Steering the Beam of a Microlaser

A photonic-crystal structure allows for on-chip control of the laser beam direction

Many applications of semiconductor lasers would benefit from an on-chip control of the beam direction – instead of using complicated mechanical systems and mirrors to deflect the beam. Researchers at Kyoto University have taken a big step towards this goal. They fabricated a composite photonic-crystal structure with artificial band edges that made it possible to continuously change the beam direction of an adjacent semiconductor laser.

Susumu Noda and his colleagues made a two-dimensional photonic crystal with triangular holes that were arranged in an unusual way. Some holes formed a square lattice whereas others were arranged in a rectangular lattice, which had one lattice constant fixed and the other slowly changing along one axis of the photonic crystal. This composite structure gave rise to artificial band edges in the band structure of the photonic crystal. Since the crystal was slowly modulated along one axis, the artificial band edges had a position-dependent wave vector δk different from 0.

At each band edge the group velocity of light vanished and the crystal supported a cavity mode. A planar semiconductor laser, which was beneath the photonic crystal, could couple resonantly to one of these cavity modes if the in-plane wave vector of a laser mode and the wave vector δk of a cavity mode matched. In this case the photonic crystal emitted laser radiation with a nonzero in-plane wave vector. The emission direction was shifted by an angle arcsin($\delta k/k_0$) from the normal direction, where k_0 was the wave number of the emitted radiation.

Since the wave vector of the band edges changed continuously along the photonic crystal, the researchers only had to excite the active layer of the laser at the right position to get emission in the desired direction. To achieve this they gave the semiconductor laser a p-electrode, which consisted of 30-40 parallel segments, each 17×50 µm² large and separated by a 3 µm wide gap, sitting on top of the photonic crystal. The bottom n-electrode consisted of a single element. The typical pump current required for lasing was 100 mA.

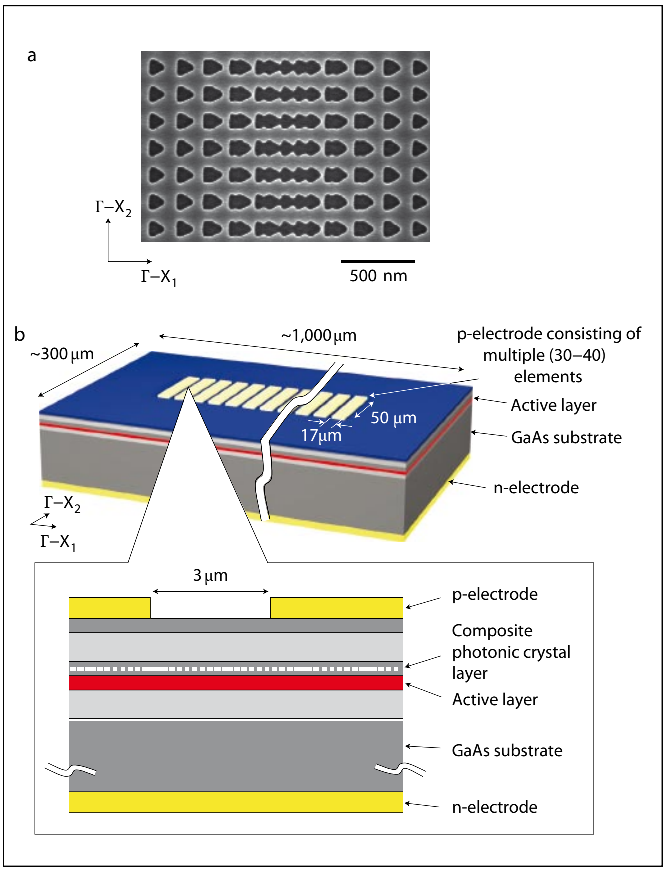

FIGURE: **Composite photonic crystal and device structure. (a) Scanning microscope image of a portion of the fabricated composite photonic crystal. (b) Device structure containing the photonic crystal.** (Courtesy of Yoshitaka Kurosaka et al., Nature Photonics)

When only two neighboring elements of the p-electrode were used to excite the laser, light was emitted along the k-vector that fit to the δk of the "local" band edge. By selecting the element pairs that excited the laser, the emission direction could be changed over a range of 30° in steps of 1°. The researchers could also change the emission direction continuously by exciting the laser with a triple of neighboring elements of the p-electrode. They let different currents flow through the electrode elements and slowly shifted the relative strengths of the currents. This continuously changed the wave vector δk of the lasing band edge and thereby smoothly varied the emission angle of the laser beam. The wavelength of the laser remained constant at 970 nm.

As the researchers point out, controlling the current injection in the laser electrodes by an integrated electronic circuit could lead to advanced control of the laser beam or even to simultaneous and multi-directional emission. They anticipate a wide-reaching effect on many applications like ultra-compact mobile-laser displays, chip-to-chip optical communication, laser-radar sensing systems and even medical laser knives.

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Further information:

- Yoshitaka Kurosaka et al.: On-chip beam-steering photonic-crystal lasers. Nature Photonics (published online: May 2nd, 2010) http://dx.doi.org/10.1038/nphoton.2010.118
- Susum Noda at Kyoto University: www.kuee.kyoto-u.ac.jp/~lab05/index_e.html
- Eiji Miyai et al.: Lasers producing tailored beams. Nature 441, 946 (2006) http://dx.doi.org/10.1038/441946a