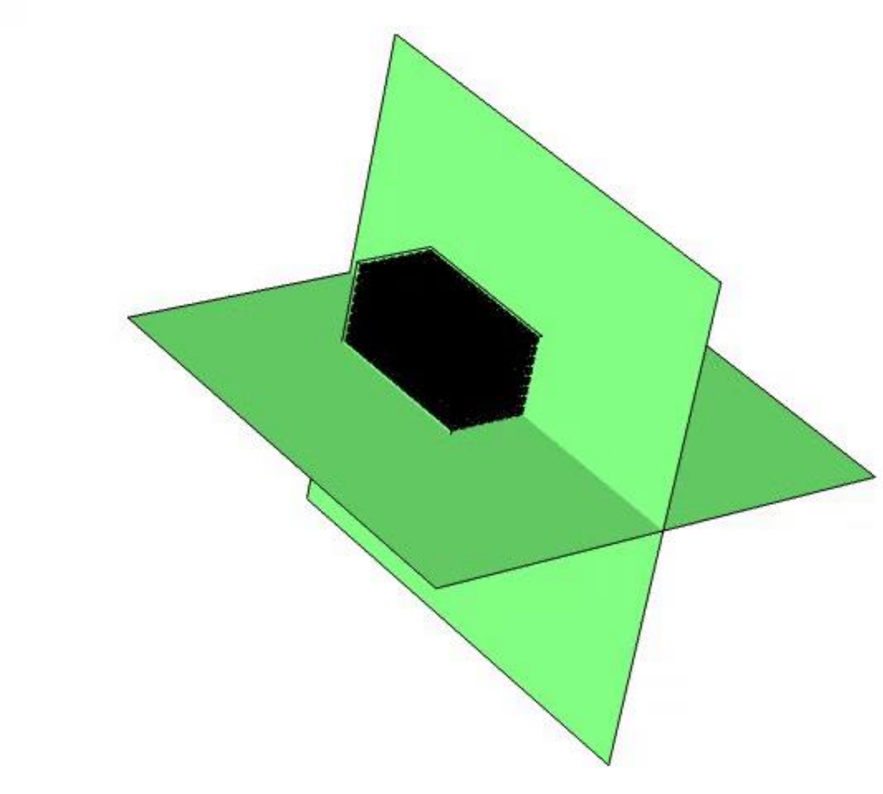


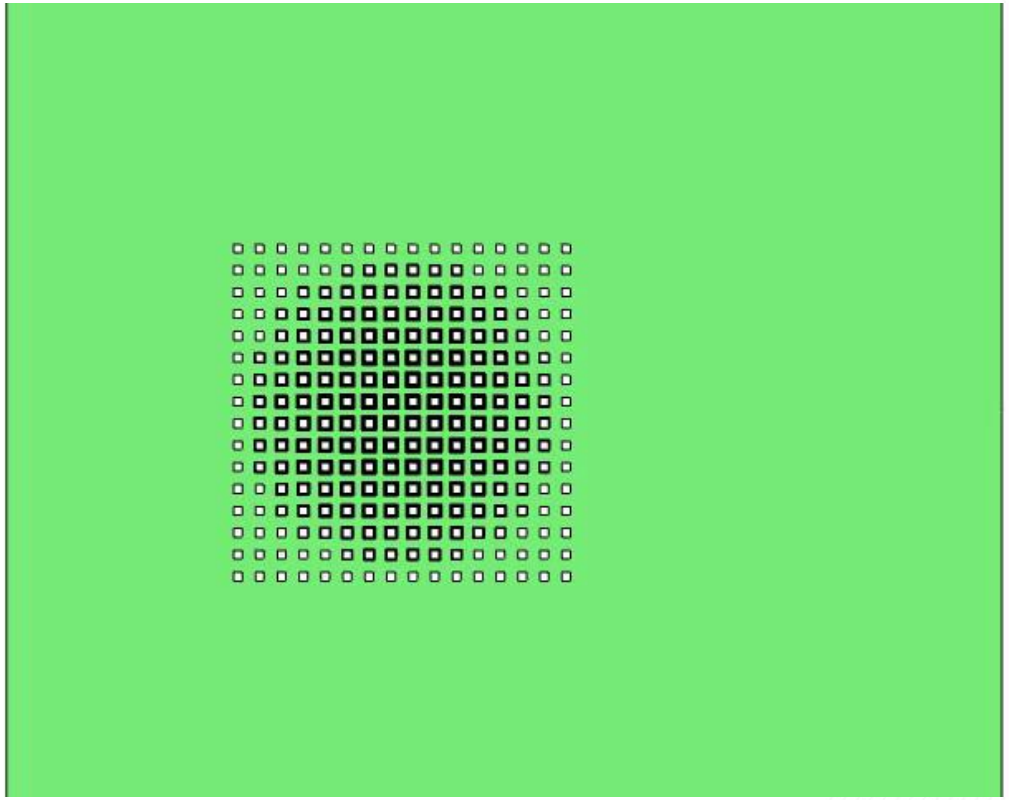




Time domain numerical model

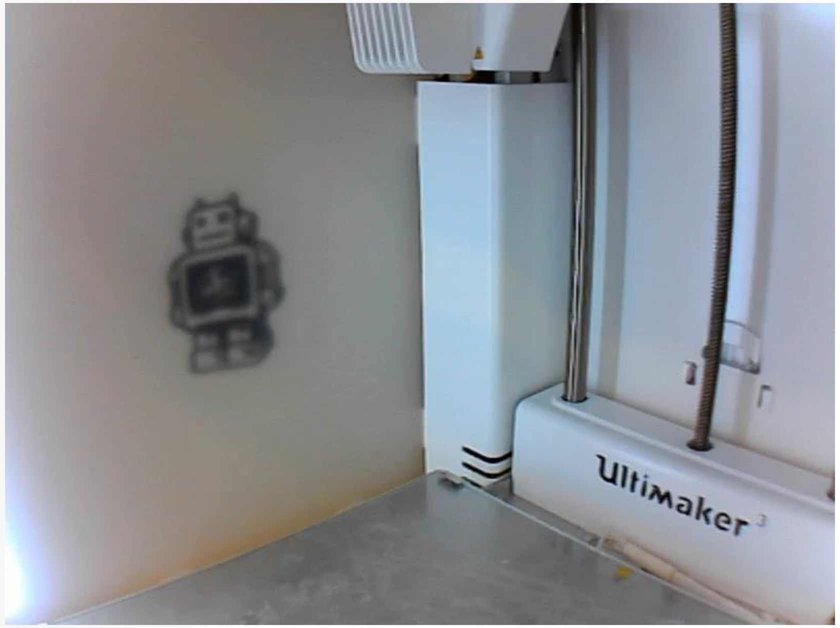
- A 3D coupled elastic-acoustic FEM model of the lens is simulated in the time domain

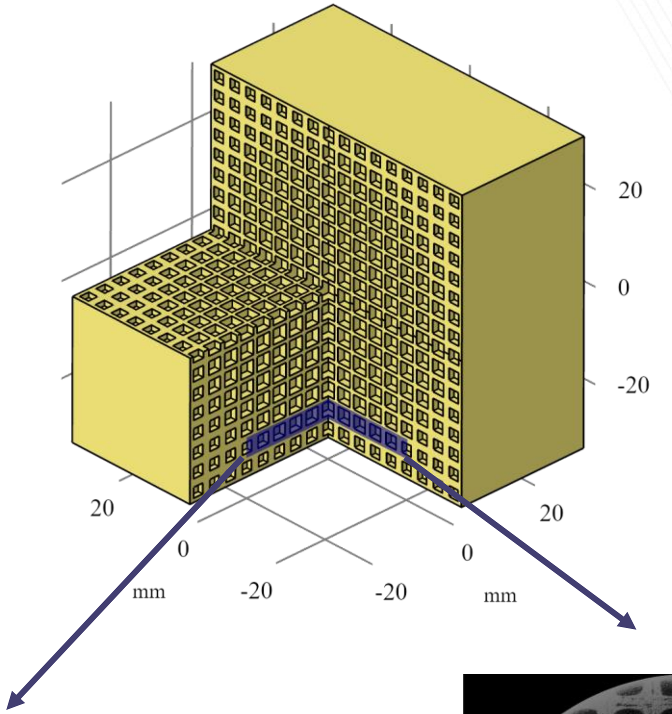


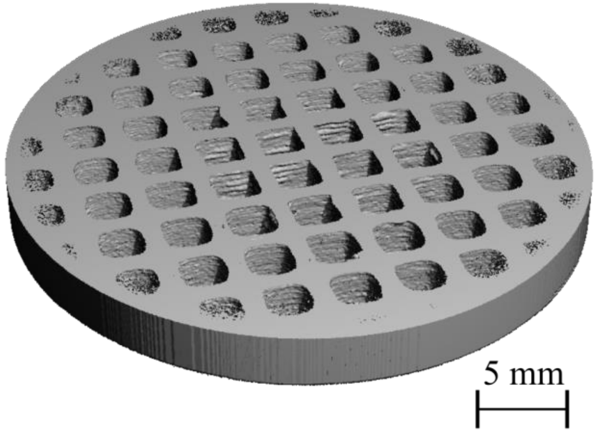


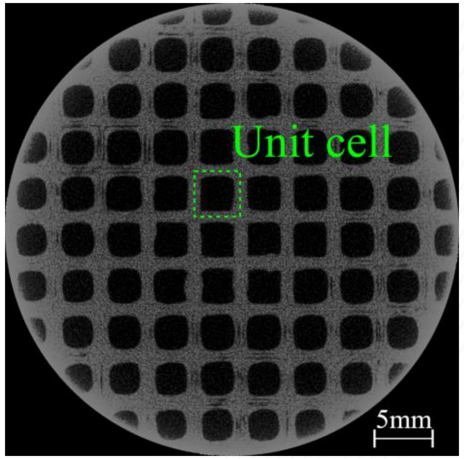
Lens fabrication

- Identified material properties:
  $E_{PLA} = 3200 \pm 50$ MPa, $\rho_{PLA} = 1117$ kg/m^3
  $\eta_{PLA} = 0.021 \pm 0.003$
- Unit cell size: $a = 3$ mm
- Lens Dimensions:
  16 cell x16 cell x16 cell = 48 mm × 48 mm× 48 mm ~ $3\ \lambda$
- Printing time:
  16-40 hours









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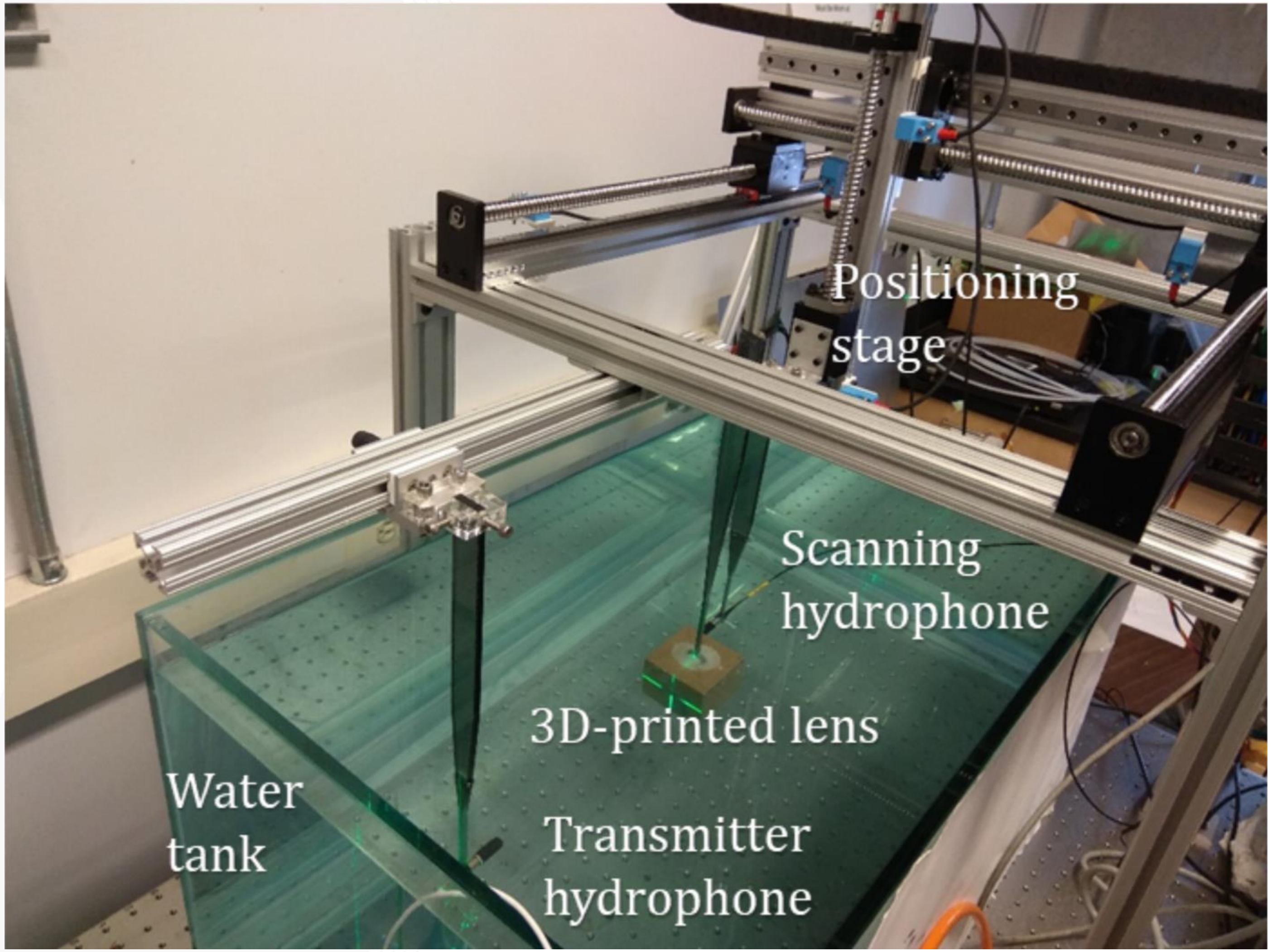
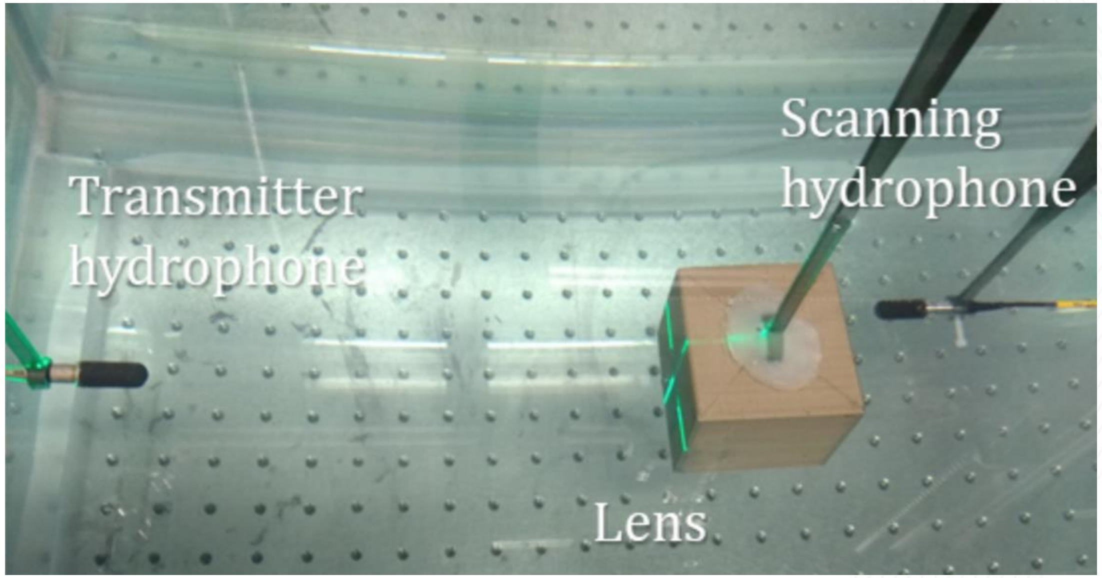
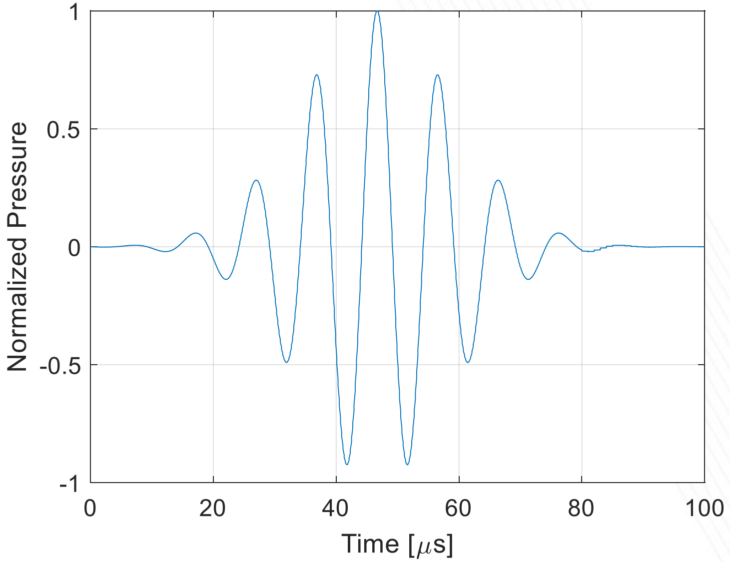
Experimental setup



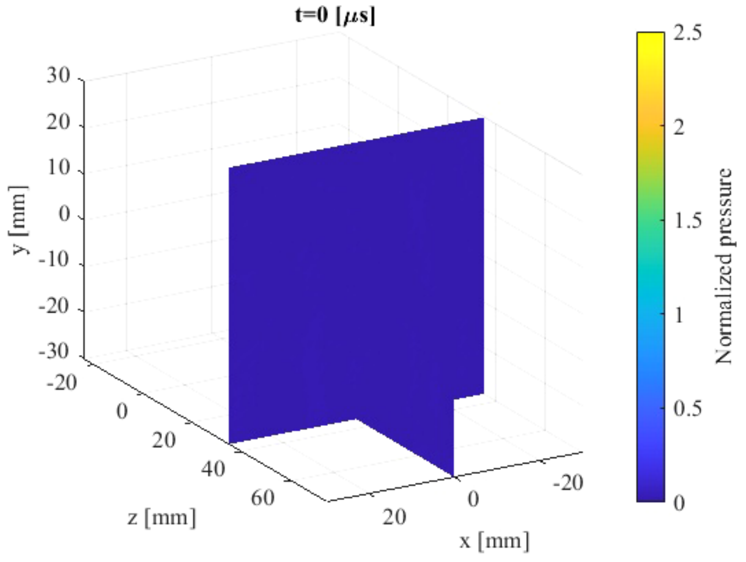


Lens performance (Time domain)

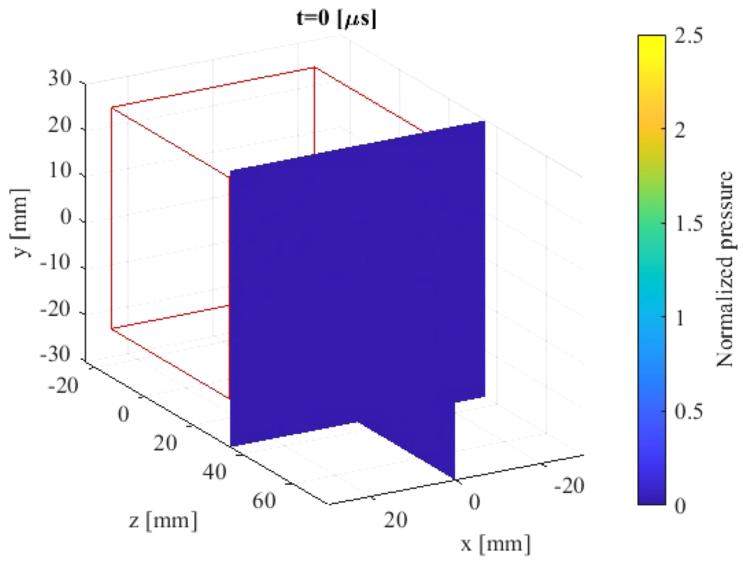
- Exciting the lens with a Gaussian pulse centered at 100 kHz with 30kHz bandwidth



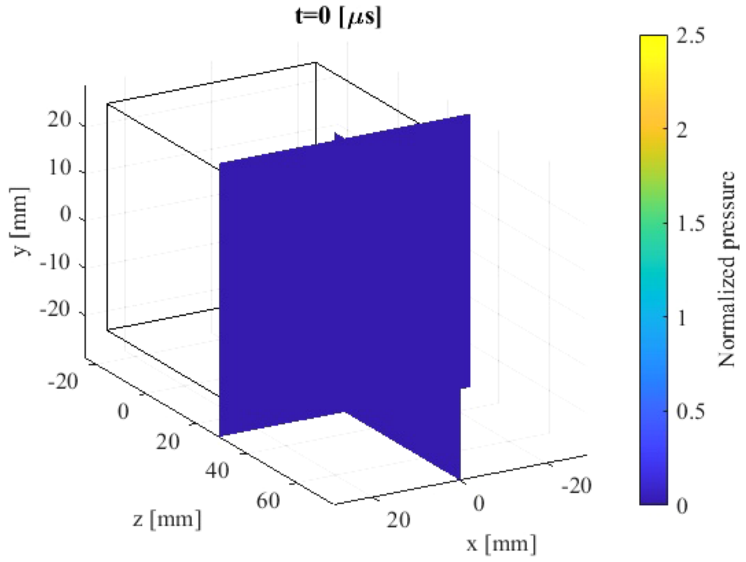
Without lens



Experimental



Numerical



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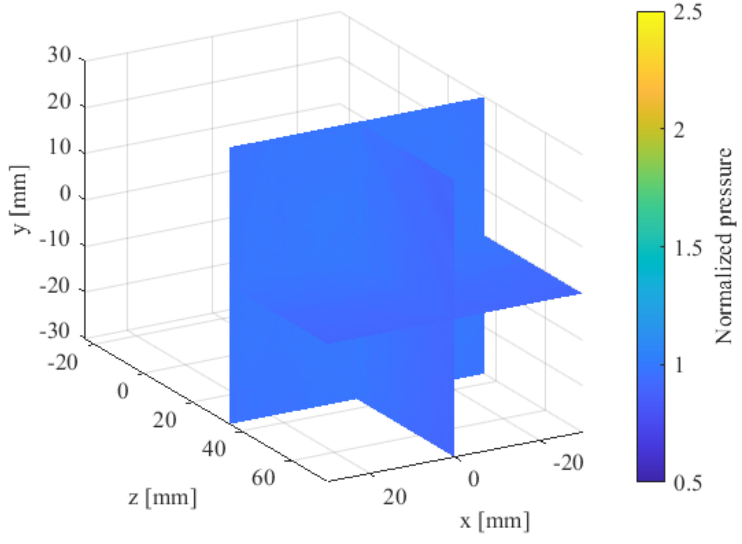
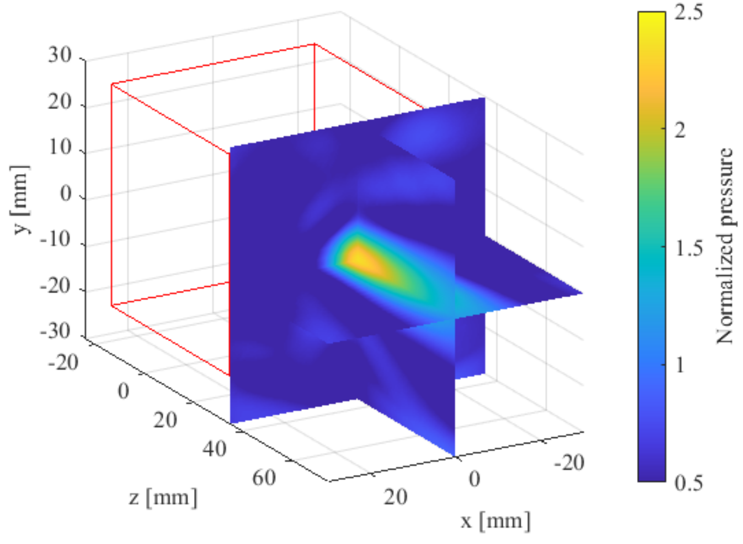
Lens performance (RMS pressure)

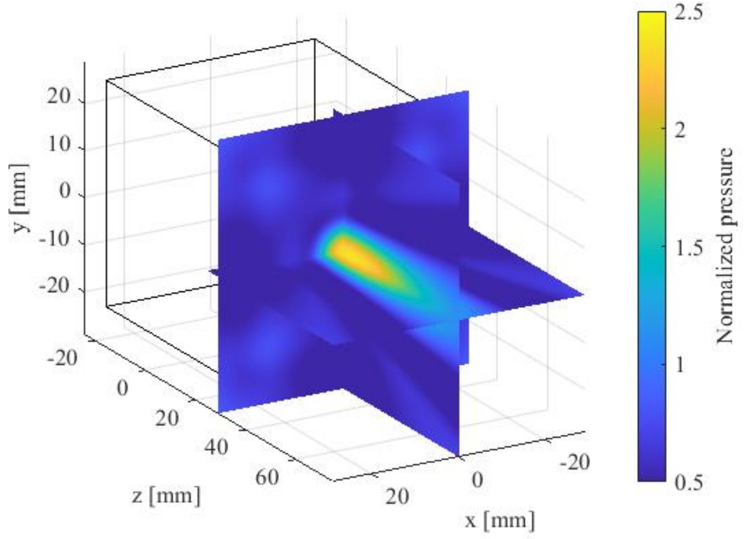
Without lens



Experimental



Numerical



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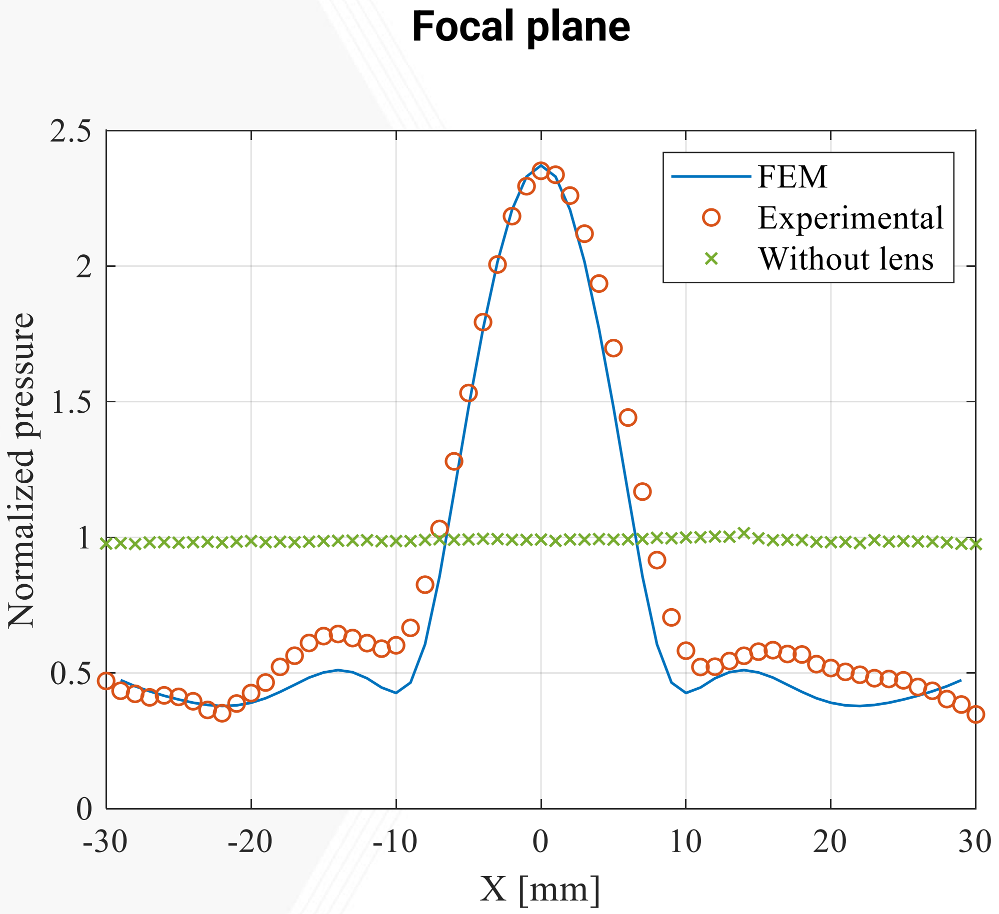
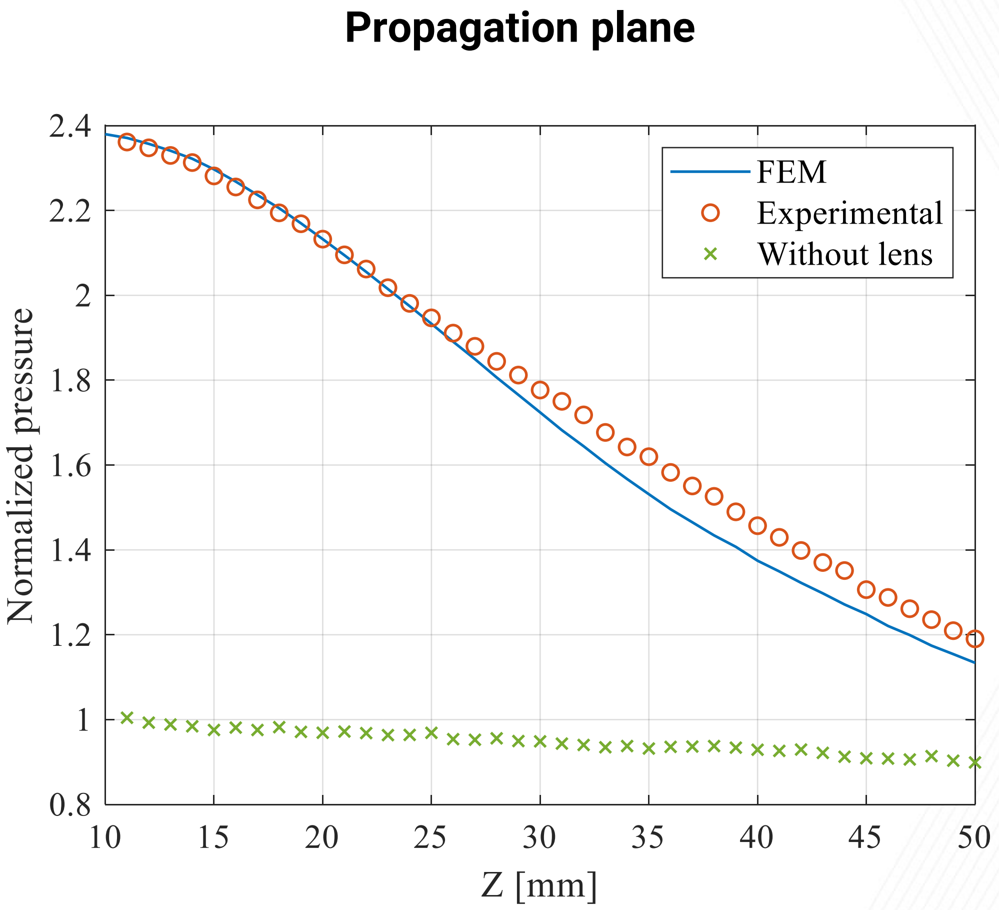
Lens performance





Conclusions

- Air inclusions in a polymer matrix phononic crystals can be used to direct ultrasonic waves underwater.
- A novel phononic crystal-based Luneburg lens has been designed, analyzed, 3D-printed, and experimentally validated.
- The realized lens achieves a power gain 8 dB at the focal point.
- The introduced lens can find potential applications in acoustic wireless power harvesting/transfer as well as signal enhancement in underwater sensing.

Acknowledgment

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Thanks!..
Questions?