Sound and light trapped by disorder

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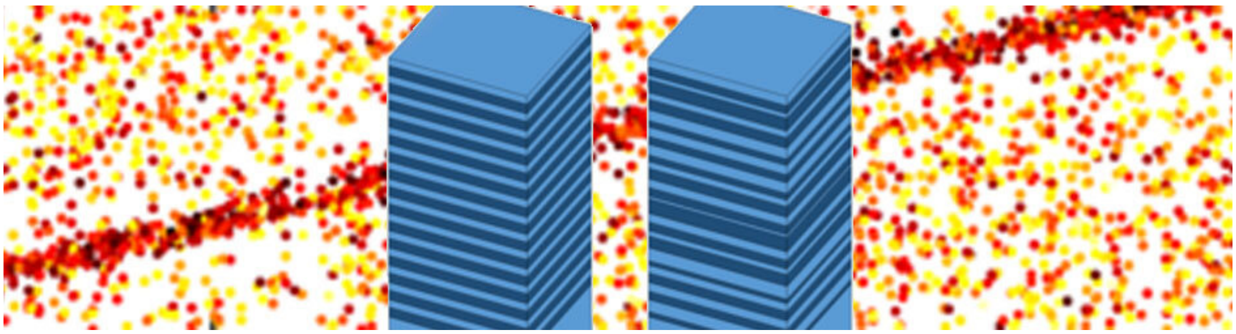

Credit: Catalan Institute of Nanoscience and Nanotechnology

Sound and light are crucial for our life and are essential in many energy, communication and information technologies. Their interaction allows many fundamental observations in physics, from the detection of cosmic gravitational waves to the cooling of quantum systems into their quantum ground state. However, their interaction may be subtle and weak. Enhancing their interaction requires confining both waves at the same place which is a considerable technological challenge.

In nanotechnology, this has been solved by creating cavities relying on very carefully fabricated patterns. This approach is demanding and easily disturbed by disorder and defects. In a work recently published in *Physical Review Letters* a totally different approach is proposed, where symmetry and periodicity are not needed, and disorder is embraced. The work has been done in close collaboration with Dr. Daniel Lanzillotti-

Kimura, a researcher at CNRS in France. The first author of the work is Guillermo Arregui and the last one is Dr. Pedro David García, both from the ICN2 Phononic and Photonic Nanostructures Group led by ICREA Prof. Dr. Clivia M. Sotomayor-Torres.

Order, symmetry and periodicity are words that have always thrilled researchers. For physicists, the appeal is that regular systems tend to obey simple (or at least symmetric) laws. Even complex systems are simplified in their description, which helps understanding their underlying mechanisms. However, the world is complex. However, understanding the inherent complexity of nature ultimately requires departing from perfect symmetry and periodicity. Remarkably, as the authors show in this work, disorder and complexity can be exploited as a resource instead of being treated just as an unavoidable annoyance. In the recently published work, disorder is used to simultaneously localize sound and light at the nanoscale.

Researchers from the Institut Català de Nanociència i Nanotecnologia (ICN2) and the Centre de Nanosciences et Nanotechnologies – C2N (CNRS / Université Paris-Sud) propose a random multilayered semiconductor structure were a subtle combination of their material properties force the simultaneous co-localization of sound and light. The equations governing the propagation of light and sound in stacks made of gallium arsenide (GaAs) and aluminium arsenide (AlAs) are extremely similar, leading to an Anderson colocalization of both excitations in random lattices. This is due to a surprising matching in the contrast of their indices of refraction and their speeds of sound, respectively, something that does not happen, for example, with other similar materials like Si/Ge or InP/GaP. The colocalization in random lattices induces an enhancement of the interaction between the light and sound fields. This interaction relies on the fact that light carries momentum which can be transferred to an object and move it. As a counterpart, a moving object can shift the frequency of light. In everyday life, this interaction is extremely small resulting in negligible effects.

To enhance these mutual interactions, the approach followed by nanotechnology is to concentrate light in small volumes and make use of small objects for which these effects become observable. Here, we show that no particular design is required to achieve this mutual observable interaction, thus relaxing substantially the fabrication needs. This achievement may be used to exploit the interaction between light and sound in arbitrarily designed structures, thus relaxing the very demanding fabrication requirements currently needed in nanotechnology. The co-localization effect shown in the new work unlocks the access to unexplored localization phenomena and the engineering of light-matter interactions mediated by Anderson-localized states.

More information: G. Arregui et al. Anderson Photon-Phonon Colocalization in Certain Random Superlattices, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.122.043903

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