Plasmonic Metamaterials for Optical Applications

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Abstract

Metamaterials are artificial materials whose electromagnetic response can be designed with unprecedented flexibility. Because metamaterials can support a wide range of values for their effective constitutive parameters, they have been used to demonstrate new properties difficult or impossible to achieve with conventional materials, such as negative refractive index. Moreover, the ability to structure the constitutive response point-by-point throughout a volume has led to a new class of gradient index (GRIN) optical devices: Transformation optical (TO) media. TO media represent an expansion of GRIN media, requiring precisely controlled and independent gradients in possibly several of the constitutive tensors. Metamaterials provide a route to the actual realization of TO media, which would otherwise be unfeasible to implement. While challenging to construct, metamaterial-based TO devices exhibit unique and often exotic scattering behavior.

To date, most metamaterials are fabricated from conducting inclusions—subwavelength circuits with identifiable regions of inductive and capacitive electrical contributions. The reason that conductors are used is that metals are strong scatterers of radiation and can be conveniently employed to achieve large electric response, with effective polarizabilities that can also be negative. Moreover, conductors can be fashioned to exhibit large, resonant, artificial magnetic response, even in the absence of inherently magnetic (spin based) materials. Thus, nearly any electromagnetic response can be obtained through structuring of conducting materials.

As metamaterials move towards infrared and visible wavelengths, the challenges—and opportunities—change, since the response of conductors changes drastically at frequencies above a few terahertz. At visible wavelengths, metals no longer resemble perfect conductors, but more resemble lossy and dispersive dielectrics. Nanostructured inclusions, of the sort needed for artificial media, have dimensions significantly smaller than the skin depth of the metal; thus, optical fields penetrate through the entire inclusion. Offsetting the large losses in metals at optical wavelengths is the potential for surface plasmons to be excited in the metal, which provides a route to recovering much of the substantial scattering response that makes metals attractive for metamaterials at low frequencies. In fact, the electronic response of metals is far more complex at optical wavelengths, with the potential for quantum and nonlinear optical effects to be manifest in the scattered light.

While optical metamaterials remain a challenge, the prospects for interesting and useful artificial materials built on conducting inclusions are strong. Leveraging the electronic response of conductors at optical wavelengths can lead to entirely new classes of metamaterials that may ultimately be used to construct competitive optical devices.

Short Biography, David R. Smith

Dr. David R. Smith is currently the William Bevan Professor of Electrical and Computer Engineering Department at Duke University and serves as Director for the Center for Metamaterial and Integrated Plasmonics. He holds a secondary faculty appointment in the Physics Department at Duke University and a Visiting Professor of Physics at Imperial College, London. Dr. Smith received his Ph.D. in 1994 in Physics from the University of California, San Diego (UCSD). Dr. Smith's research interests include the theory, simulation and characterization of unique electromagnetic structures, including photonic crystals, metamaterials and plasmonic nanostructures. Smith and his colleagues demonstrated the first left-handed (or negative index) metamaterial at microwave frequencies in 2000, and also demonstrated a metamaterial "invisibility cloak" in 2006. In 2005, Dr. Smith was part of a five member team that received the Descartes Research Prize, awarded by the European Union, for their contributions to metamaterials and other novel electromagnetic materials. In 2006, Dr. Smith was selected as one of the "Scientific American 50." In 2009, Dr. Smith was named a "Citation Laureate" by Thomson-Reuters ISI Web of Knowledge, for having among the most number of highly cited papers in the field of Physics over the past decade.