Photonic Crystal Microlens Achieves Ultrashort Focal Distance

Recent theoretical investigations of negative refractive index metamaterials opened new fields of possible optoelectronic applications. Now the group of B.D.F. Casse, W.T. Lu, Y.J. Huang, and S. Sridhar from Northeastern University has demonstrated an ultra-short focal length negative index lens at telecommunication frequencies. This could lead to immediate micro- and nano-optics applications, such as miniaturization of charge-coupled devices (CCDs) used in digital cameras and sensors.

The researchers described in the August 7 issue of *Applied Physics Letters* (DOI:10.1063/1.2968873; 053111) how, using dispersion engineering principles, they designed and fabricated a two-dimensional (2D) photonic crystal microlens with a negative refractive index of -0.7, and ultrashort focal distance of only 12 µm. The lens also possess a numerical aperture close to unity, and a near diffraction-limited spot size of 1.05 µm in the infrared range (λ = 1.5 µm).

The photonic crystal array consisted of a 2D square lattice of air holes (each hole diameter was 295 nm and the lattice spacing was 480 nm) in an InP/InGaAsP rectangular wafer with a semicircular cutting (radius 20 µm), thus creating a planoconcave microlens. The use of a pure dielectric system reduced to a minimum the intrinsic material losses.

Light originating from a continuous wave tunable semiconductor laser (λ = 1550–1580 nm) was propagated through a waveguide into the microlens, and near-field scanning optical microscopy measurements revealed the focusing of the plane wave on the optical axis of the microlens inside the air cavity. The experimental results, both with respect to the focal distance (12 µm) and to the spot size at full width at half-maximum (1.05 µm, or 0.68 λ) for the given frequency range, were in agreement with results of 2D finite-difference time-domain simulations.

The use of a photonic crystal material in a planoconcave configuration with a negative index of refraction produced focusing of the incident laser light in contrast to materials with a positive index of refraction, which require convex lens geometry to produce a real focus. The researchers said that the photonic-crystal–based planoconcave lenses "can be superior to plano-convex microlenses as they possess a larger numerical aperture (close to unity), diffraction-limited spot size, display less spherical aberrations and have shorter focal lengths." The low-loss medium will allow for the device to be scaled to work in any frequency region through appropriate adjustment of the photonic crystal design.

EUGEN PANAITESCU

Growth of Metallic-Insulator Bilayers Yields Interfacial Region Exhibiting High-T_c Superconductivity

One major goal on the path toward making useful superconducting devices has been engineering materials that act as superconductors at the nanoscale. Such nanoscale superconductors would be useful in devices such as superconductive transistors and eventually in ultrafast, power-saving electronics. Now I. Božović of Brookhaven National Laboratory, L.F. Kourkoutis of Cornell University, L.A. Giannuzzi of the FEI Company, and their colleagues have produced two-layer thin films where neither layer is superconducting on its own, but which exhibit a nanometer-thick region of superconductivity at their interface. Furthermore, the researchers demonstrated the ability to elevate the temperature of superconductivity at this interface to temperatures exceeding 50 K, a relatively high temperature deemed more practical for real-world devices.

As reported in the October 9 issue of *Nature* (DOI: 10.1038/nature07293; p. 782), the researchers used La_2CuO_4 as an insulator and $La_{1.55}Sr_{0.45}CuO_4$ as the metal in the bilayer system, neither of which is superconducting in isolation. However, within a 2–3 nm region of the interface, T_c is either ~15 K or ~30 K, depending on the layering sequence; and exceeded 50 K when a bilayer is exposed to ozone.

"This work provides definitive proof of our ability to produce robust superconductivity at the interface of two layers confined within an extremely thin, 1–2-nm-thick layer near the physical boundary between the two materials," said physicist Božović, who leads the Brookhaven thin film research team. "It opens vistas for further progress, including using these techniques to significantly enhance superconducting properties in other known or new superconductors."

Božović's team had reported in 2002 the observation that the critical temperature—the temperature below which the sample superconducts—could be enhanced by as much as 25% in bilayers of two dissimilar copper-based materials. However, at that time, the scientists had no understanding of what caused this enhancement and in which part of the sample the superconductivity was located.

To investigate this further, they synthesized more than 200 single-phase, bilayer and trilayer films with insulating, metallic, and superconducting blocks in all possible combinations and of varying layer thickness. The films were grown in a unique atomic-layer-by-layer molecular beam epitaxy system designed and built by Božović and co-workers to enable the synthesis of atomically smooth films as well as multilayers with perfect interfaces. "The greatest technical challenge was to prove convincingly that the superconducting effect does not come from simple mixing of the two materials and formation of a third, chemically and physically distinct layer between the two constituent layers," Božović said. Collaborators at Cornell University ruled out this possibility using atomic-resolution transmission electron microscopy to identify the samples' constituent chemical elements, proving that the layers indeed remained distinct.

"It is too early to tell what applications this research might yield," Božović said, "but already at this stage we can speculate that this brings us one big step closer to fabrication of useful three-terminal superconducting devices, such as a superconductive field-effect transistor." In such a device, one would be able to switch the transistor from the superconducting to the resistive state by means of an external electric field, controlled by applying a voltage and using the third (gate) electrode. Circuits built from such devices would be much faster and use less power than the current ones based on semiconductors.