be produced anywhere between the values of the two bits or even outside that range. Thus, it was demonstrated that, given the right conditions, a wide range of effective permittivity values could be produced from just two materials. Furthermore, the electromagnetic wave scattering from the digital bytes was found to be comparable to analogous homogenized structures.

The researchers substantiated the use of these digital metamaterial bytes in a number of design structures. The core–shell digital bytes performed well in an arrangement designed to mimic a dielectric convex lens with a hyperbolic profile. By altering the order and thickness of the material bits within these core–shell bytes, a 2D graded-index flat lens architecture could also be produced.

By constructing the grading in this lens from discrete, subwavelength cross-sections, spatial variation of permittivity can be controlled to a greater degree. With confirmation that these digital metamaterial bytes function well in a number of system designs, this work opens up the possibility of developing simpler, more controllable device architectures.

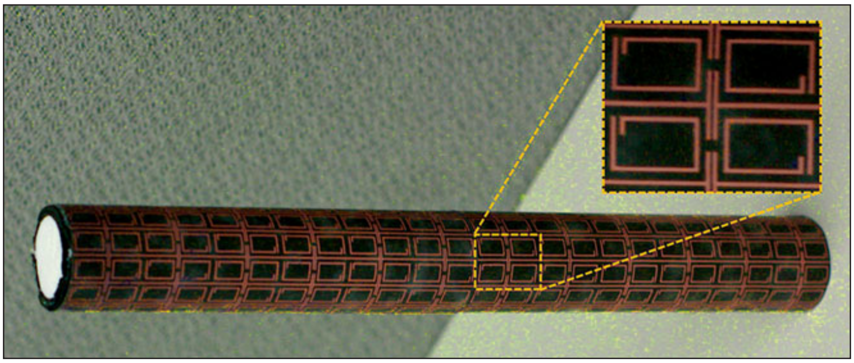
Ian McDonald

Tailored flexible illusion coatings hide objects from detection

Developing the cloak of invisibility would be wonderful, but sometimes simply making an object appear to be something else will do the trick, according to a research team at The Pennsylvania State University (Penn State).

"Previous attempts at cloaking using a single metasurface layer were restricted to very small-sized objects," says Zhi Hao Jiang, postdoctoral fellow in electrical engineering at Penn State. "Also, the act of cloaking would prevent an enclosed antenna or sensor from communicating with the outside world."

Jiang and Douglas H. Werner, the John L. and Genevieve H. McCain Chair Professor of Electrical Engineering, employ coatings made up of a thin flexible substrate with copper patterns designed to create the desired result. They can take a practical size metal antenna or sensor, coat it with the patterned film, and when the device is probed by a radio frequency source, the scattering signature of the enclosed object will appear to be that of a prescribed dielectric material like silicon or Teflon. Conversely, with the proper pattern, they can coat a dielectric and it will scatter electromagnetic waves the same as if it were a metal object. Furthermore, as they reported in the October 9 online edition of *Advanced Functional Materials* (10.1002/adfm.201401561), the metasurface is two-dimensional and lightweight rather than three-dimensional and bulky.



Antenna covered with copper patterned dielectric substrate creates a flexible metasurface that acts as an illusion coating, cloaking the antenna or making it appear to be something entirely different. Image: Zhi Hao Jiang/Penn State.

The researchers take the object they want cloaked and surround it with a spacer, in the form of either air or foam. They then apply the ultrathin layer of dielectric with copper-patterning designed for the wavelengths they wish to cloak. In this way, antennae and sensors could be made invisible or deceptive to remote inspection.

Another application of this material would be to protect objects from other emitting objects nearby, while still allowing electromagnetic communication between them. This was not previously possible because the cloaking mechanism electromagnetically blocked the cloaked object from the outside. However, this new coating allows the object surrounded to continue working while being protected. In an array of antennas, for example, interference from the nearby antennas can be suppressed.

The metasurface coating consists of a series of geometric copper patterns on a flexible substrate formed using the standard lithographic methods currently used to create printed circuit boards. Each illusion coating must be designed for the specific application, but the designs are optimized mathematically. This method of manufacture is low cost and well established.

Another advantage of this method is that it continues to operate properly within a 20° field of view, making it a better angle-tolerant shield than previous attempts that employed bulky metamaterials. Currently, the metasurface coatings only work on narrow bands of the spectrum for any application, but can be adapted to work in other bands of the electromagnetic spectrum including the visible spectrum.

"We haven't tried expanding the bandwidth yet," says Werner. "But the theory suggests that it should be possible and it will probably require multiple layers with different patterns to do that."

Illusion coatings could enhance the way radio-frequency ID tags work or could redistribute energy in different, controlled patterns making things more visible rather than less visible. The materials shielding ability can also be used to protect any type of equipment from stray or intentional electromagnetic interference, according to the researchers. □

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