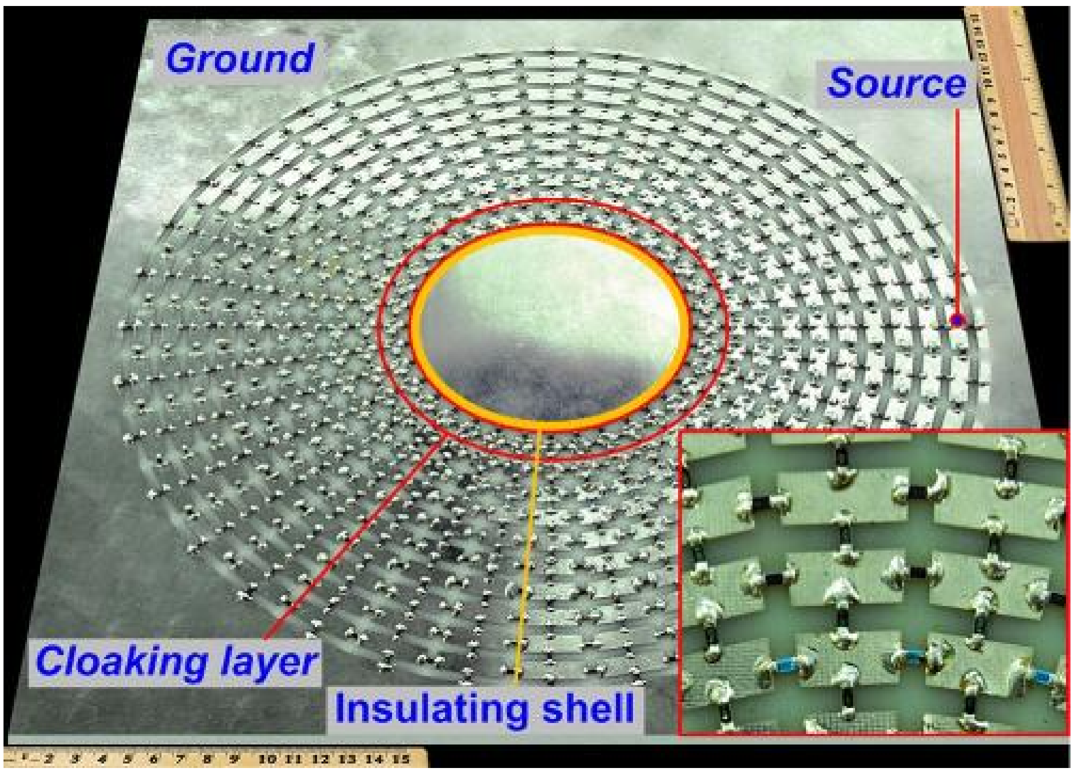
Nearly perfect, ultrathin invisibility cloak could have wide practical applications

January 17 2013, by Lisa Zyga



The dc invisibility cloak has a thickness of just one unit cell and can cloak an object nearly perfectly. The inset shows an enlarged view of the cloak's resistor network. Credit: Wei Xiang Jiang, et al. ©2013 American Institute of Physics

(Phys.org)—Researchers have created a dc invisibility cloak made of a metamaterial that not only shields an object almost perfectly, but at 1-cm thick is also the thinnest cloak ever constructed, reaching the ultimate limit of thinness for artificial materials. As the first invisibility cloak that combines both near-perfect performance and extreme thinness, it could open the doors to practical applications. In the past, invisibility cloaks have been too large to be used in many real-world applications.

The researchers, led by Tie Jun Cui at Southeast University in Nanjing, China, have published their paper on the ultrathin but nearly perfect invisibility cloak in a recent issue of *Applied Physics Letters*.

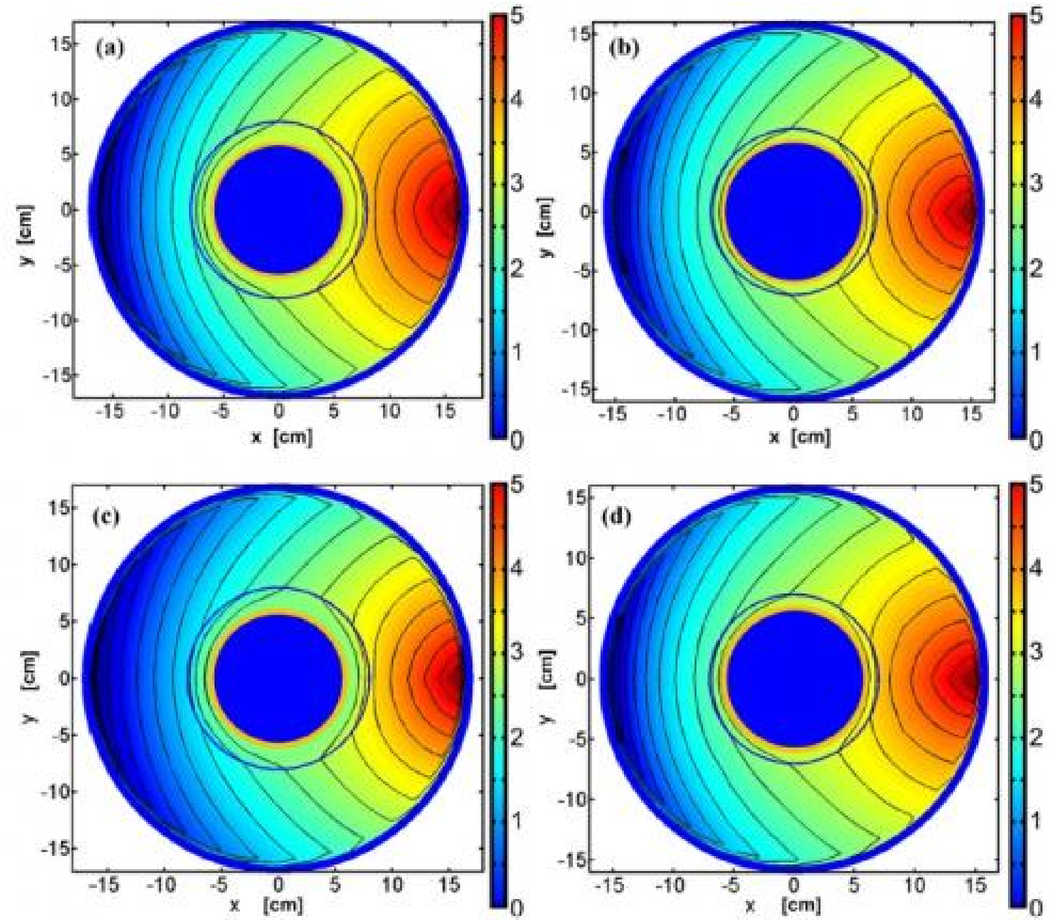
The key to making a material that can prevent another object from being seen—or from being detected by electromagnetic waves in any way—is to control two material parameters: electric permittivity and magnetic permeability. Electric permittivity corresponds to the degree to which a material permits the formation of an electric field within itself, while magnetic permeability corresponds to the degree to which a material can be permeated by a magnetic field.

As the researchers explain, a perfect invisibility cloak must have a permittivity and permeability that are both strongly anisotropic (directionally dependent) and inhomogeneous (made of different materials). A metamaterial with these parameters is currently beyond the reach of current technology. However, by loosening these strict requirements, researchers have been able to fabricate metamaterials that mimic these properties and can be used as imperfect invisibility cloaks.

During the past several years, researchers have fabricated different kinds of invisibility cloaks using the loosened requirements. One kind is a free-space cloak, which guides incoming electromagnetic waves to propagate around the enclosed objects and continue along their original paths without interacting with the objects. Mathematically speaking, this is the equivalent of compressing the objects into a point. A second cloak, called a ground-plane or carpet cloak, can hide objects on the ground by making incoming electromagnetic waves appear to be reflected by a flat plane instead of the objects. This time, the objects are mathematically compressed into a two-dimensional sheet instead of a point. Both of these two types of cloaks hide objects imperfectly, and they also both take up large amounts of space due to being inhomogeneous, which limits their applications.

More recently, researchers have turned their attention to dc cloaks, which are used to hide static electric and magnetic fields. In 2012, some of the authors of the current study fabricated a dc cloak using a resistor network. This design could mimic the anisotropic property so well that the cloak had a nearly perfect cloaking performance. However, the cloak was still very large due to the material being inhomogeneous.

"If a device is inhomogeneous, that is, the device is composed of different-property materials, then such a device will be fabricated by multi-layer materials to reach the inhomogeneity," Cui told *Phys.org*. "If a device is homogeneous, however, it is possible to be fabricated by only one single cell. For artificial materials, one single cell is the thinnest."



Simulation results of a metallic disk (blue circle) being cloaked by a dc invisibility cloak (thin blue circle surrounding the metallic disk). The color scale represents electric potentials and the thin black lines represent equipotential lines. Outside the cloak, the equipotential lines are almost concentric circles, showing nearly perfect cloaking effects. Credit: Wei Xiang Jiang, et al. ©2013 American Institute of Physics

Now, the researchers have demonstrated that it's possible to make a dc invisibility cloak that is made of a homogeneous and anistropic material, resulting in an ultrathin and nearly perfect cloak. They found that they could use a homogeneous material for this cloak, even though inhomogeneous materials were required for the other cloak types, by using a special optical transformation. They explained that, for a dc cloak, the transformation optics equations that are typically used to control the path of electromagnetic waves are simplified to transformation electrostatics equations. This simplification means that the metamaterial compresses the hidden object into a short line segment instead of a point.

Using transformation electrostatics, the researchers designed and fabricated a dc line-transformed invisibility cloak for the first time. The cloak is elliptical, but has such a small focal length that it is nearly circular. As a result, the cloak compresses the hidden object into such a short line segment that it is nearly a point, and therefore enables nearly perfect cloaking.

Equally as important as its performance, the cloak's thickness of a single unit cell makes it the thinnest invisibility cloak constructed to date. The researchers used a network of resistors as the metamaterial, and showed that a nearly perfect invisibility cloak could be made with just a single unit cell, which is the ultimate limit for metamaterials. They explained that this extreme thinness is possible due to the metamaterial being homogeneous.

The researchers hope that this invisibility cloak could make it possible to realize a variety of applications, such as electric impedance tomography (EIT), a medical imaging technique that can detect cancer. Another application could be cloaking or detecting land mines.

"Electrostatics has wide potential applications in EIT technology, graphene, natural resource exploration, and underground archaeology," Cui said. "In our paper, we designed and fabricated a dc cloak, which is possible to be used in such potential applications. The dc cloak may be used to cloaking the landmines to make them invisible. Knowing the physical principle, we may also find ways to detect the cloaked landmines."

In the near future, the researchers plan to study three-dimensional ultra-thin dc cloaks and ultrathin cloaks for harmonic fields.

More information: Wei Xiang Jiang, et al. "An ultrathin but nearly perfect direct current electric cloak." *Applied Physics Letters* 102, 014102 (2013). DOI: 10.1063/1.4774301