however, concern passive devices and near-field effects.

The latest work from Yu *et al.* offers an impressive demonstration of the versatility and usefulness of plasmonics applied to semiconductor lasers. Not only can it greatly improve the beam divergence of the lasers, but it also demonstrates how surface plasmons not only affect local fields, but radiate into the far field.

Yu and co-workers apply a special dielectric–metal structure directly to the emitting facet and substrate of their QCL (Fig. 1b). This structure consists of an electrically insulating dielectric layer (which avoids electrically shorting the laser) covered by an optically thick gold layer (that is, one that is too thick for light to penetrate), which is patterned in two ways. First, a small slit about the size of the active core at the laser facet is etched into the gold at the height and location of the laser active region. Second, a horizontal grating covers the entire front facet and substrate. There are a number of equivalent workable geometries that can be adopted, as long as they include a grating, the insulating dielectric and the metal film with a slit.

The mechanism resulting from the structure is rather straightforward. First, the laser light travels along the laser waveguide to the subwavelength slit, where it is efficiently coupled into surface plasmons of the gold film (Fig. 1b). The plasmons can travel several hundreds of micrometres along the gold film over the periodic grating. When they hit the grating they are scattered and efficiently and coherently coupled into a tightly confined mode that radiates into the far-field. The result is a much more highly focused beam of laser light.

Although the idea sounds relatively straightforward, achieving this in practice is not trivial by any means. All components must be optimized together to enable the structure to function in just the right way: the propagation constants of the laser waveguide mode that is emitted, the size and location of the slit in the gold, the thickness of the dielectric and gold layers, and the orientation, periodicity, height, depth and symmetry of the grating. The researchers achieve this by meticulous modelling of the structure, and their excellent agreement between theory and experiment implies that the process can be quickly adapted to other QCLs, and presumably a much broader range of semiconductor laser diodes.

The improvement in far-field directionality of a QCL beam is impressive. By careful choice of the grating orientation in the direction normal to the QCL waveguide layers — usually the direction in which the beam divergence is more difficult to control — the width of the central lobe of the far-field beam is reduced by a factor of approximately 25, from about 60° to 2.4°. Importantly, the total output power of the laser remains about the same despite the slit–grating structure that covers the laser facet.

These initial outstanding results immediately lead to follow-on questions and goals. How can the beam be tightened and shaped, not only in one axis, but in both axes? Can the ultimate goal of a narrow, circular beam be achieved and, if so, what type of two-dimensional patterning of the laser facet will be needed to do this? Quantum-cascade lasers with their larger size and longer wavelength lend themselves particularly well to work with surface plasmons. But what will the results be like for the smaller and shorter-wavelength telecom lasers? In the longer-term, Yu and colleagues will need to show that facet patterning can become a viable, commercial technique if their approach is to take off in earnest.

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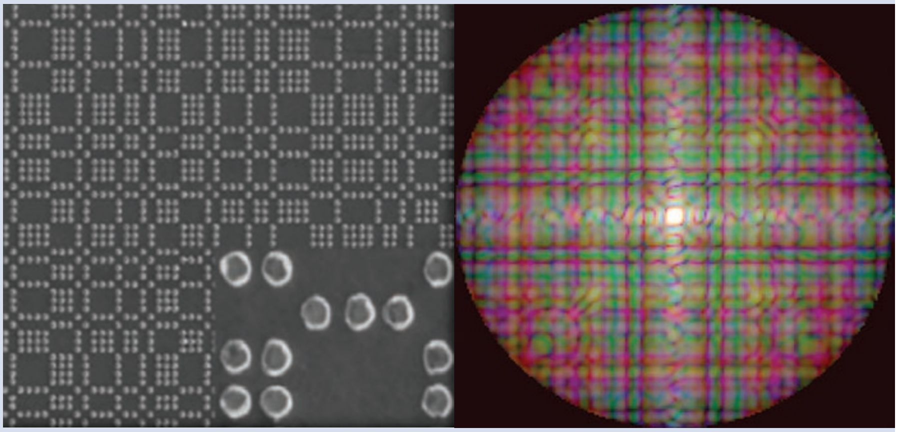
NANOSTRUCTURES

Aperiodic arrays



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Two-dimensional arrays of gold nanoparticles that are arranged according to aperiodic mathematical sequences, such as those defined by Fibonacci, Thue–Morse and Rudin–Shapiro rules, can give rise to broad plasmonic resonances that span the entire visible spectrum. That is the recent finding of researchers from Boston University in the USA (*Nano Lett.* doi: 10.1021/nl8013692; 2008). Ashwin Gopinath and colleagues fabricated their nanoparticle arrays on quartz substrates by using electron-beam lithography. The resulting nanoparticles had a diameter of 200 nm, a height of 30 nm and a minimum separation that spanned from 50 nm to 500 nm. Dark-field scattering spectroscopy of the samples revealed that for small particle separations (around 200 nm or less) the aperiodic gold nanopatterns have photonic-plasmonic resonances that are significantly broader than a periodic sample, with scattering spectra that extend from approximately 400 nm to 1,000 nm. Electrodynamic calculations based on Mie theory show good agreement with the experimental results. The team is of the opinion that far-field diffractive coupling is responsible for the generation of the characteristic scattering modes. Gopinath *et al.* say that the structures could prove useful for creating a range of broadband plasmonic devices in the future, including improved substrates for surface-enhanced Raman scattering (SERS), biosensors or structures for enhancing the light extraction from LEDs.

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