Extraordinary light enhancement technique proposed for nanophotonic devices

November 3 2010, By Lisa Zyga

(PhysOrg.com) -- In a new study, scientists have shown that simply tailoring the nanoscale geometrical parameters of dielectric structures can result in an increase in the light intensity to unprecedented levels. Theoretically, they calculate that the light intensity could be increased to up to 100,000 times that of the incident intensity over large volumes. This large light enhancement could lead to new developments in all-optical switching and biosensing applications.

The researchers, Rebecca Sainidou from the Spanish National Research Council (CSIC), Jan Renger from the Institute of Photonic Sciences (ICFO), and coauthors from various institutes in Spain, have published their study on the new method for dielectric light enhancement in a recent issue of Nano Letters.

As the scientists explain, one of the biggest problems for nanophotonic devices made of metal is that the metals in these devices absorb some light, limiting the overall light intensity. Here, the researchers proposed using dielectric rather than metallic structures, and described three different arrangements for achieving a large light enhancement: dielectric waveguides, dielectric particle arrays, and a hybrid of these two structures. In each of the three proposed arrangements, the researchers show that, by suppressing absorption losses, light energy can be piled up in resonant cavities to create extremely intense optical fields.

"Metallic structures can produce a similar level of enhancement via localized plasmon excitation, but only over limited volumes extended a few nanometers in diameter," coauthor Javier García de Abajo from CSIC told *PhysOrg.com*. "In contrast, our work involves a huge enhancement over large volumes, thus making optimum use of the supplied light energy for extended biosensing applications and nonlinear optics. In metallic structures, absorption can be a problem because of potential material damage and because it reduces the available optical energy in the region of enhancement. This type of problem is absent in our dielectric structures.

"One could obtain large light intensity enhancement just by simply accumulating it from may sources (e.g., by placing the ends of many optical fibers near a common point in space, or by collecting light coming from many large-scale mirrors). But this sounds like wasting a lot of optical energy just to have an enhancement effect in a small region of space. However, this is essentially what metallic structures do to concentrate light in so-called optical hot-spots using plasmons. In contrast, our structures do not concentrate the light in tiny spaces: they amplify it over large volumes, and this has important applications. This amplification is done through the use of evanescent and amplifying optical waves, which do not transport energy, but can accumulate it."

Although theoretically there is no upper limit to the intensity enhancement that these structures can achieve, fabrication imperfections limit the enhancement to about 100,000 times that of the incident light intensity. In a proof-of-principle demonstration of the dielectric waveguide arrangement, the researchers showed a light intensity enhancement of a factor of 100. The researchers predict that this moderate enhancement should be easily improved by reducing the interface roughness through more careful fabrication, and are currently working on experiments to demonstrate a larger light enhancement.

As the researchers explain, part of the "holy grail" of designing nanodevices for optical applications is the ability to control light enhancement, as well as light confinement and subwavelength light guiding. By demonstrating the possibility of achieving an extremely large light intensity in large volumes, the researchers have opened up new possibilities in many nanophotonics applications. For example, nanophotonics components have already been used to produce artificial magnetism, negative refraction, cloaking, and for biosensing.

"Certain molecules are produced in our bodies preferentially when we suffer some illnesses (e.g., tumors, infections, etc.)," García de Abajo said. "The detection of these molecules can sometimes be a difficult task, because they are seldom encountered in minute concentrations. A practical way of detecting these molecules, and thus unveiling the potential illness to which they are associated, is by illuminating them and seeing how they scatter or absorb light (e.g., how light of different colors is absorbed by these molecules or how they change the color of the light). Therefore, it is important to amplify the optical signal that these molecules produce, so that we can have access to them even if they are in very low concentrations. Our structures do precisely that: they amplify the light over large volumes, so that if the molecules to be detected are placed inside those volumes, they will more easily produce the noted optical signal (absorption, color change, etc.). This is thus a practical way of detecting diseases such as cancer.

"In a different direction, light amplification is useful to produce a nonlinear response to the external light, and this can be directly applied to process information encoded as optical signals. This is an ambitious goal that is needed to fabricate optical computers. Such computers are still far from reachable, but they are expected to produce a tremendous increase in the speed of computation and communication. Our structures provide an innovative way of using light in devices for information processing."

More information: Rebecca Sainidou, et al. "Extraordinary All-Dielectric Light Enhancement over Large Volumes." *Nano Letters*, ASAP. DOI: 10.1021/nl102270p