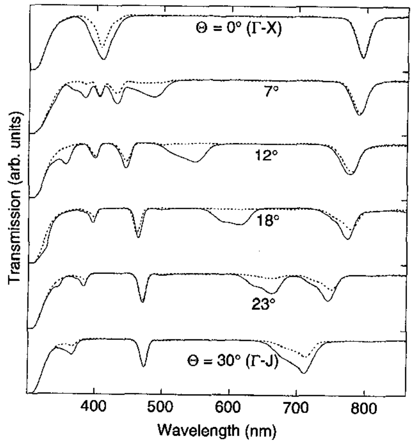

CFQ1 Fig. 3 Transmission spectra along several propagation directions, Θ, defined in Fig. 1b, for $a = 0.28$ μm. The solid (dotted) curves are as in Fig. 2.

that a polar plot of the attenuation positions seen in Fig. 3 reproduces the geometry of the Brillouin zones (depicted in Fig. 1). This has been confirmed experimentally, both in the near-infrared[2] and in the visible.[4]

Our low-index-contrast nanochannel-glass-based photonic crystals can allow the fabrication of devices, such as filters, tunable by adjusting the propagation direction and polarization. Unlike materials used in previous work, the present photonic crystals are easily scaled to very large physical dimensions, exceeding 2 inches on a side.

1. R. J. Tonucci, B. L. Justus, A. J. Campillo, C. E. Ford, Science **258,** 783 (1992).
2. A. Rosenberg, R. J. Tonucci, E. A. Bolden, Appl. Phys. Lett. **69,** 2638 (1996).
3. A. Rosenberg, R. J. Tonucci, H.-B. Lin, A. J. Campillo, Opt. Lett. **21,** 830 (1996).
4. A. Rosenberg, R. J. Tonucci, H.-B. Lin, Eric L. Shirley, Phys. Rev. B **54,** R5195 (1996).

CFQ2 1:30 pm

Lasers incorporating two-dimensional photonic crystal mirrors

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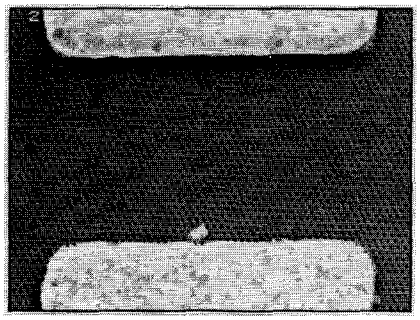
Photonic bandgap crystals are expected to be of use in defining microcavities for modifying spontaneous emission and as highly reflective mirrors. There are several reports of microfabricating one-dimensional structures.[1–3] Here, we describe the incorporation of a microfabricated two-dimensional photonic lattice in an edge-emitting semiconductor laser structure. We demonstrate laser operation in a cavity formed between a cleaved facet and a microfabricated periodic lattice.

The photonic lattice used was a two-dimensional hexagonal close-packed lattice etched vertically into the semiconductor. The lattice was designed to have a TE photonic bandgap that spectrally overlapped the gain



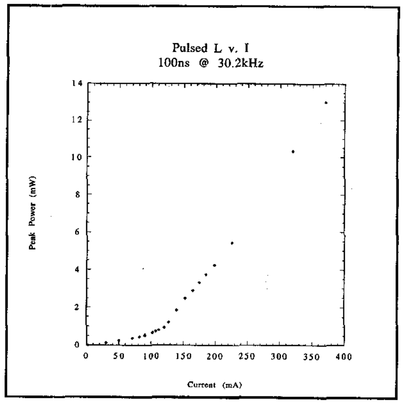
CFQ2 Fig. 1 SEM micrograph of the photonic lattice.

region of the semiconductor laser structure.[4] The lattice constant a of the structure was 212 nm, and the ratio of the hole radius to the lattice constant, r/a, was approximately 0.35. The lattice was etched through the active region and well into the bottom waveguide cladding to ensure a good overlap with the optical field.

The sample was an MBE-grown GRINSCH laser structure. The active region contained a single 10-nm GaAs quantum well. A 50-nm-thick AlAs layer surrounded by 15-nm-thick $Al_{0.3}Ga_{0.7}As$ layers was included above the p-doped cladding in the top contact layers. This layer was necessary for the fabrication of the dielectric lattice as described below.

The hexagonal lattice is first transfered into a 70 nm layer of 2% PMMA (polymethyl methacyclate) with use of a focused electron beam lithography process. Following the beam writing, a chemically assisted ion beam etch (CAIBE) is used to transfer the holes through the 20 nm GaAs cap layer and the 50 nm AlAs mask layer. This results in holes that penetrate through the AlAs layer and terminate in a GaAs buffer layer. High temperature field oxidation of the AlAs is subsequently performed at 340 °C for 12 minutes.[5] This oxidizes the AlAs around the holes and thus forms a very sturdy mask.[6] The hexagonal array of holes is then transferred to a depth of 2–3 μm into the laser structure so as to overlap the optical field. Figure 1 shows an SEM micrograph of the etched lattice. After this last CAIBE, the surface mask is gone and the Ni covered top contacts thus define a waveguide structure.

The structures lased in pulsed operation. The L-I characteristic of one of these lasers is shown in Fig. 2. The lowest threshold current measured was 110 mA from a 180-μm-long laser. There was considerable scatter in the threshold currents and in the measured external efficiencies of these devices. We believe this is a result of etch depth variations and roughness in the laser stripe and in the photonic lattice. Because of this, it is very difficult to estimate a modal mirror reflectivity for the photonic bandgap gratings. Based on the threshold current densities of the best devices, we estimate a modal reflectivity of 50% from the photonic lattice. The emission spectrum below threshold was used to do Hakke–Paoli analysis. This indicated that the photonic lattice was eight times more reflective than a dry-etched facet. The lasers operated around 800 nm, which is the transition resulting from the second quantized state in the quantum well.



CFQ2 Fig. 2 Pulsed L-I characteristic of a 180-μm-long laser.

In summary, we have demonstrated lasers incorporating a photonic lattice as an end mirror in a Fabry–Perot cavity. The microfabricated photonic lattice consisted of a two-dimensional hexagonal close-packed array of holes approximately 200 nm in diameter etched 2.5 μm deep into the sample. Considerable scatter was observed in the device threshold currents and external efficiencies.

1. J. P. Zhang, D. Y. Chu, S. L. Wu, W. G. Bi, R. C. Tiberio, R. M. Joseph, A. Tavlove, C. W. Tu, S. T. Ho, IEEE Photon. Technol. Lett. **8**(4), 491–493 (1996).
2. T. Baba, M. Hamasaki, N. Watanabe, P. Kaewplung, A. Matsutani, T. Mukaihara, F. Koyama, K. Iga, Jpn. J. Appl. Phys. **35,** pt. 1, no. 2B, 1390–1394 (1996).
3. T. F. Krauss, Richard De La Rue, Appl. Phys. Lett. **68**(12), 1613–1615 (1996).
4. J. D. Joannopoulos, R. D. Meade, J. N. Winn, *Photonic Crystals* (Princeton University Press, Princeton, NJ, 1995).
5. J. M. Dallesasse, N. Holonyak Jr., A. R. Sugg, T. A. Richard, N. El-Zein, Appl. Phys. Lett. **57**(26), 2844–2846 (1990).
6. C. C. Cheng, A. Scherer, V. Arbet-Engles, E. Yablonovitch, "Lithographic bandgap tuning of 3-D photonic crystals," to appear in J. Vacuum Sci. Technol. B.

CFQ3 1:45 pm

Light scattering in free standing semiconductor slab waveguides exhibiting 2D photonic band structure

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We have textured free-standing semiconductor slab waveguides with a 2D square lattice of through-holes. Figure 1 is an SEM micrograph of the facet cleaved through one of these structures: details of the fabrication process have been described elsewhere.[1] The objective of this work is to theoretically and experimentally characterize the manner in which the texture modifies the resonant electromagnetic excitation spectrum of the untextured slab. Since even small perturbations of this excitation