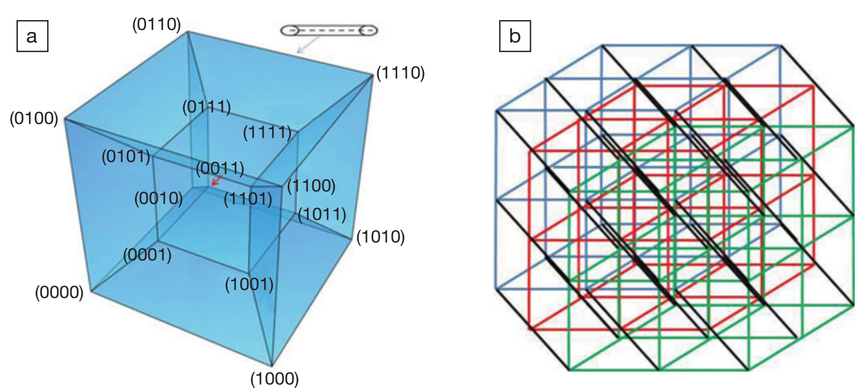
Simulation of hyperdimensional waveguide models demonstrates new approach in metamaterial design

Electromagnetic metamaterials are fabricated structures that affect electromagnetic waves; their structural features are smaller than the wavelength of light, and they can therefore be described by an effective refractive index. Applications include optical cloaking and perfect lenses that do not suffer from the diffraction limit. Optical device modeling is facilitated with the employment of "optical spaces," that is, coordinate systems associated with a refractive index. In transformation optics (TO)—a recent development in optical device design—equations describe how light can be directed in a manner analogous to gravity distorting space, as described in the Theory of General Relativity. Although metamaterials development generally involves the continuous control of the local dielectric permittivity and magnetic permeability, A.I. Smolyaninov and I.I. Smolyaninov of the University of Maryland recently demonstrated the power of a lattice-based approach, where networks of metamaterial waveguides control electromagnetic signal propagation within a given three-dimensional volume.

In the July 1 issue of *Optics Letters* (DOI: 10.1364/OL.36.002420; p. 2420), Smolyaninov and Smolyaninov presented metamaterials lattice models of four-dimensional hypercubes, that is, optical hyperspace, that cannot be simulated using conventional TO. The researchers used as an example the simplest model of a four-dimensional lattice projected onto three dimensions (see figure). Eight cubic faces act as boundaries of the neighboring hypercubic cells (analogous to square faces in three-dimensional cubes). All edge lines represent thin, single-mode, coaxial waveguides with the same impedance and optical length, attached at the vertices with beam splitters. The elementary unit is filled with metal, so that the waveguides can only communicate at the vertices. Electromagnetic waves therefore propagate in the lattice by traveling from vertex to vertex.



(a) A perspective projection of an elementary four-dimensional hypercube with the vertices labeled with their (x,y,z,w) coordinates. (b) A perspective projection of a 2×2×2×2 region of the hypercubic lattice, where three 2×2×2 elements of the cubic lattice (shown in blue, red, and green) are shifted along the projected "fourth orthogonal direction" (shown in black). Reproduced with permission from *Opt. Lett*. **36**(13)(2011), DOI: 10.1364/OL.36.002420; p. 2420. © 2011 Optical Society of America.

The researchers performed electromagnetic simulations for 2×2×2×2 and 3×3×3×3 hypercubic lattices of waveguides using a commercial software package that iteratively solves Maxwell's equations and generates a mesh for the physical model with the finite element method. Placing a Hertzian dipole source at the center of each lattice, simulations were run at 0.5 THz, and field intensity (I) was measured at each lattice point. The researchers showed that I is a linear function of R^{-3} (where R is the four-dimensional distance from the dipole source), as expected for a four-dimensional system. The researchers also simulated a lattice model for the five-dimensional Kaluza-Klein model that unifies gravitation and electromagnetism, with results in good agreement with theory.

The researchers said that while "studying fundamental linear and nonlinear optics in the emulated '4D space' may be quite an interesting fundamental exercise," their work demonstrates that "the metamaterial lattice-based approach to 'optical space' design may supplement the more common approach of continuous engineering of dielectric permittivity and magnetic permeability tensors."

Steven Trohalaki

Bio Focus

Freeze-dried nanoparticles treat brain cancer

Researchers J.J. Green, S.Y. Tzeng, H. Guerrero-Cázares, and their colleagues at the Johns Hopkins University School of Medicine have developed a technique that delivers gene therapy into human brain cancer cells using polymer-DNA nanoparticles that can be freeze-dried and stored for up to three months prior to use.

The shelf-stable nanoparticles may obviate the need for virus-mediated gene therapy, which is associated with a number of safety concerns. The report appears in the August issue of *Biomaterials* (DOI:10.1016/j.biomaterials.2011.04.016; p. 5402).

"Most nonviral gene therapy methods have very low efficacy," said Green, an assistant professor of biomedical engineering at Johns Hopkins. "Nanoparticle-based gene therapy has the potential to be both safer and more effective than conventional chemical therapies for the

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