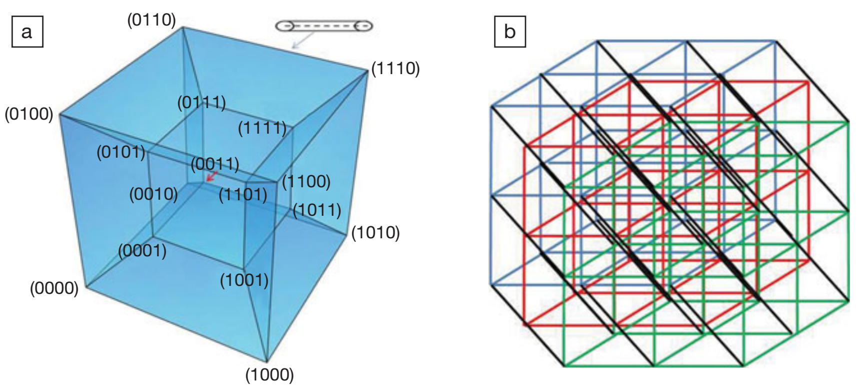
Simulation of hyperdimensional waveguide models demonstrates new approach in metamaterial design

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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treatment of cancer."

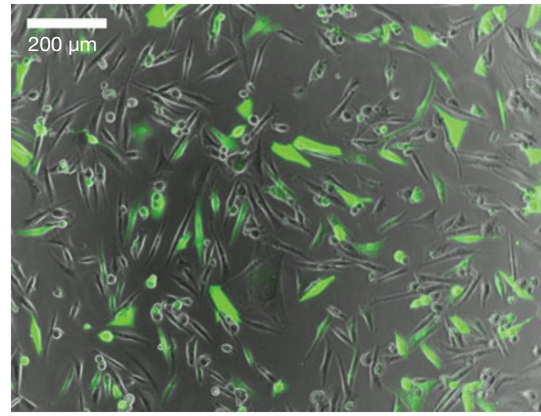
To develop the nanoparticles, Green's team prepared a library of cationic poly(b-amino esters) from commercially-available small molecules. They then mixed DNA that encodes a glowing protein with each different polymer to allow the DNA to bind to the polymers and form polymer-DNA nanoparticles. Each different sample was added to human brain tumor and glioblastoma cells. After 48 hours, the team examined and counted how many cells glowed. These cells had taken up the nanoparticles and synthesized the fluorescent protein encoded by the introduced DNA.

The team rated success by counting how many cells survived, and what percentage of those glowed.

Of the many combinations tested, the researchers found that one particular formulation of polymer nanoparticles were particularly successful in entering both glioblastoma and brain tumor stem cells. These nanoparticles were then freeze-dried and stored at different temperatures (freezer, refrigerator, and room temperature) for between one and three months. Their ability to be taken up by the cells was then re-tested. According to Green, after six months in storage, the effectiveness dropped by about half, but there was virtually no change in effectiveness after three months of storage at room temperature.

Furthermore, the team found that certain nanoparticles had a particular affinity for brain tumor cells over healthy brain cells.

"I could imagine particles based on this technology being used in conjunction with, and even instead of brain surgery," said A. Quiñones-Hinojos, an associate professor of neurosurgery and oncology at Johns Hopkins.



Brain cancer cells produce a green fluorescent protein. DNA encoded to produce the protein was delivered to the cancer cells by freeze-dried polymer-DNA nanoparticles. *Credit*: Stephany Tzeng.

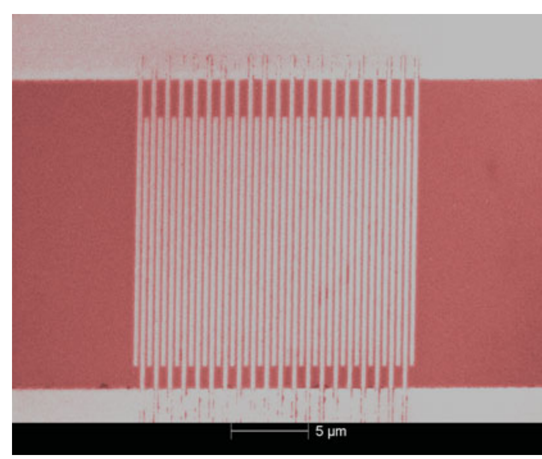
Nano Focus

Change in material boosts prospects of ultrafast single-photon detector

By swapping one superconducting material for another, B. Baek and colleagues at the National Institute of Standards and Technology (NIST) have boosted the efficiency of an ultrafast single-photon detector while also extending light sensitivity to longer wavelengths. The new tungsten-silicon alloy could make the ultrafast detectors more practical for use in quantum communications and computing systems and emerging applications such as remote sensing.

The detector, made of superconducting nanowires, is one of several sensor designs developed or used at NIST to register individual photons. The original, uncoated nanowire detector uses wires made of niobium nitride and has a detection or quantum efficiency of less than 10% when coupled to a fiber. As reported in the June 21 online edition of *Applied Physics Letters* (DOI:10.1063/1.3600793), the tungsten-silicon alloy version has an efficiency of 19–40% over a broad wavelength range of 1280–1650 nm, including bands used in telecommunications. The limitations are due mainly to imperfect photon absorption, suggesting that, with further design improvements, detector efficiency could approach 100% reliably, the researchers said.

Niobium nitride is difficult to make into nanowires that are narrow, long, and sensitive enough to work well. The researchers selected the tungsten-silicon alloy mainly because it has higher energy sensitivity, resulting in more reliable signals. A photon breaks more electron pairs in the tungsten-silicon alloy than in niobium nitride. The tungsten alloy also has a more uniform and less granular internal structure, making the nanowires more reliably sensitive throughout. As a result of the higher energy sensitivity, tungsten-silicon nanowires can have larger dimensions (150 nm wide versus 100 nm or less for niobium nitride), which enlarges the detectors' functional areas to more easily capture all photons.



Colorized micrograph of an ultrafast single-photon detector made of superconducting nanowires. Electron beam lithography is used to pattern the nanowires (colorized vertical lines) on a thin film of tungsten-silicon alloy, which produces more reliable signals than the niobium nitride material used previously. *Credit*: Baek/NIST.

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