Photonic Crystal Devices

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Research Opportunity:

- To construct compact, robust, monolithic and multi-functional nano-photonic integrated circuits.
Report Documentation Page

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Collaborators on Photonic Crystal Devices: Design, Fabrication and Measurements

- Dan Dapkus U.S.C. InGaAsP growth
- Tom Pearsall Corning Waveguides
- Amnon Yariv Caltech Device Integration
- Dennis Deppe U. Texas Quantum Dots
- Eli Yablonovitch UCLA PBG design

Goal: To develop photonic crystal devices and connect them together to form compact integrated WDM systems.
Dense arrays of optical elements can be lithographically coupled together.

Low threshold lasers with ultra-small mode volumes can be constructed and tuned.

Photonic integrated circuits can be constructed with sources, modulators, filters and detectors.

- Mirrors and active area are controlled by crystal growth
- Light emits perpendicular to the wafer surface
- Threshold currents as low as 10 µA have been reported
- VCSELs are presently used for fast optical interconnects

J.L. Jewell, A. Scherer, S. McCall, J. Harbison
Ultra-small vertical cavity lasers

The mode volume of VCSELs could be reduced to one cubic wavelength.

2D Photonic Crystal Waveguide

- TIR provides vertical guiding in an optically thin slab as in the microdisk.
- High index contrast periodic dielectric lattice provides strong dispersion photonic bandgap.

Note: 2-D photonic crystals were first proposed by Joannopolous et al. at MIT.
Photonic Crystal membranes are constructed by lithography, ion etching, and chemical etching.

Fabrication Sequence:
- Mask deposition
- PMMA developing
- Ion etching
- Undercutting/HCl etch
- Mask removal
The defect cavity localizes light through total internal reflection at the air/slab interface and Bragg reflection from the 2D photonic crystal.

The high-index slab (n=3.4) contains 4 QWs for gain, and is only 200 nm in thickness.
Single defect photonic crystal cavities can be useful high Q (>20,000) resonators.

Qs of 2-D Fabry-Perot resonators increase with number of PBG layers.

High quality cavities with 0.03 cubic micron volumes can be defined.
VCSELs and Photonic Crystal Lasers

- Mirrors are defined by lithography and etching.
- Only one or two lasing modes are supported in the cavity.
- Lasers can easily be coupled together in-plane.

- Mirrors are defined by growth
- The cavity can support many lasing modes
- Devices are difficult to couple together
Room Temperature Lasing

Laser Spectrum of single defect

L-L curve of PBG laser
The distances between holes determine the wavelength of emission from photonic crystal lasers.

Multi-wavelength laser arrays can easily be constructed.
Multi-Wavelength Laser Array

- Wavelength tuning from 1500 - 1620 nm.
- Wavelength resolution of 10 nm [limited by fabrication tolerances].
Controlling the direction of laser emission

To control the direction and polarisation of the laser emission, we can:

(a) increase the radius of some of the holes next to the cavity, or

(b) move some of the holes closer or further away from the cavity.
Both deep donor and shallow acceptor modes can be supported by the same cavity.

These modes can also be identified in the luminescence spectra.
Split-2 Spectra

- Dipole modes
- Shallow acceptor modes
Split-1 Spectra

- Y-dipole mode: DD
- Shallow acceptor modes
- Acceptor modes
Polarization Measurements

Un-Split

Split-1

Split-2

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Emission Pattern from Optimized Cavity

- Defect mode can be controlled through lithography to radiate vertically or in-plane.
- Two enlarged holes concentrate the in-plane emission along one-axis.
Lithographically connected optical cavities

Several cavities can be connected lithographically to form routers and switches.

Diffraction losses can be minimized by using photonic crystal mirrors between devices.
Coupled Resonant Optical Waveguides

Waveguides can be constructed to change the phase velocity of light.

Applications may include:
- optical traveling wave tubes
- higher harmonic light generation
- pulse reshaping

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A photonic crystal waveguide can be defined by eliminating lines of holes from the photonic crystal.

This waveguide can be used to connect lasers, detectors and filters.
Guided Light in a PBG Waveguide (FDTD model)
Bend geometries can be designed in both 2-D and 3-D by using FDTD programs distributed on a multi-computer cluster.
Si Photonic Crystal Waveguides

- Silicon on Insulator (SOI) allows the easy fabrication of single mode optical waveguides for 1.55 µm.
- Photonic crystal mirrors can be used to construct very sharp waveguide bends with low losses.