Invisibility carpet cloak can hide objects from visible light

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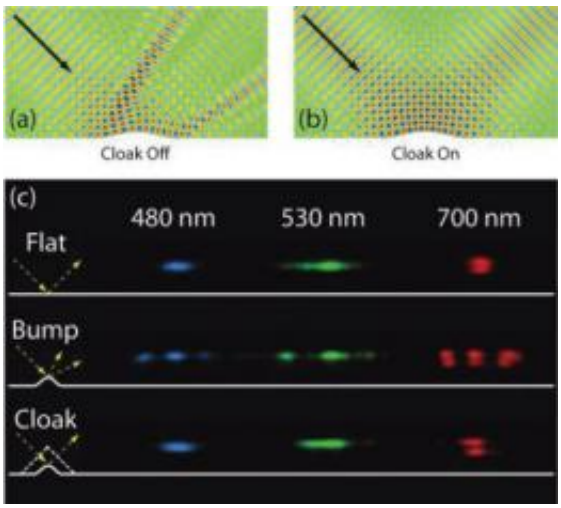

When an input beam (black arrow) reflects off (a) a bump without a cloak, the bump causes a perturbation. When the beam reflects off (b) a bump covered by a cloak, the cloak masks the bump, and the reflected beam is reconstructed as if the bump did not exist. (c) Light after reflection from a flat mirror, a bump without a cloak, and a cloaked bump, at three different wavelengths. Image credit: Majid Gharghi, et al. ©2011 American Chemical Society

(PhysOrg.com) -- Most of the invisibility cloaks that have been demonstrated to date conceal objects at frequencies that are not detectable by the human eye. Designing invisibility cloaks that can conceal objects from visible light has been more challenging due to the strict material requirements. But in a new study, researchers have fabricated a carpet cloak that can make objects undetectable in the full

visible spectrum.

The researchers, led by Prof. Xiang Zhang at the University of California, Berkeley, and Lawrence Berkeley National Laboratory, have published their study in a recent issue of Nano Letters.

As the researchers explain, most previous invisibility cloaks have used metallic metamaterials for cloaking at microwave frequencies. But at optical frequencies, the metal absorbs too much light and leads to significant metallic loss, and Berkeley and other groups have had to design dielectric cloaks at infrared frequencies. More recently, researchers at University of Birmingham (UK) have experimented with using uniaxial crystals as the cloak material, which can enable cloaking in visible frequencies, but only for a certain polarization of light.

In the current study, the researchers used a technique called quasi conformal mapping (QCM) to conceal an object with a height of 300 nm and a width of 6 μm underneath a reflective "carpet cloak." The carpet itself has the appearance of a smooth optical mirror, so that the object and the bump that the object makes underneath the carpet are undetectable by visible light.

"The carpet cloak means that you conceal the object under a layer, which we call carpet, but you see the carpet like a normal mirror, as if it is flat with no bump caused by putting the object underneath," Zhang told *PhysOrg.com*. "This way, the observer won't recognize something is concealed underneath."

In order to guide visible light around the concealed object, the researchers had to make light travel at different speeds while approaching the bump. They achieved this by designing the materials to have a variable refractive index, transforming them into metamaterials, since they don't appear in nature. The researchers placed a silicon nitride

waveguide on a transparent nanoporous silicon oxide substrate that they specially developed to have a much lower refractive index than that of the waveguide. Using nanofabrication techniques, the researchers etched tiny holes into the nitride to make a desired pattern, giving the waveguide the cloaking refractive index profile.

“The concept of the carpet cloak was originally suggested so that you can design a certain pattern for a given size of the bump, and hide an object of arbitrary shape under that,” Zhang said. “If you need to make a bigger size bump to hide a bigger object, a new hole pattern will be required.”

With this refractive index profile, along with the transparency of both the waveguide and the substrate, the cloak could completely conceal an object by producing a light beam profile identical to a beam reflected from a flat carpet with no object underneath.

“This device is among the first cloak devices that operate at visible frequencies; the other very recent visible light cloaks operate based on a principle that relies on a certain polarization of light, whereas the quasi-conformal-based principle does not rely on the polarization,” Zhang said. “Of course, the waveguide geometry entails different operation for different polarizations, which is extrinsic to the QCM design.”

In addition to cloaking, the new technique provides an important step toward implementing optical transformation structures in the visible range. Using transformation optics (TO), researchers can manipulate light for applications such as powerful microscopes and computers.

“The carpet cloak is an example of a wide family of devices that can be made based on transformation optics,” Zhang said. “Besides invisibility, all kinds of optical illusion schemes can be made based on the concept, where the observer receives a different impression when looking at an object. The capability to manipulate light propagation can be used in

energy devices, optical computing devices, and beyond, wherever it is desired to have full control on the light path; TO lets us redirect light and re-route it."

More information: Majid Gharghi, et al. "A Carpet Cloak for Visible Light." *Nano Letters*. DOI: 10.1021/nl201189z

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