Crystal Structure for Approximate Optical Invisibility Cloaking Proposed

Electromagnetic cloaking of materials has long been fantasized in science fiction tales, but has recently been shown to be theoretically possible. Experimentally, limited forms of cloaking have been realized in the microwave region of the spectrum. Significant work is underway to investigate approaches to cloaking in the optical region of the spectrum. D. Xiao and H. Johnson, of the University of Illinois at Urbana-Champaign, propose a photonic crystal structure capable of approximate cloaking in the optical regime. Their calculations, reported in the April 15 issue of *Optics Letters* (p. 860), show that anisotropy in an axisymmetric silicon photonic crystal can serve as a waveguide to bend light around an object.

Xiao and Johnson develop a cloaking schema based upon a perfectly layered silicon and air structure that provides approximate cloaking in the optical regime. As opposed to an ideal cloak, a refractive index matched material, this approximate scheme uses a multiply layered structure to guide the light around an obstacle and prevent it from entering the object, as illustrated in Figure 1. The photonic band structure of the proposed axisymmetric crystal structure in silicon results in a tangential index of refraction of 1.13 and a radial index of 2.07, resulting in double action as both waveguide and waveblock.

In order to establish a baseline for the efficacy of the cloak, the researchers conducted numerical experiments to compare the optical properties of the proposed cloak with those of an ideal cloak, both illuminated with a Gaussian beam of light. They used these simulations to predict the sensitivity of the cloak to the ratio of particle size to wavelength. Their analysis indicates that the index matched cloaking functions well when the object size is less than 0.05% of the wavelength of the incident light, but that these cloaks are very sensitive to material perturbations and fail as object size-to-wavelength ratio increases. Though the cloak proposed here is approximate, these results show a potential way to engineer a cloaking device on a larger scale, said the researchers.

Arthur Feldman

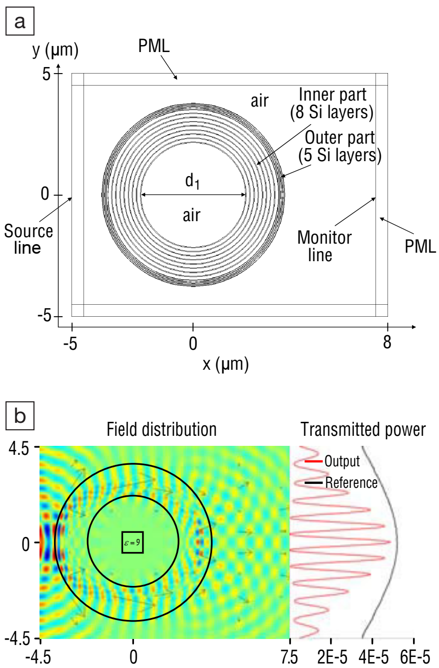

Figure 1. (a) Illustration of the axisymmetric silicon cloaking device.
(b) Demonstration of the magnetic field and power distribution of the device in response to a Gaussian beam. The red lines illustrate the output with the cloaking device and the black is the reference system without the object. Reprinted with permission from *Optics Letters* **33** (8) (April 15, 2008) p. 860. ©2008 Optical Society of America.

Superlattices of $PbTiO_3/SrTiO_3$ Exhibit Improper Ferroelectricity

As materials researchers gain increasingly fine control over epitaxial thin film growth, they often find that unexpected properties emerge at the interface between compounds. A new discovery in this type of "interface engineering" is improper ferroelectricity in superlattices of $PbTiO_3$ and $SrTiO_3$ as reported in the April 10 issue of *Nature* (DOI: 10.1038/nature06817; p. 732). E. Bousquet of the University of Liège, M. Dawber of the University of Geneva, and their co-workers have used a combination of experimental and computational techniques to demonstrate the emergence of improper ferroelectricity in short period superlattices of $PbTiO_3/SrTiO_3$, governed by the interface between the films. The superlattices have a very large dielectric constant that is roughly independent of temperature and a sizable polarization.

The researchers used density functional calculations to determine the structural ground state. Bulk $PbTiO_3$ is polar with a ferroelectric (FE) structural distortion, while bulk $SrTiO_3$ is nonpolar with an antiferrodistortive (AFD) distortion in which the oxygen octahedra in successive (001) layers rotate in opposite directions. When layered in a superlattice, however, the behavior changes. In superlattices of $PbTiO_3/SrTiO_3$ unit cell periodicity of 1/1, the researchers found a polar ground state in which FE and AFD distortions coexist. The energy profile as a function of polarization reveals a term in the Landau expansion of the free energy that is linear in polarization, indicative of improper ferroelectricity. In superlattices with larger periodicity the improper ferroelectricity gives way to regular ferroelectricity because the FE and AFD modes only coexist at the interface, with the AFD distortions disappearing rapidly in the bulk-like segments.

Bousquet and co-workers confirmed this behavior experimentally. They grew $PbTiO_3/SrTiO_3$ superlattices of 9/3 and 2/3 periodicities by off-axis magnetron sputtering on (001) $SrTiO_3$ substrates and measured structural distortion, dielectric properties, and polarization. They found that the polarization, octahedral tilting, and tetragonality of the superlattices all scale with temperature in the manner of a regular ferroelectric for the 9/3 samples but scale like an improper ferroelectric, as described by Landau theory, in the 2/3 superlattices. The dielectric susceptibility follows a Curie-Weiss law for the 9/3 sample in the typical manner for a ferroelectric, but remains essentially constant at all temperatures for the 2/3 sample, with a small step at the transition temperature of 500 K. The researchers conclude that improper ferroelectricity is evident in the 2/3 superlattices and, with a polarization of 11 $\mu C\ cm^{-2}$ and a dielectric constant of ~600 at room temperature, this is an appealing material for technological applications. The researchers said that the coupling of instabilities at the interfaces in artificially layered structures might be transferable to other types of oxides, and could be a particularly interesting strategy in the emerging domain of multiferroics.

Alison Hatt

Hyperfine Interactions in Graphene Calculated from First Principles

The approach of current silicon-based electronics technology toward its intrinsic limitations has motivated industrial and academic researchers to seek alternate computing paradigms. Spintronics and quantum computing, which use electron spins for operating information, are recognized as the most promising approaches to extend the limits of current charge-based electronics. However, these novel approaches require novel materials. In particular, the problem of electron spin relaxation and decoherence can be solved by using carbon materials, such as graphene and carbon nanotubes. Spin-orbit interactions that couple electrons to phonons are intrinsically weak in these materials. Another source of spin relaxation and decoherence is the interaction with nuclear spins, the so-called hyperfine interaction.