Scientists create mechanism to precisely control soundwaves in metamaterials

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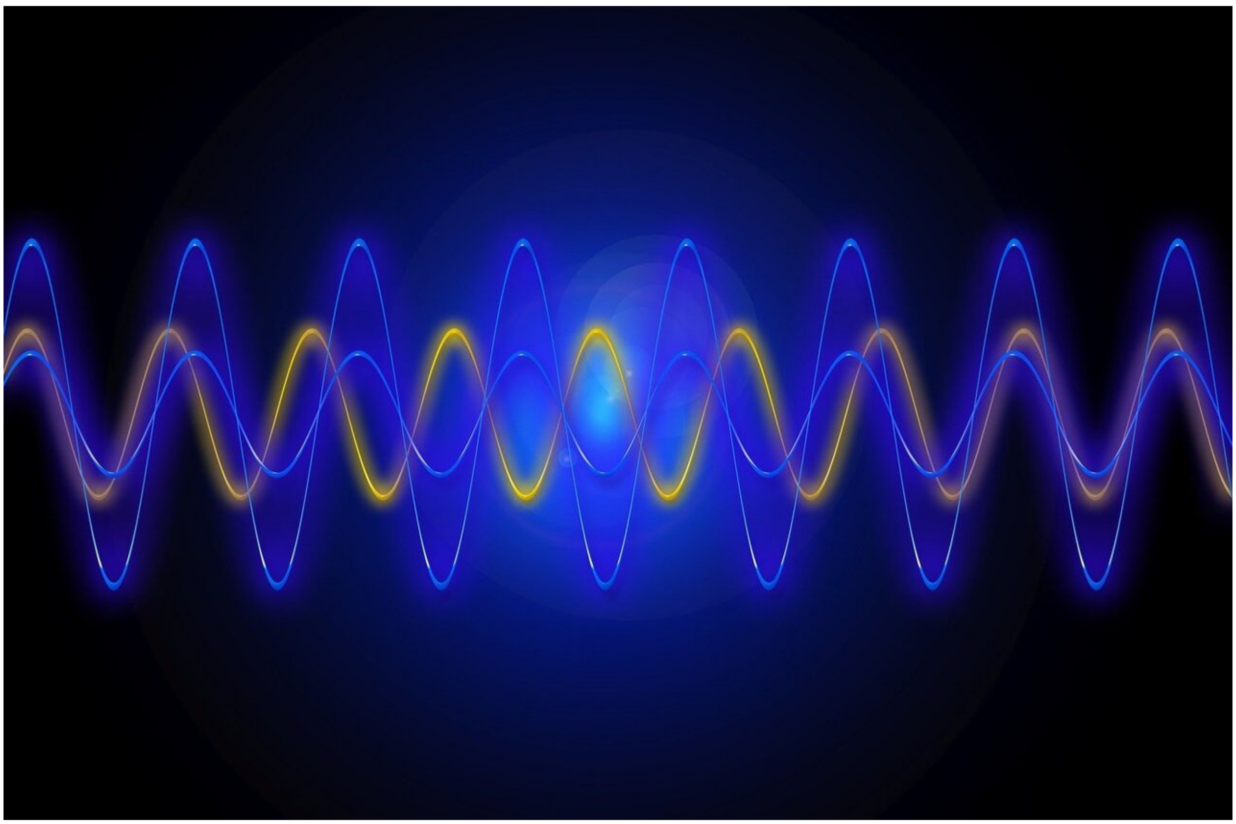

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University of Oregon physicists have developed a new method to manipulate sound—stop it, reverse it, store it and even use it later—in synthetic composite structures known as metamaterials.

The discovery was made using theoretical and computational analysis of the mechanical vibrations of thin elastic plates, which serve as the building blocks for the proposed design. The physicists, Pragalv Karki and Jayson Paulose, also developed a simpler minimal model consisting of springs and masses demonstrating the same signal manipulation ability.

"There have been a lot of mechanisms that can guide or block the transmission of sound waves through a metamaterial, but our design is the first to dynamically stop and reverse a sound pulse," said Karki, a postdoctoral researcher in the UO's Department of Physics and Institute for Fundamental Science.

The interplay between bending stiffness and the global tension—two physical parameters governing sound transmission in thin plates—is at the heart of their signal-manipulation mechanism. While bending stiffness is a material property, global tension is an externally controllable parameter in their system.

Karki and Paulose, an assistant professor of physics and member of the Institute for Fundamental Science, described their new mechanism, which they call dynamic dispersion tuning, in a paper published online March 29 in the journal *Physical Review Applied*.

"If you throw a stone onto a pond, you see the ripples," Karki said. "But what if you threw the stone and instead of seeing ripples propagating outward you just see the displacement of the water going up and down at the point of impact? That's similar to what happens in our system."

The ability to manipulate sound, light or any other waves in artificially made metamaterials is an active area of research, Karki said.

Optical or photonic metamaterials, which exhibit properties such as a negative refractive index not possible with conventional materials, were initially developed to control light in ways that could be used to create invisibility cloaks and super lenses.

Their use is being explored in diverse applications such as aerospace and defense, consumer electronics, medical devices and energy harvesting.

Acoustic metamaterials are usually static and unchangeable once produced, and dynamically tuning their properties is an ongoing challenge, Karki said. Other research groups have proposed several strategies for tuning acoustic transmission, ranging from origami-inspired designs to magnetic switching.

"In our case, the tunability comes from the ability to change the tension of the drum-like membranes in real time," Karki said.

Additional inspiration, Karki and Paulose noted, came from research in the UO lab of physicist Benjamín Alemán. In *Nature Communications* in 2019, Alemán's group unveiled a graphene nanomechanical bolometer, a drum-like membrane that can detect colors of light at high speeds and high temperatures. The approach exploits a change in global tension.

While the mechanism in the new paper was identified theoretically and needs to be proven in lab experiments, Karki said, he is confident the approach will work.

"Our mechanism of dynamic dispersion tuning is independent of whether you are using acoustic, light or electronic waves," Karki said. "This opens up the possibility of manipulating signals in photonic and electronic systems as well."

Possibilities, he said, include improved acoustic signal processing and computation. Designing acoustic metamaterials based on graphene, such as those developed in Alemán's lab, could lead to variety of uses like wave-based computing, micromechanical transistors and logic devices, waveguides and ultra-sensitive sensors.

"Our design could be built at the microscale with graphene and at large scales using drum-like membrane sheets," Karki said. "You strike the chain of drums, creating a particular pattern of sound that moves in one direction, but by tuning the tension of the drums, we can stop the sound and store it for future use. It can be reversed or manipulated into any number of other patterns."

More information: Pragalv Karki et al, Stopping and Reversing Sound via Dynamic Dispersion Tuning in a Phononic Metamaterial, *Physical Review Applied* (2021). DOI: 10.1103/PhysRevApplied.15.034083

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