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New 'metamaterial' practical for optical advances

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(Phys.org) -- Researchers have taken a step toward overcoming a key obstacle in commercializing "hyperbolic metamaterials," structures that could bring optical advances including ultrapowerful microscopes, computers and solar cells.

The researchers have shown how to create the metamaterials without the traditional silver or gold previously required, said Alexandra Boltasseva, a Purdue University assistant professor of electrical and computer engineering.

Using the metals is impractical for industry because of high cost and incompatibility with semiconductor manufacturing processes. The metals also do not transmit light efficiently, causing much of it to be lost. The Purdue researchers replaced the metals with an "aluminum-doped zinc oxide," or AZO.

"This means we can have a completely new material platform for creating optical metamaterials, which offers important advantages," Boltasseva said.

Doctoral student Gururaj V. Naik provided major contributions to the research, working with a team to develop a new metamaterial consisting of 16 layers alternating between AZO and zinc oxide. Light passing from the zinc oxide to the AZO layers encounters an "extreme anisotropy," causing its dispersion to become "hyperbolic," which dramatically changes the light's behavior.

"The doped oxide brings not only enhanced performance but also is compatible with semiconductors," Boltasseva said.

Research findings are detailed in a paper appearing Monday (May 14) in the Proceedings of the National Academy of Sciences.

The list of possible applications for metamaterials includes a "planar hyperlens" that could make optical microscopes 10 times more powerful and able to see objects as small as DNA; advanced sensors; more efficient solar collectors; quantum computing; and cloaking devices.

The AZO also makes it possible to "tune" the optical properties of metamaterials, an advance that could hasten their commercialization, Boltasseva said.

"It's possible to adjust the optical properties in two ways," she said. "You can vary the concentration of aluminum in the AZO during its formulation. You can also alter the optical properties in AZO by applying an electrical field to the fabricated metamaterial."

This switching ability might usher in a new class of metamaterials that could be turned hyperbolic and non-hyperbolic at the flip of a switch.

"This could actually lead to a whole new family of devices that can be tuned or switched," Boltasseva said. "AZO can go from dielectric to metallic. So at one specific wavelength, at one applied voltage, it can be metal and at another voltage it can be dielectric. This would lead to tremendous changes in functionality."

The researchers "doped" zinc oxide with aluminum, meaning the zinc oxide is impregnated with aluminum atoms to alter the material's optical properties. Doping the zinc oxide causes it to behave like a metal at certain wavelengths and like a dielectric at other wavelengths.

The material has been shown to work in the near-infrared range of the spectrum, which is essential for optical communications, and could allow researchers to harness "optical black holes" to create a new generation of light-harvesting devices for solar energy applications.

The PNAS paper was authored by Naik, Boltasseva, doctoral student Jingjing Liu, senior research scientist Alexander V. Kildishev, and Vladimir M. Shalaev, scientific director of nanophotonics at Purdue's Birck Nanotechnology Center, a distinguished professor of electrical and computer engineering and a scientific adviser for the Russian Quantum Center.

Current optical technologies are limited because, for the efficient control of light, components cannot be smaller than the size of the wavelengths of light. Metamaterials are able to guide and control light on all scales, including the scale of nanometers, or billionths of a meter.

Unlike natural materials, metamaterials are able to reduce the "index of refraction" to less than one or less than zero. Refraction occurs as electromagnetic waves, including light, bend when passing from one material into another. It causes the bent-stick-in-water effect, which occurs when a stick placed in a glass of water appears bent when viewed from the outside. Each material has its own refraction index, which describes how much light will bend in that particular material and defines how much the speed of light slows down while passing through a material

Natural materials typically have refractive indices greater than one. Metamaterials, however, can make the index of refraction vary from zero to one, which possibly will enable applications including the hyperlens.

The layered metamaterial is a so-called plasmonic structure because it conducts clouds of electrons called "plasmons."

"Alternative plasmonic materials such as AZO overcome the bottleneck created by conventional metals in the design of optical metamaterials and enable more efficient devices," Boltasseva said. "We anticipate that the development of these new plasmonic materials and nanostructured material composites will lead to tremendous progress in the technology of optical metamaterials, enabling the full-scale development of this technology and uncovering many new physical phenomena."

More information: A Demonstration of Al:ZnO as a New Plasmonic Component for Near-Infrared Metamaterials, *Proceedings of the National Academy of Sciences.*

ABSTRACT
Noble metals such as gold and silver are conventionally used as the primary plasmonic building blocks of optical metamaterials. Making subwavelength-scale structural elements from these metals not only seriously limits the optical performance of a device due to high absorption; but it also substantially complicates the manufacturing process of nearly all metamaterial devices in the optical wavelength range. As an alternative to noble metals, we propose to use heavily doped oxide semiconductors that offer both functional and fabrication advantages in the near-infrared wavelength range. In this letter, we replace a metal with aluminum-doped zinc oxide as a new plasmonic material and experimentally demonstrate negative refraction in an Al:ZnO/ZnO metamaterial in the near-infrared range.

Provided by Purdue University

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