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Invisibility cloaks closer thanks to 'digital metamaterials'

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The concept of "digital metamaterials" – a simple way of designing metamaterials with bizarre optical properties that could hasten the development of devices such as invisibility cloaks and superlenses – is reported in a paper published today in Nature Materials.

Metamaterials are artificially engineered out of microscopic subunits – such as glass, metal or plastic – arranged in a repeating fashion. Once assembled, these metamaterials possess unique properties, such as interacting with light in unusual ways, which aren't often seen in natural materials.

“The idea behind metamaterials is to mimic the way atoms interact with light, but with artificial structures much smaller than the wavelength of light itself,” said Boris Kuhlmey, associate professor of photonics and optics at the University of Sydney.

“This way, optical properties are no longer restricted to those of the constituent materials, and can be designed almost arbitrarily.”

The material world goes digital

The researchers of the Nature Materials paper, from the University of Pennsylvania, were inspired to develop digital metamaterials by the binary numeral system of Boolean algebra.

The binary system is used internally by most digital electronic devices, such as computers and smartphones. Complex digital devices have their digital information simply encoded as a string of 1s and 0s called “bits”.

The proposed method for digital metamaterials is a simplified way of building metamaterials, yet still allows for complex and diverse properties to be achieved.

“The beauty of the new method is its simplicity,” said Min Gu, professor of optoelectronics at Swinburne University of Technology.

Through the use of simulations in two-dimensional space, the researchers explored the possibility of creating metamaterials with only two specially chosen component parts, called metamaterial bits – analogous to the 1 and 0 “bits” of binary computer code. The arrangement of metamaterial bits represents the “digitising” of metamaterials.

In their study, the researchers chose to use nano-sized pieces of silver and silica (glass) as their repeating metamaterial bits. These are materials that interact with light in very different ways on an individual level. Once they were “digitised”, the resulting metamaterial had its own unique properties, very different to those of its constituent parts.

“The components of the material work together to generate effects or give rise to phenomena that you wouldn’t observe if they weren’t arranged together in 3D (or in this case, 2D) space as an ordered assembly,” said Tiffany Walsh, professor of bionanotechnology at Deakin University.

Sourcing material parts in order to achieve unusual properties of a metamaterial can be time consuming and expensive. This new way of thinking about the design of metamaterials may allow researchers to produce the optical properties they want from the metamaterial using only two component parts.

“What this [research] really does is put a new spin on the idea that with only two set materials arranged with the right portions – one metal, one insulator, here silver and silica – almost any optical property can be achieved,” said Associate Professor Kuhlmey.

Professor Walsh said: “This is like the concept of turning sound waves from analog into digital – and they’ve pushed it into a new realm of physics.

"They've been able to take the permittivity – the response of the material when it's exposed to radiation – and digitised this. They've turned it into something that is more readily manipulated."

Waves and matter collide

One of the key applications for metamaterials lies in their ability to manipulate light.

"We already have knowledge about how to manipulate radiation (such as light) – we can use lenses, like a magnifying glass, for example, which focus light down on a spot; we can use mirrors to reflect light and change its direction," Professor Walsh said.

"But what these [metamaterials] can do is something more sophisticated: they're able to bend light, to scatter it, to manipulate it in unusual ways."

Using their digital method, the researchers showed that it is possible to create certain metamaterials with very low permittivity, which are rarely found in nature. Having control over these properties may open doors to more advanced technological applications, such as invisibility cloaking devices.

"It would be interesting in future to see if such a digital design method can facilitate the construction of optical, or invisibility, cloaks," said Professor Gu.

"With varying changes of silver/glass ratios (structured at the nanoscale) it is then in principle possible to make flat lenses and other tiny optical elements," Associate Professor Kuhlmey said.

"The authors […] showed in simulations that nano-patterned glass/silver structures can then bend light, which is also the principle behind invisibility cloaking."

He added that fabricating the proposed structures would be challenging but not impossible.

"[It would] require structuring glass and metal with a precision of a few atoms in thickness only – but thinking of metamaterials as binary structures may help devise new nano-patterning lithography (printing) techniques that take advantage of this," he said.