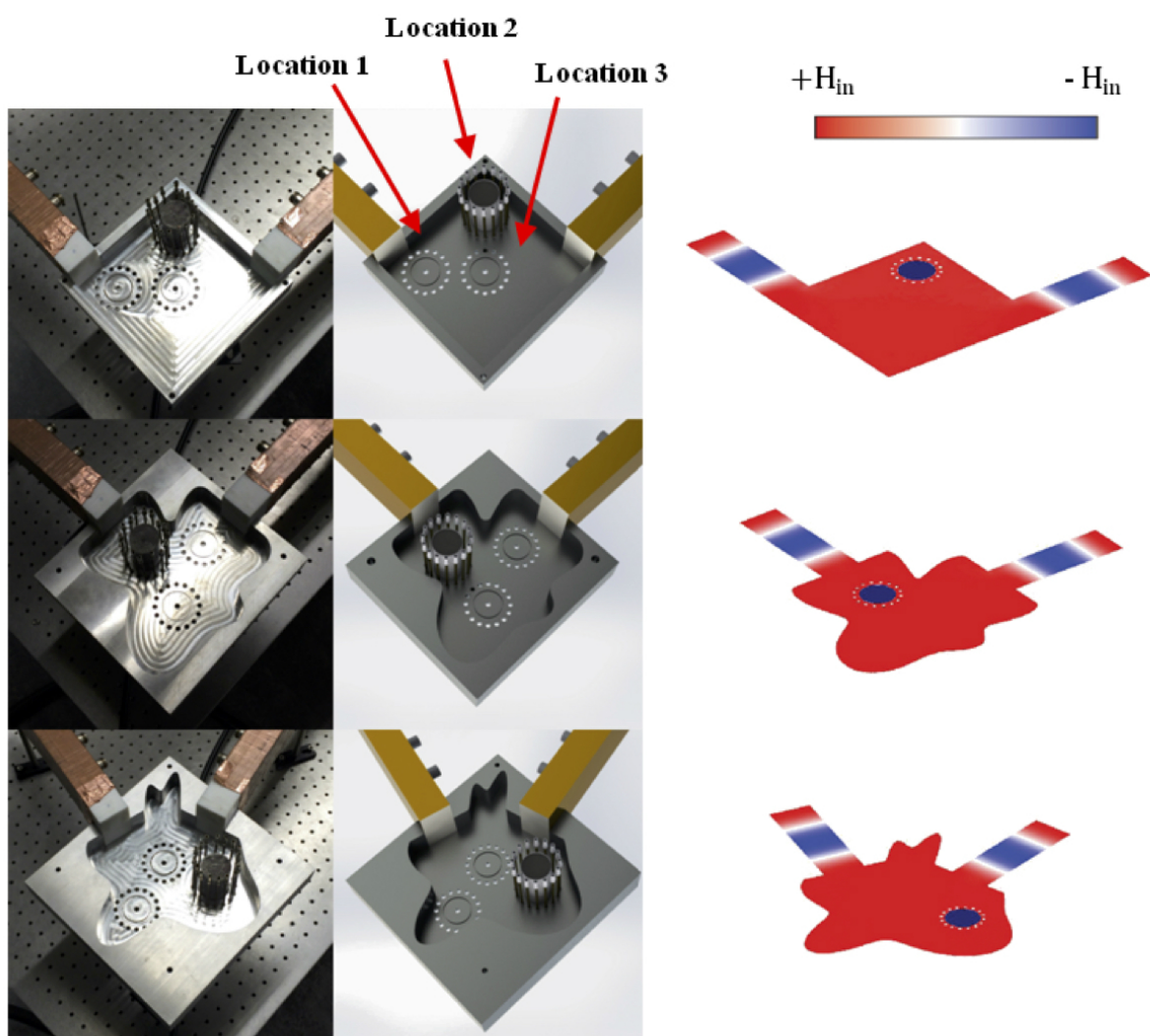


'Photonic doping' makes class of metamaterials easier to fabricate

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"Physical experiments showed that the location of the dielectric rod and the

shape of the ENZ material did not effect the properties of the resulting metamaterial." Credit: University of Pennsylvania

The field of metamaterials, an intersection of materials science, physics, nanotechnology and electrical engineering, aims to produce structures with unusual electromagnetic properties. Through the careful combination of multiple materials in a precise periodic arrangement, the resulting metamaterials exhibit properties that otherwise couldn't exist, such as a negative index of refraction. Some metamaterials can even channel electromagnetic waves around their surfaces, rendering them invisible for certain wavelengths of light.

The precision needed for arranging a metamaterial's constitutive parts, also known as inclusions, has been a challenging step in their development and application.

Now, University of Pennsylvania engineers have shown a way to make metamaterials with a single inclusion, providing easier fabrication, among other useful features.

Analogous to electronic "doping," where adding a small amount of atomic impurities to a "pure" material gives it electronic properties necessary for many computational and sensing devices, this "photonic doping" would allow for new ways of sculpting and tailoring light-matter interactions, with future impact on optical technology, such as flexible photonics.

The study, published in the journal *Science*, was led by Nader Engheta, H. Nedwill Ramsey Professor of Electrical and Systems Engineering, together with members of his group, Iñigo Liberal, Ahmed M. Mahmoud, Yue Li and Brian Edwards.

"Just as in electronic doping, when adding a set of foreign atoms in an otherwise pure material can significantly alter the electronic and optical properties of the host," Engheta said, "'photonic doping' means adding a foreign photonic object in a specialized photonic host structure can change the optical scattering of the original structure in a major way."

The phenomenon works with a specific class of materials that have permittivity, a parameter that has to do with the electric response of the material, mathematically represented by the Greek letter epsilon, that is nearly zero.

The key quality of these epsilon-near-zero, or ENZ, materials is that the wave's [magnetic field](#) is distributed uniformly throughout the two-dimensional ENZ hosts, regardless of their cross-sectional shape. Such ENZ materials occur either naturally or can be made by traditional metamaterial means.

Rather than engineer complicated periodic structures that significantly alter the optical and magnetic properties of such materials, Engheta and his group devised a way for a single inclusion in a 2-D ENZ structure to accomplish the same task: changing which wavelengths of light that will reflect or pass through, or altering the magnetic response of the structure

"If I want to change the way a piece of material interacts with light, I normally have to change all of it," Engheta said, "Not here. If I place a single dielectric rod anywhere within this ENZ material, the entire structure will look different from the perspective of an external wave."

The dielectric rod is a cylindrical structure made out of an insulating material that can be polarized. When inserted in a 2-D ENZ host, it can affect the magnetic field within this host and consequently can notably change the optical properties of the host ENZ material.

Because the wave's magnetic field in the 2-D ENZ host has a uniform spatial distribution, the dielectric rod can be placed anywhere within the material. Incoming waves thus behave as if the host material has a significantly different set of [optical properties](#). Since the rod does not need to be placed at a precise location, construction of such photonically doped structures may be achieved with relative ease.

Applying these metamaterial concepts via "photonic doping" has implications for information processing systems and applications within telecommunications.

"When we're working with a wave, this photonic doping can be a new way for us to determine the path this wave takes from A to B within a device," Engheta said. "With a relatively small change in the dielectric rod, we can make waves 'go this way' and 'don't go that way.' That we only need to make a change to the rod, which is a tiny part of the host material, should help with the speed of the device, and, because the effect is the same for the ENZ host with arbitrary shape while keeping its cross-sectional area fixed, this property may be very useful for flexible photonics."

Further research demonstrates more complicated ways of applying photonic doping to ENZ [materials](#), such as adding multiple rods with different diameters.

"The dielectric property of the rod can be responsive to thermal, optical or electrical changes," Engheta said. "That means we could use the [host](#) ENZ material as the read-out of a sensor, as it would transmit or reflect light due to changes in that rod. Adding more rods would allow for even finer tuning of the material's response."

More information: "Photonic doping of epsilon-near-zero media," *Science*(2017). [DOI: 10.1126/science.aal2672](https://doi.org/10.1126/science.aal2672)

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