The shape of things, illuminated: Metamaterials, surface topology and light-matter interactions

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(Phys.org) -- Finding new connections between different disciplines leads to new – and sometimes useful – ideas. That's exactly what happened when scientists in the Department of Physics, Queens College, City University of New York (CUNY), in collaboration with City College of CUNY, Purdue University and University of Alberta, leveraged mathematical topology to create an artificially nanostructured anisotropic (exhibiting properties with different values when measured along axes in different directions) metamaterial that can be switched from a non-conductive dielectric state to a medium that behaves like metal in one direction and like a dielectric another. The metamaterial's optical properties was mapped onto a topological transformation of an ellipsoidal surface into an hyperboloid – and transitioning from one to the other dramatically increases the photon density, resulting in dramatic increase in the light intensity inside the material. The researchers state that by allowing topologically-based manipulation of light-matter interactions, these types of metamaterials could lead to a wide range of photonic applications in solar cells, light emitting diodes, displays, and quantum computing and communications.

Associate Professor Vinod M. Menon recalls that the project started out with theoretical predication and computational modeling. "Our subsequent experimental work was based on computational modeling of the structures and the anticipated effects," he relates to *Phys.org*. "At that point, the main challenge in describing the ellipsoid-to-hyperboloid transition was the design of the structure that will show the transition in the relevant spectral range. Relatedly," Menon continues, "showing that this topological transition manifests itself in increased rates of spontaneous emission of emitters positioned near the metamaterial required the identification of a suitable light emitting material. In our case, that material was quantum dots." This critical choice of emissive material allowed the researchers to study the enhancement in spontaneous emission in both the elliptical and hyperbolic ranges.

Menon is equally to-the-point when describing the key insights, innovations and techniques the team used to address the above challenges. "In addition to the right photon emission source and a suitable material system for metamaterial fabrication, it was necessary to come up with an appropriate control sample to isolate the effect that we were looking for."

Menon adds that the team's next steps are to reduce optical losses, improve the quality of silver films, and look into new material systems that will show similar effects. "Silver is the metallic component in the metamaterial that allows us to realize the anisotropy. Theoretically one could use any metal or even doped oxides and semiconductors. In our case silver was used because of the lower optical losses in the visible wavelength range, but the roughness of silver layers used in the present structure is an issue. This will have to be addressed in the next round of experiments," Menon cautions. "Additionally, the optical losses in the material need to be alleviated. Finally, approaches to enhance the transmission properties need to be addressed for light emitting applications."

According to Menon, the team's findings impact the development of new routes to manipulating light-matter interactions through using metamaterials and controlling the topology of the iso-frequency surface – that is, one having a constant frequency. "The structure that we demonstrated shows a large increase in the light intensity over a wide spectral range," he explains. "Such structures can help in enhanced light harvesting, which could result in more efficient solar cells. One could also envision using these to develop single photon sources necessary for quantum communication protocols and quantum computers. Finally, through engineering of transmission properties of these systems, and by combining them with light emitters, one may also realize super bright LEDs that would be useful for display applications."

Venturing further afield, Menon descries more exotic possibilities. "Ideas of light manipulation used here could be extended for control of thermal properties as well. More esoteric are the proposed ideas of realizing a table top optical black hole and manipulation of space-time curvature – and in fact, these proposals have been recently made[1,2] by one of my co-authors, Evgenii Narimanov, and his collaborators."

More information: Topological Transitions in Metamaterials, *Science* 13 April 2012: Vol. 336 no. 6078 pp. 205-209, doi: 10.1126/science.1219171

Related:

[1]*Optical black hole: Broadband omnidirectional light absorber*, Applied Physics Letters 95, 041106 (2009), doi: 10.1063/1.3184594

[2]*Metric Signature Transitions in Optical Metamaterials*, Physics Review Letters 105, 067402 (2010), doi: 10.1103/PhysRevLett.105.067402