Applications of Acoustic Metasurfaces

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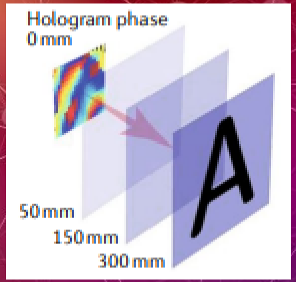
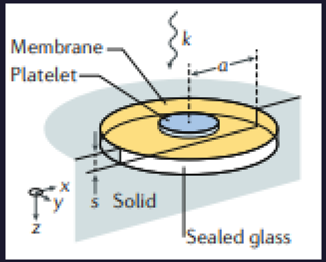
Acoustic Metasurfaces

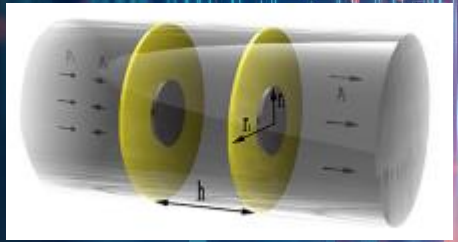
Reflection



Transmission



Absorption



Tunability

Introduction

- Acoustic metasurfaces are designed 2D materials created for manipulation of acoustic waves by exploiting metasurface geometry and material properties for reflection, transmission, absorption, and tuning of acoustic wave propagation.

Acoustic Metasurfaces: Physics Overview

GENERALIZED SNELL'S LAW:

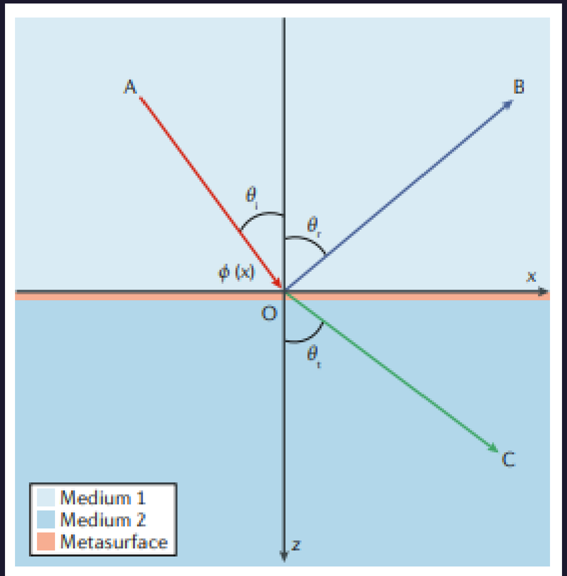


FIG 1. Generalized Snell's Law graphed with two mediums separated by an acoustic metasurface, showing angle of incidence (θ_i), angle of reflection (θ_1), angle of transmission (θ_t), and phase discontinuity ($\varphi(x)$) [1].

EQUATIONS:

$$\Psi_r(x) = \phi(x) + k_1\sqrt{(x-x_A)^2 + z_A^2} + k_1\sqrt{(x_B-x)^2 + z_B^2} \quad (1)$$

$$\frac{d\Psi_r(x)}{dx} = \frac{d\phi(x)}{dx} + \frac{\lambda_1(x-x_A)}{2\pi\sqrt{(x-x_A)^2 + z_A^2}} - \frac{\lambda_1(x_B-x)}{2\pi\sqrt{(x_B-x)^2 + z_B^2}} = 0 \quad (2)$$

$$\frac{d\phi(x)}{dx} + \frac{\lambda_1}{2\pi}(\sin\theta_i - \sin\theta_r) = 0 \quad (3)$$

$$\sin\theta_r - \sin\theta_i = \frac{\lambda_1}{2\pi}\frac{d\phi(x)}{dx} \quad (4)$$

$$\Psi_t(x) = \phi(x) + \frac{2\pi}{\lambda_1}\sqrt{(x-x_A)^2 + z_A^2} + \frac{2\pi}{\lambda_2}\sqrt{(x_C-x)^2 + z_C^2} \quad (5)$$

$$\frac{d\Psi_t(x)}{dx} = \frac{d\phi(x)}{dx} + \frac{2\pi}{\lambda_1}\sin\theta_i - \frac{2\pi}{\lambda_2}\sin\theta_t = 0 \quad (6)$$

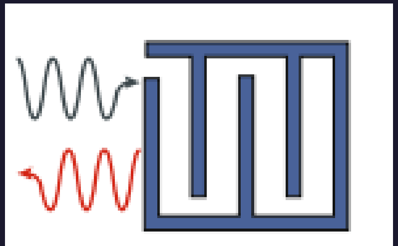
$$\frac{1}{\lambda_2}\sin\theta_t - \frac{1}{\lambda_1}\sin\theta_i = \frac{1}{2\pi}\frac{d\phi(x)}{dx} \quad (7)$$

$$\sin\theta_r - \sin\theta_i = \frac{\lambda_1}{2\pi}\beta \quad (8)$$

$$\frac{1}{\lambda_2}\sin\theta_t - \frac{1}{\lambda_1}\sin\theta_i = \frac{1}{2\pi}\beta \quad (9)$$

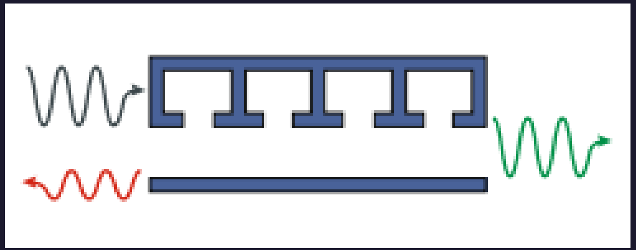
1) Reflection acoustic path
2) Differentiating, set equal to 0
3) Simplification of eqn. 2
4) Non-linear relationship between θ_r and θ_i
5) Transmitted acoustic path
6) Differentiating, set equal to 0
7) Simplification of eqn. 6
8) Linear dependance ($\varphi(x) = \beta x$) simplification (if independent eqn. 4 & 7, recover conventional Snell's Law)
9) Simplification of eqn. 8

Acoustic Metasurfaces: Designs



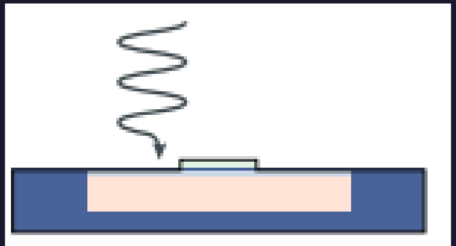
Coiling-up Space

For Reflection



Helmholtz-resonator-like

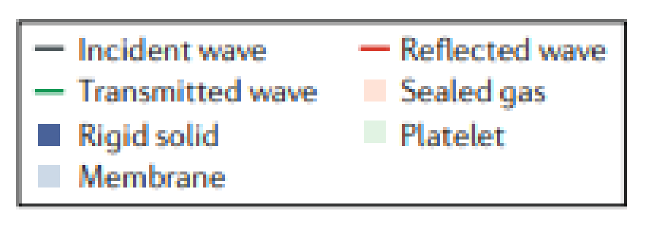
For Transmission



Membrane-type

For Absorption

Key:



Slide Source(s): [1]

Acoustic Metasurfaces: Reflection

REFLECTION TYPE METASURFACE:

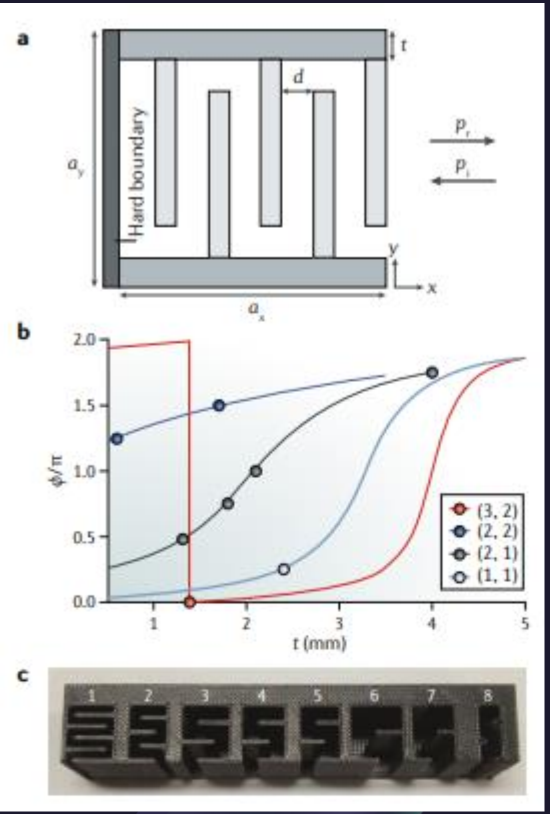


FIG 2. a. Schematic of acoustic reflection metasurface with with a_x and height a_y, channel width d, b. phase shifted waves reflected of different configurations, where (3,2) represents 3 plates on top and 2 plates on bottom, c. 3D-printed coiling-up space type metasurface [1].

- Simple means of tuning reflected waves
- Readily available, with improved 3D printing technologies, easily fabricated
- Able to phase shift reflected wave from 0 to 2π

Acoustic Metasurfaces: Transmission

TRANSMISSION TYPE METASURFACE:

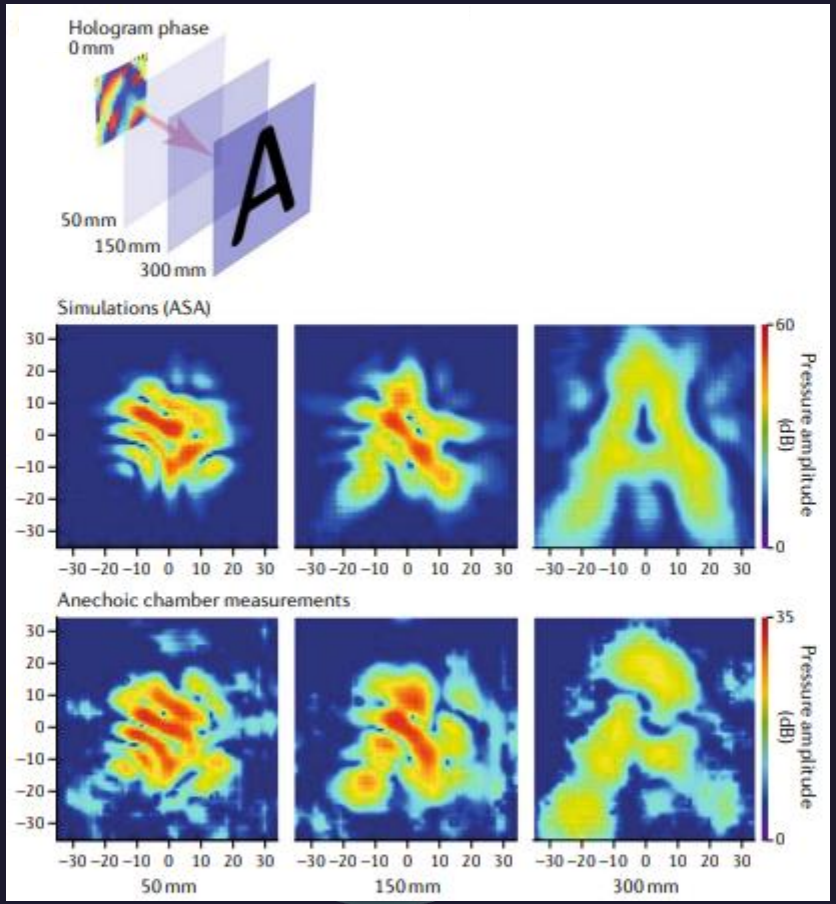


FIG 3. Top. Phase distribution of metasurface will produce letter A on image plane, middle. shows simulated approach, bottom. shows experimental approach. Displayed a different thickness [1].

- Enables reconstruction of related acoustic field
- Using angular spectrum approach
- Able to phase shift reflected wave from 0 to 2π

Acoustic Metasurfaces: Absorption

ABSORPTION TYPE METASURFACE:

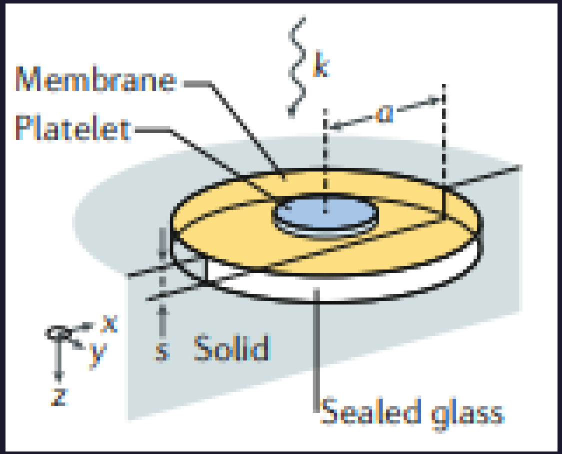


FIG 4. Schematic of an impedance matched metasurface of radius *a*, a reflecting hard surface, sandwiched between a gas sealed cell of depth, *s* [1].

- Use thin membrane, sealing gas and reflecting plate add impedance
- Resonance of platelet and elastic membrane form new hybrid resonance mode for absorption of incoming acoustic waves
- Material selection with weak dissipation for total absorption

Acoustic Metasurfaces: Innovative Programmable Method

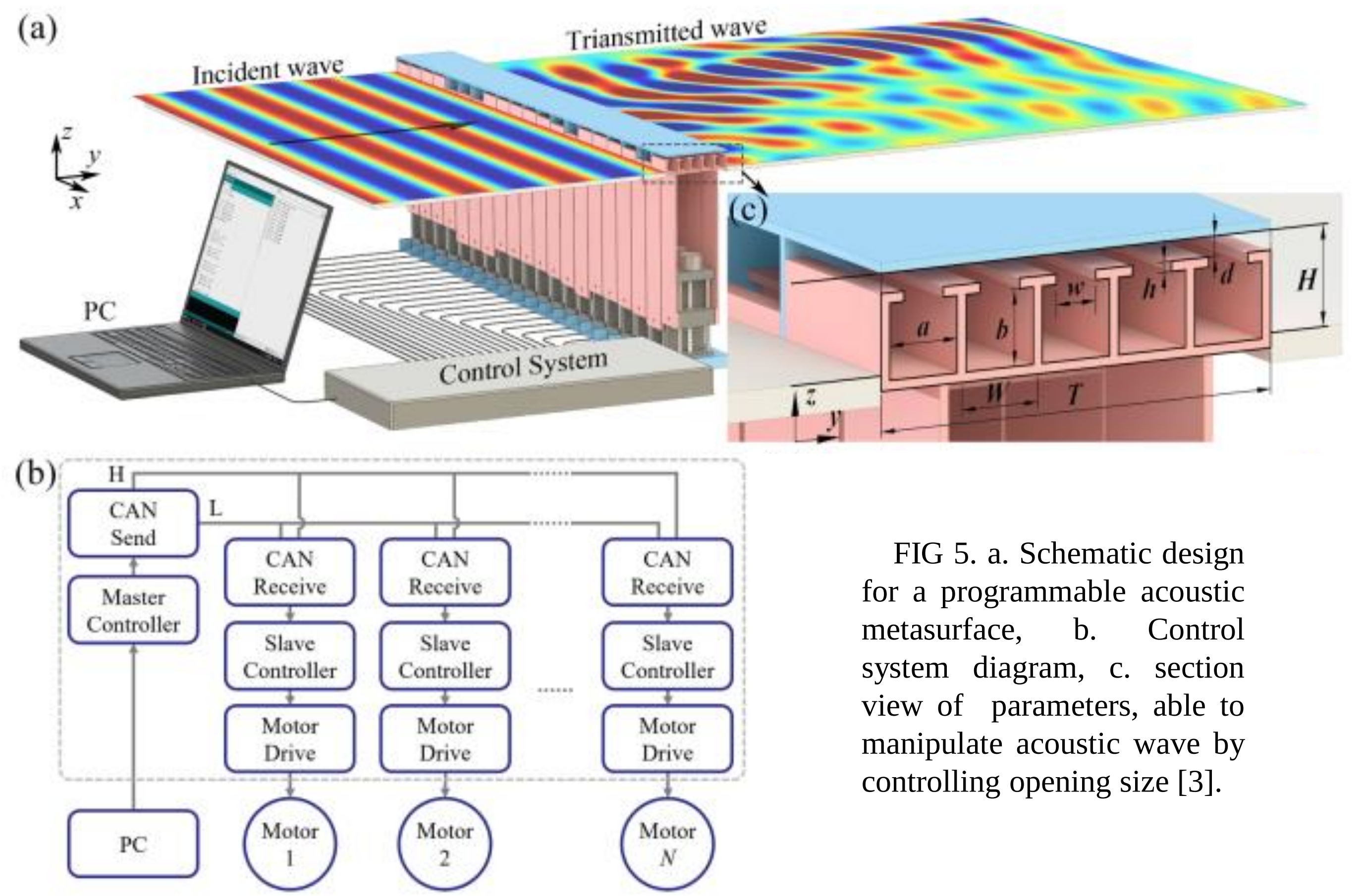
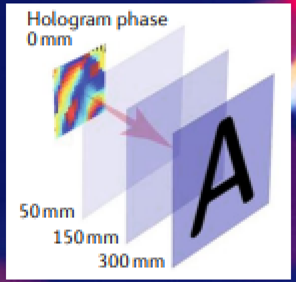


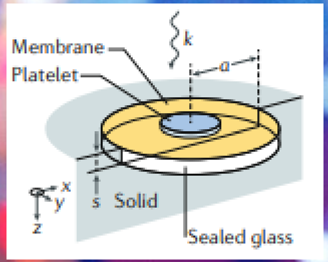
FIG 5. a. Schematic design for a programmable acoustic metasurface, b. Control system diagram, c. section view of parameters, able to manipulate acoustic wave by controlling opening size [3].

- Computer controlled motors for programmable input opening for tuning transmitted wave
- Able to phase shift reflected wave from 0 to 2π

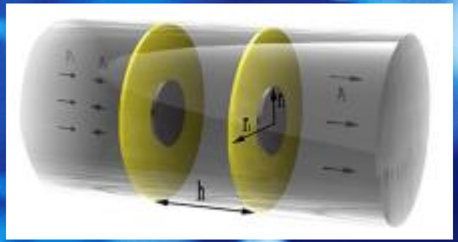
Reflection



Transmission



Absorption



Tunability

Summary

Acoustic metasurfaces are an exceptional method for controlling acoustic sources. By exploiting and controlling acoustic reflections, transmission, absorption, and tunability, various functions including acoustic imaging, communications, nondestructive flaw detection and particle trapping, allowing for a multitude of real-world applications.

Thank You

Questions?

References

[1] Assouar, B., Liang, B., Wu, Y., Li, Y., Cheng, J. C., & Jing, Y. (2018). Acoustic metasurfaces. Nature Reviews Materials, 3(12), 460-472.

[2] Fan, S. W., Zhao, S. D., Chen, A. L., Wang, Y. F., Assouar, B., & Wang, Y. S. (2019). Tunable broadband reflective acoustic metasurface. Physical Review Applied, 11(4), 044038.

[3] Gong, K., Zhou, X., Ouyang, H., & Mo, J. (2021). Continuous manipulation of acoustic wavefront using a programmable acoustic metasurface. Journal of Physics D: Applied Physics, 54(30), 305302.

[4] Liu, P., Chen, X., Xu, W., & Pei, Y. (2020). Magnetically controlled multifunctional membrane acoustic metasurface. Journal of Applied Physics, 127(18), 185104.

[5] Gong, K., Wang, X., Ouyang, H., & Mo, J. (2019). Tuneable gradient Helmholtz-resonator-based acoustic metasurface for acoustic focusing. Journal of Physics D: Applied Physics, 52(38), 385303.