discovery, it should be possible to guide higher powers in single-mode fiber than previously.

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References

1. J.C. Knight *et al.*, "All-silica single-mode optical fiber with photonic crystal cladding," Opt. Lett. **21,** 1547 (1996); *errata* **22,** 484–485 (1997).
2. T.A. Birks *et al.*, "Endlessly single-mode photonic crystal fibre," Opt. Lett. **22,** 961 (1997).
3. J.C. Knight *et al.*, "Properties of photonic crystal fiber and the effective index model," J. Opt. Soc. Am. A **15,** 748–752 (1998).
4. J.C. Knight *et al.*, "Large mode area photonic crystal fibre," Electron. Lett. **34,** 1347–1348 (1998).

Creation of a 3-D Silicon Photonic Crystal

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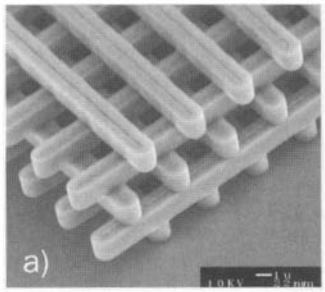
A 3-D photonic crystal is an attractive optical material for controlling and manipulating the flow of light on a semiconductor chip. High-speed tera-hertz optical switches, high efficiency μA edge-emitting-lasers, and the guiding and routing of optical signals in all three dimensions are but a few of the potential benefits of these new engineered "materials."

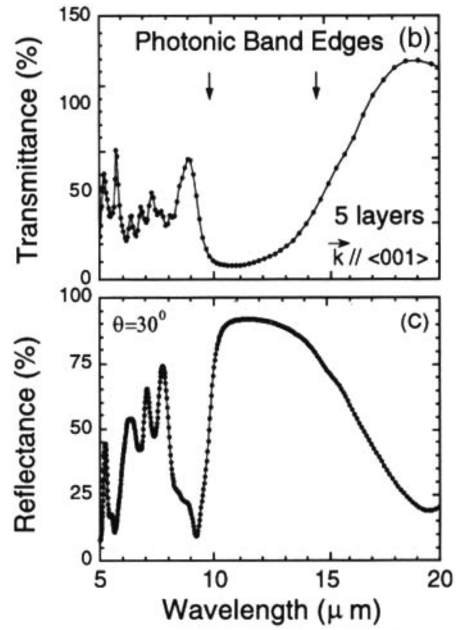
Although the original concept of 3-D photonic crystals was proposed more than a decade ago,[1] its successful experimental realization in the IR and optical wavelengths has always been thwarted by micro-fabrication complexities.

In this work, we report the creation of the first ever silicon 3-D photonic crystal operating in the IR.[2] Our approach takes advantage of two recent breakthroughs: one in the new design of photonic crystals, the other in the advances in micro-fabrication technology. First, after re-examining the elegant, yet difficult to fabricate, 3-hole pattern photonic crystal structure proposed by Yablonovitch,[1] several groups independently suggested a simpler layer-by-layer design[3–5] that is amenable for fabrication at sub-micrometer scale. Second, advances in silicon processing, especially chemical mechanical polishing, has supplied the tools required for the successful fabrication of devices active in the IR.

Using these new tools, a 5-layer photonic crystal structure was successfully fabricated. An SEM of a layer-by-layer 3-D photonic crystal built on a silicon substrate is shown in Figure 1a. The structure possesses a distorted face-center-cubic crystal symmetry.

The transmission spectrum of light propagating along the <001> direction of the 3-D crystal, *i.e.*, normal to the substrate, is shown in Figure 1b. At λ = 10–14.5 μm, a strong transmission dip was observed, signifying the existence of photonic bandgap in the 3-D structure. A reflectance spectrum taken from the same sample is shown in Figure 1c. As expected, a high reflectivity was observed in the bandgap regime. Indeed, a 3-D photonic crystal may be regarded as a 3-D dielectric high reflector and applied to construct a truly single-mode high-Q cavity for enhancing spontaneous emission rate.





Lin Figure 1. (a) SEM image of a 5-layer 3-D photonic crystal built on silicon. The pitch between adjacent rods is 4.2 μm. (b) A transmission spectrum taken from the 5-layer 3-D crystal. (c) A reflectance spectrum taken from the same sample.

This demonstration will not only lead to high performance optoelectronic devices, such as thresholdless lasers, but also opens the door for Si-based photonic devices that are compatible with the well-developed Si microelectronics processes and are suitable for large scale photonic integration.

References

1. E. Yablonovitch, "Inhibited spontaneous emission in solid state physics and electronics," E. Phys. Rev. Lett. **58,** 2059–2063 (1987).
2. S.Y. Lin *et al*, "A three dimensional photonic crystals operating at infrared wavelengths," Nature **394,** 251–253 (1998).
3. S. Fan *et al.*, "Design of three dimensional photonic crystals at submicron lengthscales," Appl. Phys. Lett. **65,** 1466–1468 (1994).
4. K.M. Ho *et al.*, "Photonic band gaps in three dimensions: New layer-by-layer periodic structures," Solid State Comm. **89,** 413–416 (1994).
5. H.S. Sozuer *et al.*, "Photonic band calculation for woodpile structures," J. Modern Phys. **41,** 239–231 (1994).

Efficient Polarized Laser Mirror

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Waveguide-mode resonance effects in thin-film layers can be applied to realize an efficient laser mirror. We have demonstrated the application of a high-efficiency guided-mode resonance (GMR) filter as an output-coupling mirror in a dye laser. This simple two-layer device provides polarized output laser light without the use of laser Brewster windows. The experimental value of the mirror reflectance is ~98% at the resonance peak with corresponding laser transmission of ~2%.[1] Similar experiments with an ~50% reflective corrugated-waveguide mirror have been reported in which parasitic lasing via Fresnel bulk reflections occurred simultaneously due to the low value of the mirror reflectance.[2]

Thin-film dielectric multilayers incorporating a periodic element and a waveguide layer exhibit sharp varia-