For example, an X-ray laser with a high average power in the extreme ultraviolet region could be used to produce new techniques for high-quality nanoscale laser machining and for detecting nanoscale phase defects in extreme ultraviolet lithography masks. Moreover, the extension of the wavelength towards the water window region ($\lambda = 2.33$–4.37 nm), which is one of the main research goals of high-intensity laser facilities worldwide, may help to fill the gap in X-ray sources that exists between present XFELs operating in the keV region and laser-plasma-based X-ray lasers that generate output in the extreme ultraviolet region. Such a high-brilliance, coherent X-ray source in the water window region could extend the range of applications to biomedical and life sciences. ❐

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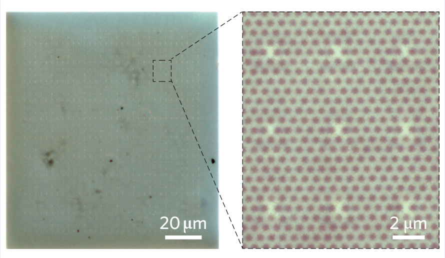
INTEGRATED PHOTONICS

10,000 tiny lasers

One of the promises of photonic crystals is the dense integration of optical components (such as waveguides and laser sources) on a chip or wafer. However, mechanical fragility has proved to be a limiting factor, especially for fragile air-bridge photonic-crystal structures. Now, Takumi Watanabe and co-workers at Yokohama National University in Japan have demonstrated 100 × 100 μm^2 samples that contain 1,089, 2,376 and 11,664 integrated photonic-crystal lasers (*Appl. Phys. Lett.* **104,** 121108; 2014).

Although photonic crystals have been around for over a decade, many demonstrations still employ pulsed pumping. Additionally, very small mode volumes (less than the cube of the wavelength) together with room-temperature, continuous-wave operation were demonstrated only in 2007, according to Watanabe.

Talking to *Nature Photonics*, Watanabe explained that one of the main reasons for the success of their present approach is the simplicity of the fabrication process, making it suitable for large-scale array integration. Another factor is the use of the air-bridge structure, which provides strong optical confinement. However, such structures are mechanically fragile and are typically unsuitable for large-scale integration. To solve this problem, the team developed resin-mediated bonding to attach a slab to a glass substrate.



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In the present study, the spacing between the lasers was 5 μm, but the team had previously demonstrated independent lasing with a 2.5 μm spacing. Noticeable coupling between neighbouring nanolasers occurs if the spacing becomes much less than about 2 μm; this reduces the Q-factor of the cavities.

The cladding beneath the slab is the adhesive (polydimethylsiloxane), resulting in lower optical confinement than for a usual single photonic-crystal laser with an air-bridge structure. This slightly increases the threshold, according to Watanabe, who notes that in sensing applications the sensitivity would decrease by approximately half relative to that of a conventional air-bridge nanolaser.

Regarding the limitation on the total number of lasers that could be fabricated, Watanabe says that it is mainly a technical limitation. For example, producing the photonic-crystal patterns by electron-beam lithography took about 10 h using one machine for the 11,664-laser array and several days for many arrays. Of course, when lithography is conducted over a long time and over large areas, the pattern accuracy is degraded. Measurement of large numbers of lasers also takes considerable time.

“We use a spectrometer with a one-dimensional InGaAs image sensor and automatic stage control, and it takes 2 h to measure 1,089 lasers,” Watanabe explained. “These problems may be resolved if we use, for example, nano-imprint lithography for the patterning, and batch pumping and measurement using high-power lasers.”

DAVID PILE