Promising new metamaterial could transform ultrasound imaging

June 1 2006

Using the same principles that help create a guitar's complex tones, researchers at the University of California, Berkeley, have developed a new material that holds promise for revolutionizing the field of ultrasound imaging.

The substance, dubbed an "ultrasonic metamaterial," responds differently to sound waves than any substance found in nature. Within a decade, the researchers report, the technology they developed to create the material could be used to vastly enhance image resolution of ultrasound, while at the same time allowing for the miniaturization of acoustic devices at any given frequency.

"We've been very interested in developing artificial materials with extraordinary properties that do not exist in nature," said Xiang Zhang, Chancellor's Professor in Mechanical Engineering at UC Berkeley and principal investigator of the study that describes the new material.

Zhang's interest in acoustic metamaterials was inspired by the five years he and his group have already spent exploring optical metamaterials. "The goal is to create artificial materials that will be useful in both optical and acoustical applications," Zhang said.

The study, "Ultrasonic metamaterials with negative modulus," will be published June 1 in Nature Materials. The journal released the study in its early online version on April 30.

Metamaterials are novel, manmade structures designed to have properties that respond to light, sound and other waves in ways that do not occur in naturally occurring substances. An example would be a material created to have a negative refractive index, which means that it could bend light in a different direction than normal materials do, explained Cheng Sun, a senior scientist in Zhang's group and one of the paper's authors.

A basic element of metamaterial design is a lattice of identical building blocks, each smaller than the wavelength of the light wave or sound wave with which the material is designed to interact. As a result, when waves move through the material, they do not "see" individual blocks, but respond to the material as a whole, as if it were a homogeneous substance.

The material designed by Zhang and his colleagues consists of a series of water-filled chambers connected by a long channel built into a bar of aluminum. Known as Helmholtz resonators, the rigid-walled, narrow-mouthed chambers are designed to vibrate - or resonate - in response to the sound of a certain pitch. A better-known example of a Helmholtz resonator is the body of a guitar, which resonates when the instrument's strings are plucked.

Designed to respond to 30 kHz sound waves moving through water, each chamber in the aluminum is a little smaller than a pencil's eraser. Their spacing at 9.2 mm is one-fifth the length of one 30 kHz sound wave.

As sound waves pass through the water-filled channel, a significant amount of their energy gets stored in the connected chambers, explained Nicholas Fang, who designed the metamaterial when he was a post-doctoral researcher in Zhang's lab. Now an assistant professor of mechanical engineering at the University of Illinois at Urbana-Champaign, Fang is lead author of the study.

"There is a natural frequency that determines the tone of a resonator," Fang said. "In this material, we are trying to excite the resonators with a tone that is higher than the one that they are tuned to. And because there are so many resonators in the series all tuned to the same frequency, every one lags just a bit behind the other."

In the complex dynamics of acoustical physics, this triggers various phenomena:

-- As opposed to natural materials that compress when a force (such as a sound wave) is applied to them, the metamaterial expands. This response, called "negative modulus," occurs when the fluid in the neck of the resonators oscillates in and out, causing the fluid in the chambers to spread apart and push into its walls.

-- The response makes it appear as if the sound wave is propagating backward instead of moving forward.

-- The material supports sound waves that are shorter and finer than sound waves that propagate through any other material.

The result?

"Basically, the resonators work together, supporting a much higher modulation of the acoustic wave," Fang said. "They are reacting as a very precise ruler, allowing us to measure the finer features of the wave."

This ability provides the basis for the material's usefulness in ultrasound imaging. One of the factors limiting resolution quality of sonograms is the ability of the ultrasound lens to capture sound waves. Currently, these lenses are made with elastic materials such as polymers. The elasticity of the materials is what allows them to capture and focus the

waves. But there is a limit to the finest resolution that they can capture.

"With this new material with a negative modulus, all the limits can be overcome," Fang said.

The material that Zhang's research group fabricated is 55 centimeters long and houses 60 resonators. In its present form, it can be used only for one frequency and can capture sound from only one direction. The group's plan, said Zhang, is to develop "three-dimensional" materials that will not only be able to capture sound from every direction, but will also be tunable. That is, the size of the resonators will be adjustable so that the material can respond to any frequency. Once they have designed and tested such a material, Zhang expects to be able to use microfabrication techniques to build materials with hundreds of thousands of resonators.

Because its resonators are many times smaller than wavelengths of the sound wave, Zhang said, the material can be used to make compact sonar and ultrasonic devices. Conventional lenses in these devices must be at least as large as the waves they are meant to capture. Sonar devices, which use long-length waves, would particularly benefit from this miniaturization.

Source: University of California - Berkeley