Research team proposes a novel type of acoustic crystal with smooth, continuous changes in elastic properties

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Density of states of phononic crystals consisting of steel cylinders embedded in high-density polyethylene (HDPE), depicted here for $\sigma = 50$. Separate calculations were performed for two distinct cases: $xy$ modes perpendicular (left) and $z$ modes parallel to the scatterers (right). Notably, when broadening $\eta$ softens the parameter step function, numerous new complete band gaps (vanishing DOS) appear for both modes. Credit: Europhysics Letters (2024). DOI: 10.1209/0295-5075/ad1de9
In dim light a cat sees much better than you do, as do dogs and nocturnal animals. That's because the structure of a cat's eye has a tapetum lucidum, a mirror-like layer immediately behind the retina. Light entering the eye that is not focused by the lens onto the retina is reflected off the tapetum lucidum, where the retina gets another chance to receive the light, process it, and send impulses to the optic nerve.

Optical scientists call this a **photonic crystal**. For a cat it's periodic parallel rods—it contains photonic bandgaps that are used to modify the flow of light, akin to the electron bandgaps in semiconductors, which are energy regions where no electron energy states exist. These materials have changes in their **index of refraction** and so modify and redirect the propagation of light.

Another example is the reflective markers on the pavement of highways that glow at night from a car's headlights. Photonic crystals, like the latter, are fabricated via layers of thin films using photolithography, hole drilling, laser writing and other techniques.

Photonic crystals prohibit light of certain frequencies in the parts of the crystalline medium that the light is traveling through. As defined by science, such crystals have periodic, distinct regions each with a periodic dielectric constant.

A dielectric is an electrically insulating material, without free electrons or atoms, opposing the flow of electrons when an electric field is applied. Instead, a dielectric material polarizes when an electric field is applied, with its molecules all pointing in the same direction. Distilled water—purified water that contains no minerals—is a dielectric material, and so is glass, porcelain, dry air, paper, and many other materials. Dielectrics are used in capacitors, liquid crystal displays, and other devices.
Extending this concept, "function photonic crystals" are materials that have a smooth, continuous change in refractive index, instead of a sharp, distinct periodicity. This enables fast electronic control of a material's properties.

The same concepts exist for phononic crystals. Phonons are quantized sound waves, just as photons are quantized light waves. A phononic crystal is a solid with continuous changes in its properties, creating a bandgap for photonic energies. Artificial structures with a periodic variation of elastic parameters can manipulate the propagation of elastic waves.

Now a team led by David Röhlig at the Technische Universität Chemnitz in Germany is proposing to create function phononic crystals, with smooth and continuous changes in elastic properties instead of strict periodic variations. The research is published in the journal *Europhysics Letters*.

The refractive index for sound would continually change inside the propagating medium, instead of step function discontinuities. In nature such substances are responsible for the long-wave propagation of sound waves in water and bent sound waves in the lower atmosphere.

Using high-performance computer simulations, the team focused on understanding the effect of a small deviation in material properties from the typical step function discontinuity on the phononic density of energy states.

Their results were surprising: even just small deviations from the ideal step function of a material could cause large, radical changes in the phononic band structure. This would lead to the emergence of many sought-after features, such as larger phonon band gaps and multiple phononic band gaps.
Because the phononic density of states can change so quickly for only small changes in the material properties, such properties would prove useful in making, for example, phononic lens in solid materials or water, or for new devices in materials science, applied physics and engineering.

"Our findings present a novel perspective on phononic structures," said Röhlig, "offering an additional avenue to induce bandgap formation in specific geometries that lack this characteristic." Noting that the swift convergence of the density of states as the step function parameters change to be more continuous, Röhlig notes that the rapid changes would streamline potential manufacturing approaches.

"If further studies can validate our predictions experimentally, our results could find applications in microtechnology and mechatronics for the design of acousto-mechanical transducers and actuators," he said.

Even large-scale environments could be shaped, "such as arranging trees or other wooden building units, [objects] that have a known or specially designed radially continuous parameter profile regarding density and elastic properties, to enhance ambient soundproofing."


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