alternating layers of epitaxially grown materials with different indices of refraction, such as AlAs and GaAs, which are then etched to form the pillar. The DBR mirrors provide vertical confinement, and horizontal confinement is provided by total internal reflection inside the pillar owing to its large refractive index. Such devices have already demonstrated the main features of a useful single-photon source[2–4], including suppression of the multiphoton probability far below the Poisson level, enhanced photon extraction efficiency, and high spectral purity of the emitted photons. However, the performance, especially the efficiency, is still not adequate for many applications. It has not been entirely clear whether this is due to problems in the microresonator fabrication, the quantum dot itself, or both.

Strauf *et al.*[1] report important improvements on this micropillar structure (Fig. 1b) leading to much higher efficiencies. Their design uses an oxide aperture rather than an etched surface to confine light horizontally. Their devices are mechanically stronger than the conventional design and better protected from environmental degradation. This also enabled the incorporation of electrodes for tuning the quantum dot's transition frequency relative to the resonator modes. This tuning occurs through resistive heating when an electrical current is applied to the electrodes. Finally, they have chosen to work with a charged quantum-dot state instead of a neutral state to avoid 'dark exciton' spin states where radiative recombination is forbidden. The calculated efficiency, 0.38 photons per pulse collected by the first lens at a repetition rate of 82 MHz, is a new record, in fact several times higher than in previous demonstrations.

How relevant is this improvement for potential applications? The application of single-photon sources to quantum key distribution has recently come into question following the advent of decoy-state protocols[5], which provide an alternative means of overcoming the 'photon-splitting' eavesdropping attack — previously thought to be a limitation to the use of 'classical' light sources. Nevertheless, to extend the communication distance through a lossy channel, repeater devices will be needed, and repeaters based on solid-state single-photon emitters could be the answer[6]. The use of quantum dots containing single electrons, as demonstrated here, is crucial for such a scheme, and it has become increasingly apparent that a single-photon device is much more useful if it contains a long-lived matter qubit (that is, an electron spin). Looking further into the future, in such devices the microresonator could provide a means of efficient, reversible transfer of quantum states between a photon and a matter qubit[7], with suitable manipulation of the quantum dot's excited-state structure[8]. A critical requirement is to find a way to fabricate multiple devices operating at exactly the same wavelength. Only then will distributed quantum networks, perhaps the most exciting long-term application for single-photon sources, become possible.

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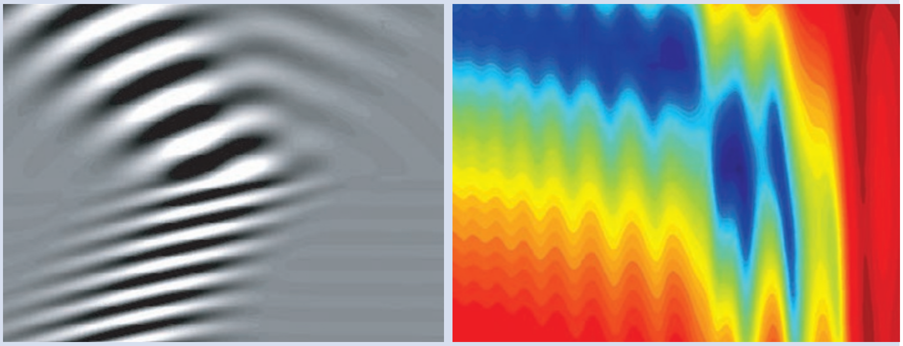
METAMATERIALS

Semiconductor surprise

The ability to integrate metamaterials, which exhibit useful and unique optical properties, with semiconductor optoelectronics could be about to become easier. Researchers from Princeton University, Oregon State University and Alcatel-Lucent have now fabricated an all-semiconductor metamaterial that exhibits negative refraction in the long-wavelength region of the infrared (*Nature Mater.* **6,** 946–950; 2007).

Although metamaterials with similar properties in the visible and infrared have been demonstrated previously, they rely on metallic nanostructures and often incur a large optical loss. They are also relatively complex to manufacture and potentially difficult to directly integrate with semiconductor devices.

The new material is composed of 80-nm-thick interleaved layers of heavily doped InGaAs and AlInAs, which give it a strongly anisotropic dielectric function. The layers are grown by molecular-beam epitaxy on lattice-matched InP substrates.



According to the researchers, the transition wavelength from a positive to a negative refractive index is determined by the electron density of the doped InGaAs layers. By controlling the level of doping, the team successfully fabricated four samples with transition wavelengths of 8.8, 9.1, 10.1 and 13.1 μm. In all cases, the spectral bandwidth of the region of negative index was around 27%–30% wide, with the short-wavelength limit marked by a discontinuity of the Brewster angle, and the long-wavelength limit marked by a large increase in reflectivity.

To confirm the negative-index properties of the material, the team performed a series of reflection measurements (see right image, for a map of reflection measurements at different incidence angles and wavelengths, where regions of negative index are shown in blue). The team also conducted theoretical simulations of the beam propagation across an air–metamaterial boundary (left image) and geometric beam-blocking experiments that indicate the angle of refraction.

The researchers are confident that the material will prove to be useful for waveguiding and imaging applications.

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