Lenses can bend light and sound in almost any direction

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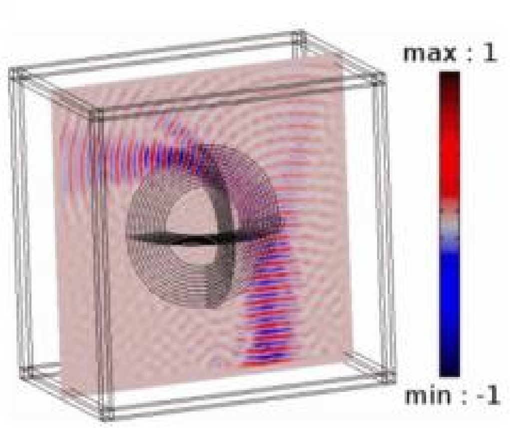

3D view of the electric field for a lens that bends light 90 degrees. Image credit: T. M. Chang, et al. ©2012 IOP Publishing Ltd and Deutsche Physikalische Gesellschaft

(PhysOrg.com) -- When an optical fiber is bent by 90° or more, the light begins to leak away, posing a problem for fiber optics communications. But by using special lenses that can bend light by not only 90°, but also 180° (i.e., a U-turn) or 360° (i.e., a full loop), scientists may limit light leakage in optical fibers and overcome this problem, not to mention provide a useful material for many other applications. Recently, a team of scientists has theoretically investigated materials for achieving this kind of advanced light control, which could work equally well for sound waves.

The scientists, Sebastien Guenneau and coauthors from Institut Fresnel, CNRS, University of Aix-Marseille in Marseille, France, have published their study on the focusing and bending of light and sound waves in a recent issue of the New Journal of Physics.

As Guenneau explained, both light and sound control techniques use gradient index (GRIN) lenses, which can effectively be used to curve space for light and sound trajectories. By creating a change, or gradient, in the refractive index of a lens, the scientists could create anisotropies – that is, make the lens' refractive index directionally dependent.

“We explain how one can either focus or bend (at 90°, 180° and 360°) electromagnetic or pressure waves simply by creating some gradient of the refractive index, which in essence is associated with effective anisotropy,” Guenneau told *PhysOrg.com*. “In layman's terms, we have curved the metric of space in the electromagnetic and acoustic contexts. We used realistic physical parameters and stress that one can use analogies between optics and acoustics to further the understanding: sometimes, thinking in terms of sound waves allows us to better grasp the foundations of transformational optics, as light waves are more elusive (light has complex physical properties such as polarization and moreover, it can propagate in vacuum unlike sound waves, which is something that still puzzles me).”

These GRIN lenses, which can be considered metamaterials and metafluids, build upon the principles of the invisibility cloak, which was co-discovered in the spring of 2006 by Sir John Pendry of Imperial College London and Ulf Leonhardt of the University of St. Andrews in Scotland.

“GRIN lenses considered in the *NJP* paper are designed using structured solids (for light) or structured fluids (for sound) deduced from a homogenization approach: when the size of the structural elements in a solid (or a fluid) is small compared to the wavelength of light (or sound), one can replace the solid (or the fluid) by an effective anisotropic solid (or fluid)," Guenneau said. "The trick is that light or sound, depending upon the physical context, will then follow curved trajectories in the anisotropic effective medium (solid or fluid): waves propagate in the direction of highest anisotropy, which is the principle of Einstein's relativity."

In the future, the ability to control wave trajectories could lead to solving problems such as the light leakage in optical fibers.

"One of the greatest challenges in optical fibers nowadays is that, as soon as you bend the waveguide by an angle of 90°, light leaks away and you lose the signal at the end of the fiber," Guenneau said. "So one would like to find ways to limit this unwanted leakage. One way to do so is to use ideas from our paper: one can use the GRIN spherical lens in order to bend light at a sharp angle in optical fibers."

The 180° bend (the U-turn), which is called a retro-reflector, can also be used to build a photonic or phononic micropolis, in which a variety of devices are assembled to resemble a tiny city. Another application of these lenses involves mimicking black holes, which Leonhardt demonstrated both theoretically and experimentally in a previous study.

"A lens that mimics a black hole for light or sound offers a beautiful paradigm of a device that mimics the quantum effects of a black hole, which is a black body radiation near the event horizon known as Hawking radiation," Guenneau said.

Invisibility cloaks, arguably the most well-known application of metamaterials, may also experience exciting advances in the future due to better light control. One area that scientists are working on is hiding bigger and bigger objects.

"One of the biggest challenges in the control of light is dealing with the very high absorption of metamaterials for visible wavelengths (due to the fact they use metals), which is the reason why invisibility cloaks are most of the time fabricated for microwaves (where metals have much less absorption), and nearly always hide only very small objects you would not see with the naked eye," Guenneau said, noting that some recent experiments have achieved macroscale cloaking.

"For sound waves, one does not need to go into nanotechnologies, as frequencies of sound waves are much smaller than visible light," he explained. "Also, there is no such thing as absorption for acoustic metamaterials, which is a good thing. Therefore, one can structure fluids with particles a few millimeters in size without having to resort to nanotechnology (to be compared with a few nanometers for light). So, in terms of fabricating nice paradigms, one should first think of sound waves, and if that works, then try to replicate for light."

In the future, Guenneau said that he plans to fabricate the acoustic metamaterials studied in this paper, as well as investigate hydrodynamic and seismic metamaterials, which control water and geological waves, respectively.

More information: T. M. Chang, et al. "Enhanced control of light and sound trajectories with three-dimensional gradient index lenses." *New Journal of Physics* 14 (2012) 035011. DOI: 10.1088/1367-2630/14/3/035011

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