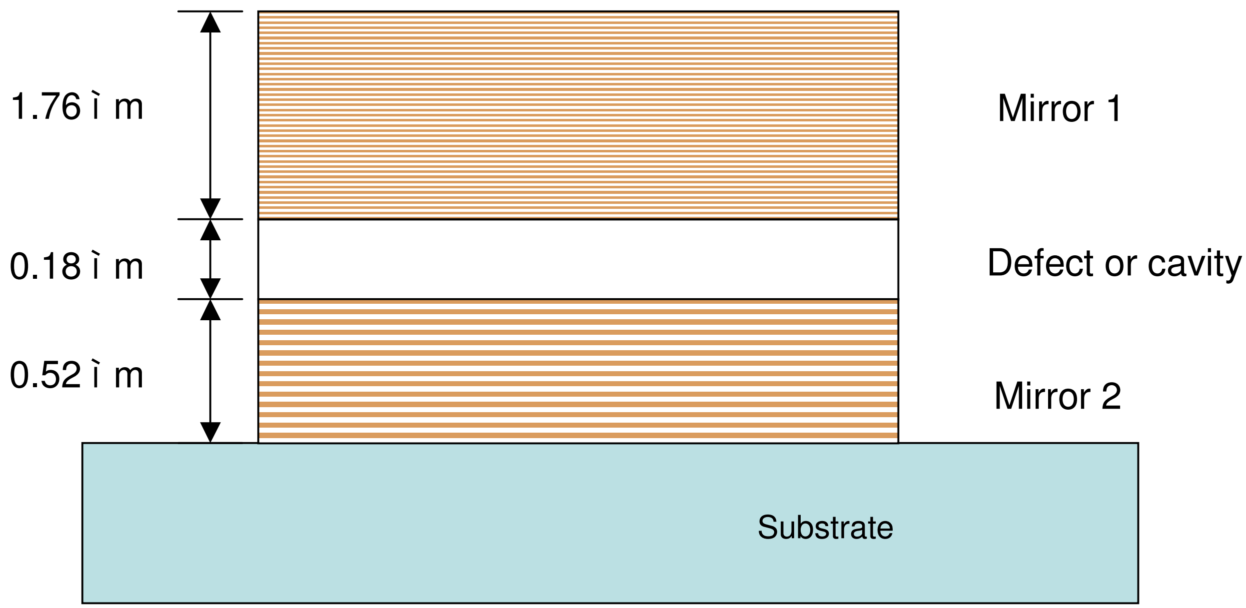
Porous Silicon Laser Structure



Cavity layer is formed with 42 % Porosity

* Not to scale

Mirrors are formed with alternate low and high refractive Indices Porous layers .ie, with 74 % and 42% porosities and 0.08 ì m and 0.14 ì m respectively

Mirror 1 is formed with 16 layers and mirror 2 with 5 layers

This structure us fabricated from p doped (0.005-0.02 Ùcm) silicon

E.K.Squire et al./ Journal of Luminescence 80 1999 125-128

Design Consideration

Stop Band Based Design

Cavity mode is positioned at wavelength, where negligible emission occurs and mirror resonance is placed close to the centre of the emission spectrum

Higher degree of photon confinement

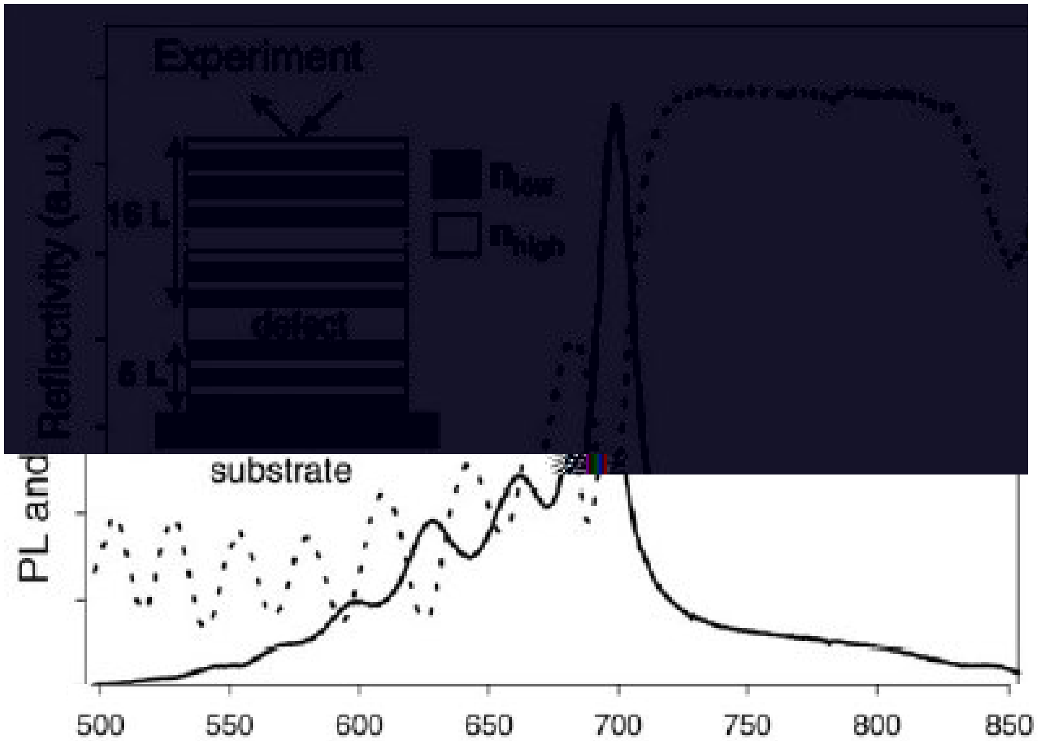
Higher the light confinement in the active layer (microcavity), more the emission due to longer photon life time and increased number of its passes in active alyer

Photonic Bandgap effect

Porous Si multilayer mirrors and cavities are considered as one dimensional photonic bandgap structures and this effect plays vital role in controlling light mission

E.K.Squire et al./ Journal of Luminescence 80 1999 125-128

Experimental Emission Spectrum

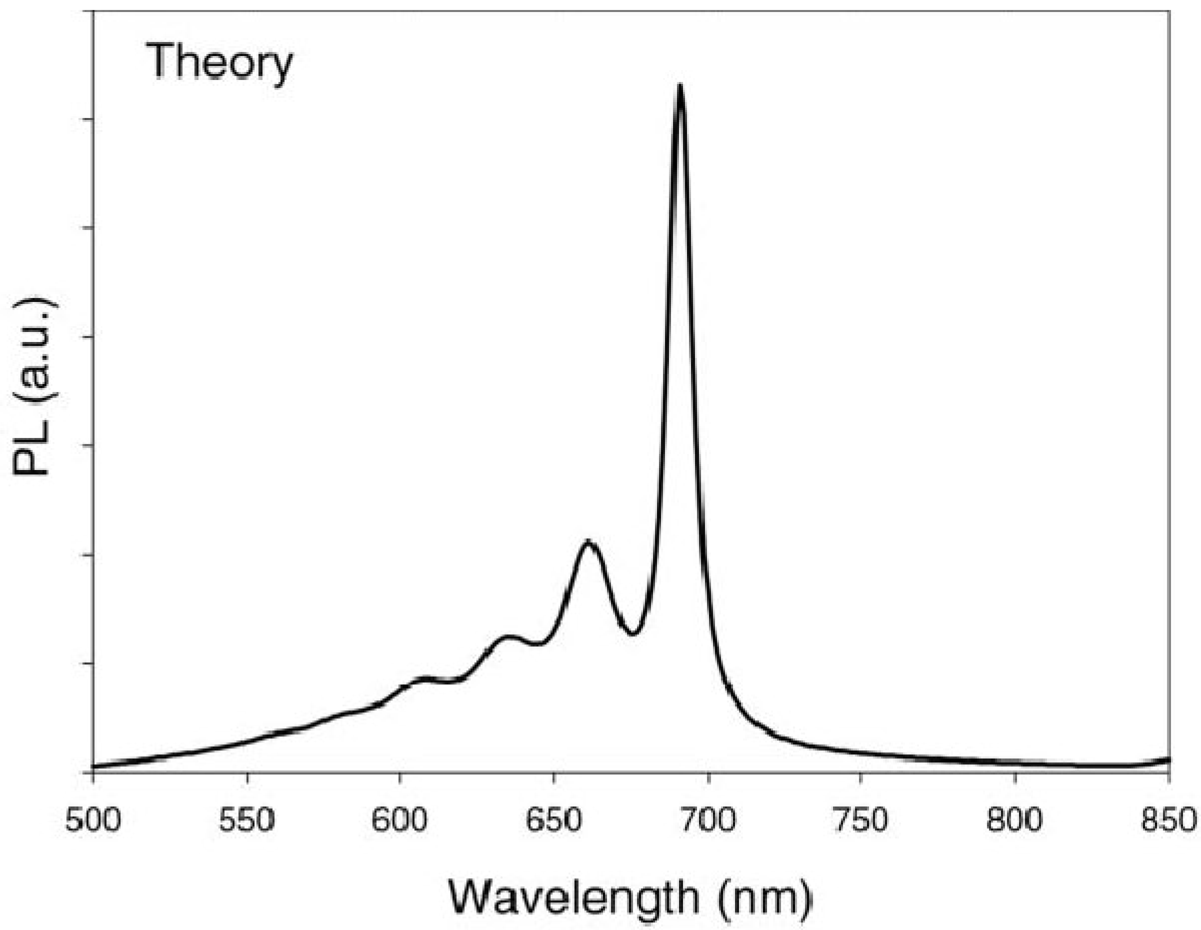


majority of the PL is emitted into the first transmission mode (FWHM&20 nm) on the low wavelength edge of the stopband instead of the cavity mode itself. In this case the modes are placed such that the cavity mode is positioned at a wavelength where negligible emission occurs whereas the mirror resonance is placed close to the centre of the emission spectrum.

E.K.Squire et al./ Journal of Luminescence 80 1999 125-128

Transfer Matrix Model for Emission Spectrum

The model accounts for the effects of dispersion, emission, and absorption



A Probability-Amplitude Transfer Matrix Model for Distributed-Feedback Laser StructuresGordon B. Morrison and Daniel T. Cassidy, IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. 36, NO. 6, JUNE 2000

Refractive Index of Silicon Vs Wavelength

Using Salzberg Equation,

$$n_s(\lambda) = A + BL + CL^2 + D\lambda^2 + E\lambda^4$$

$$where\ \mathrm{L} = (\lambda^2 - F)^{-1}$$

$$A = 3.41696$$

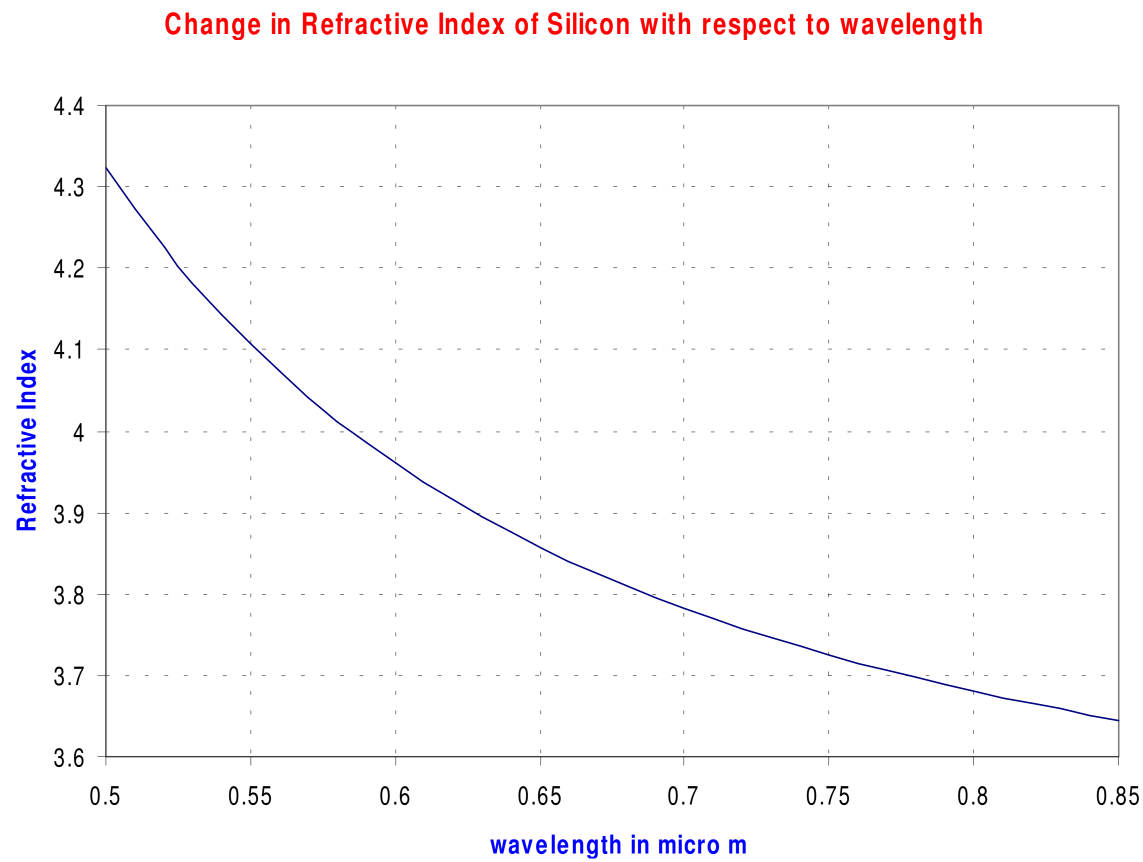
$$B = 0.138497\mu m^2$$

$$C = 0.013924\mu m^4$$

$$D = -2.09E - 5\mu m^{-2}$$

$$E = 1.48E - 7\mu m^{-4}$$

$$F = 0.028\mu m^2$$



C.D.Salzberg,"refractive indices of Silicon,Germanium and modified selenium glass",J.Opt.Soc.Am.47,244-246(1957)

Porous Si Laser Structure Analysis

$$n_L = \sqrt{\langle \varepsilon_L \rangle} + i[n_\alpha(\lambda) - \lambda g(\lambda)/4\pi]$$

$$n_H = \sqrt{\langle \varepsilon_H \rangle} + i[n_\alpha(\lambda)]$$

where

$\varepsilon_L and \varepsilon_L$ can be found from ε_{eff} *formula.*

gain term using Gaussian distribution

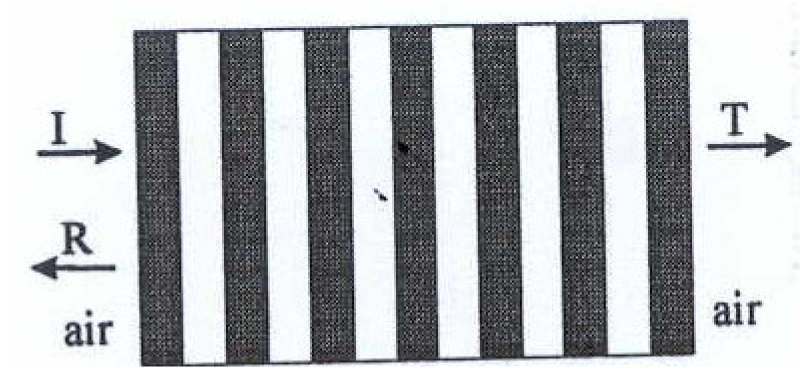
$$g(\lambda) = g_0 \exp(-0.5[(\lambda - \lambda_0)/\Delta\lambda]^2)$$

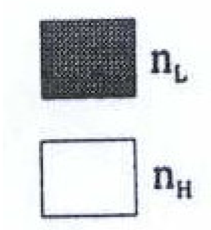
$\lambda_0 = 760nm$ and $\Delta\lambda = 50nm$

$$n_\alpha = 0.815 \exp\left(\frac{-(\lambda - 0.3827)^{0.6398}}{0.1207}\right) f_s$$

$f_s = fraction$ of silicon in the layer and λ is in μm

ε and ε_m is dielectric constant of Si and Air





$$\varepsilon_{eff} = (1 - p)\varepsilon^{1/3} + p\varepsilon_M^{1/3}$$

Where P is Porosity

EEL 6935-007 System On a Chip; Fall 2002;
Porous Silicon Laser Design
Ashok Rangaswamy

Emma K.Squire et al, Optimised Light Emission from layered Porous Si Structures, Applied Optics Vol 37, No 30

Equation governing the position of Fabry-Perot Resonance mode in the stop band

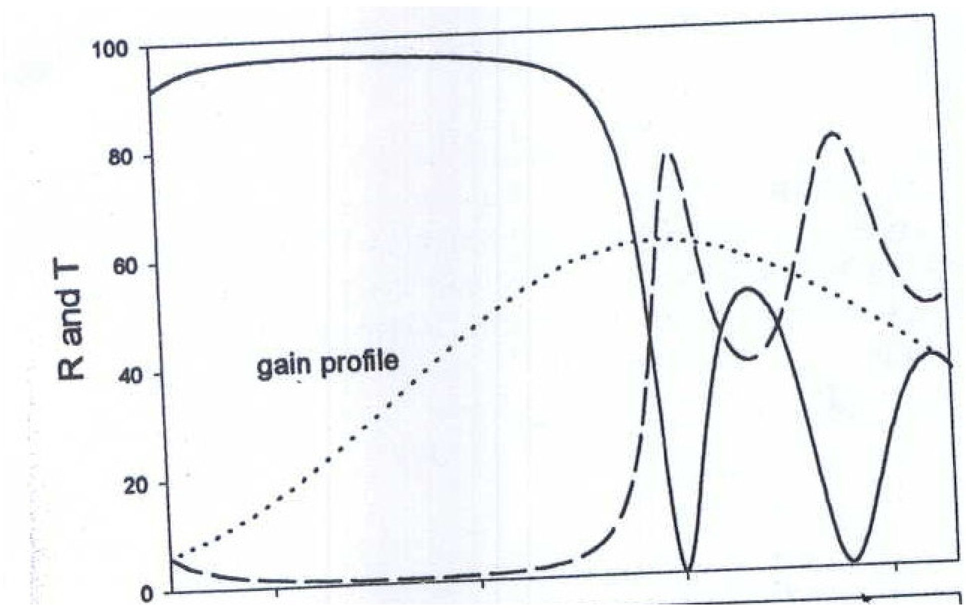
$$\lambda_B = 2(n_L d_L + n_H d_H)$$

where

d_L *and* d_H *are* thicknesses of alternating low and high index layers

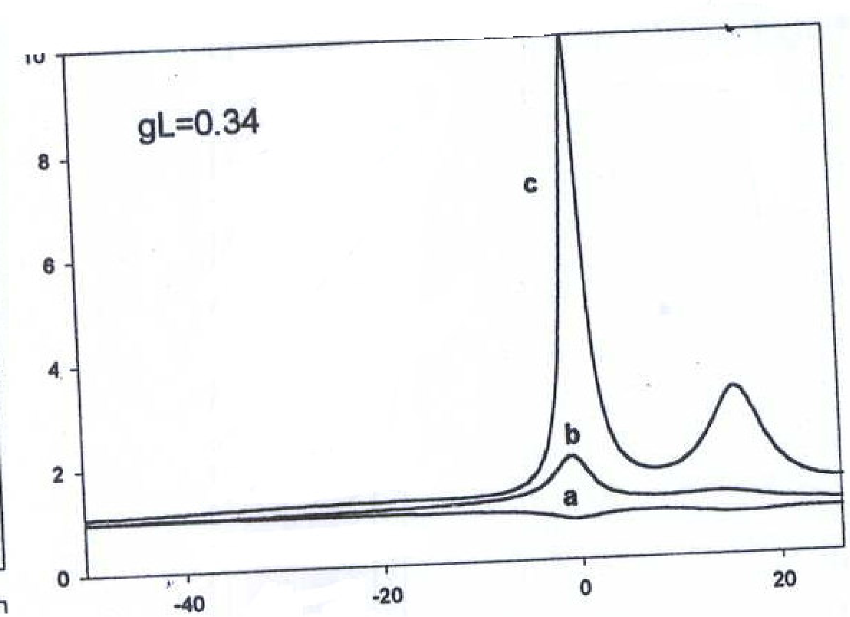
Emma K.Squire et al, Optimised Light Emission from layered Porous Si Structures, Applied Optics Vol 37, No 30

Fabry Perot Resonance on high Frequency side of the side band



Frequency Deviation in THz

Reflectivity and Transmissivity of 39 layer stack



Frequency Deviation in THz

Sum ofReflectivity and Transmissivity of 39 layer stack added with gain

The layer widths are 0.14 Micro m (low index) and 0.12 micro m (high index)

Photonic Integrated Circuit 3D Simulator for Laser Diodes

PICS3D (Photonic Integrated Circuit Simulator in 3D) is a three dimensional (3D) simulator for laser diodes and related waveguiding photonic devices/circuits. Based on 2/3D finite element analysis, it solves the semiconductor and optical wave equations to provide an accurate description of the device characteristics. When calibrated with specific material/process, it can be used as a computer-aided design tool to optimize existing devices or to assess new designs

Manual
http://www.crosslight.com/manuals/pics3d_man/

Demo
http://www.crosslight.com/downloads/downloads.html

Appendix

Porous Silicon

- Porous silicon is made by electrochemical etching bulk silicon wafer with aqueous hydrogen fluoride solution.
- The porosity of a sample is defined as the amount of air in the material after processing has finished, so a 45% porous sample would contain 45% air and 55% silicon.
- Light emission from porous silicon occurs mainly in the visible region of the electromagnetic spectrum.
- The emission has the unique property that the wavelength of the emitted light can be changed simply by increasing or decreasing the porosity of the material.
- For example, a highly porous sample (70-80% porosity) will emit green/blue light while a less porous sample (40%) will emit red light.

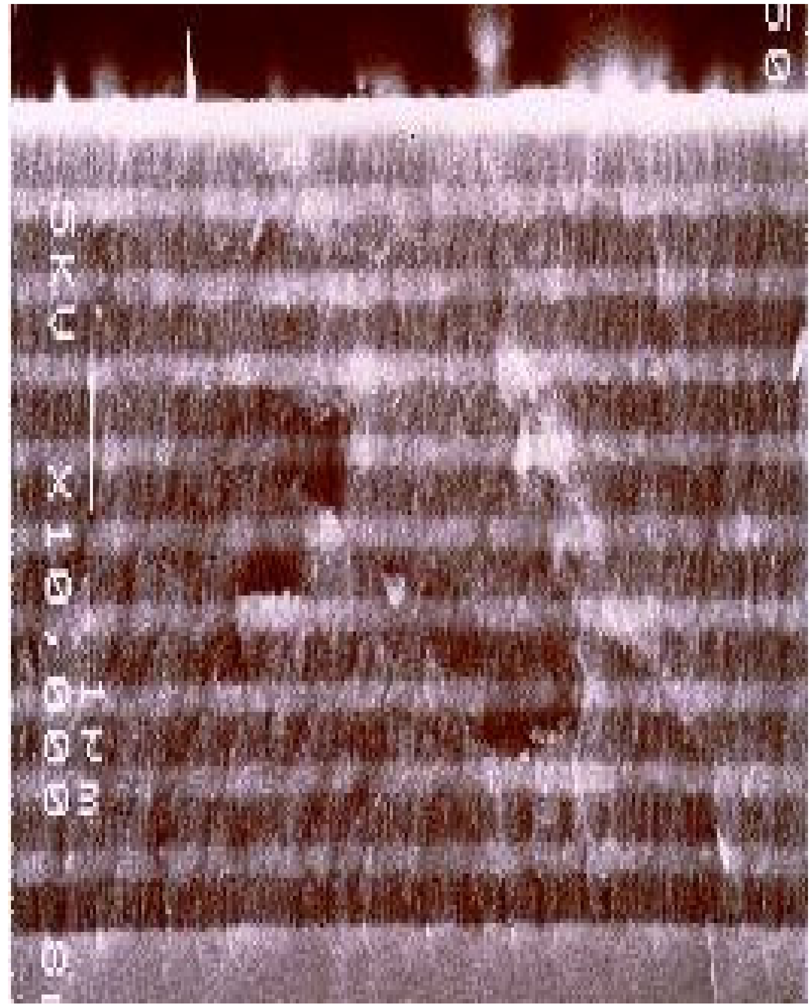


Fig: A porous silicon multilayer stack with a pitch of about half a micron, made by the electrochemical etching of a normal silicon wafer. The lighter layers are more porous than the darker layers. The stack is a very effective mirror, with a peak reflectivity of 95% at a wavelength of 950 nm.

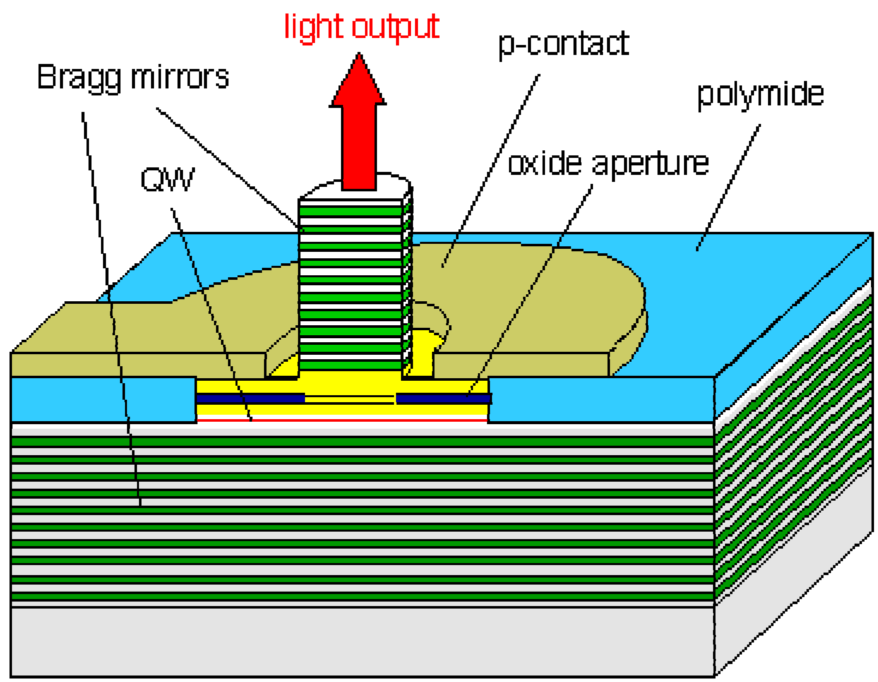
http://www.bath.ac.uk/physics/groups/opto/old/research.htm

Microcavity

1. When a semiconductor layer is placed in between an optical microcavity, Any slight change in the refractive index will induce a change in the reflectivity spectrum as well as in its photoluminescence spectrum[1].

2. The porous **silicon microcavity** was formed with a porous **silicon** active layer in the middle and sandwiched in between two multi-layered Bragg reflectors. Compared with a porous **silicon** single layer, the peak value of the emission intensity increased and the full width at half maximum value of the photoluminescence resonance noticeably narrowed when a **microcavity** structure was used [3].

3. The luminescence from a microcavity resonator is highly directional, so the power efficiency is improved because the loss of optical power along unwanted directions is minimized 2.



Lateral Patterning made by lithography and dry etching[4]

1. http://www.ece.rochester.edu/users/schan/sensor.html
2. http://www.ece.rochester.edu/users/schan/electrical.html
3. Young-You Kim [a]; Jong-Hyun Jeon; Eun-Jun Ahn; Ki-Won Lee Photoluminescence resonance properties of a porous silicon microcavity Sae Mulli Volume 44, Issue 4, 2002, Pages 224-228
4. http://www.physik.uni-wuerzburg.de/TEP/Website/groups/opto/vcsel.htm

Porous Silicon Multilayer Formation

It can be obtained by two ways:
1) By periodically varying the etch parameters, such as current density
2) By using periodically doped surfaces

PS is formed by electrochemical etching in HF solution.Thickness is controlled by etching time[1].

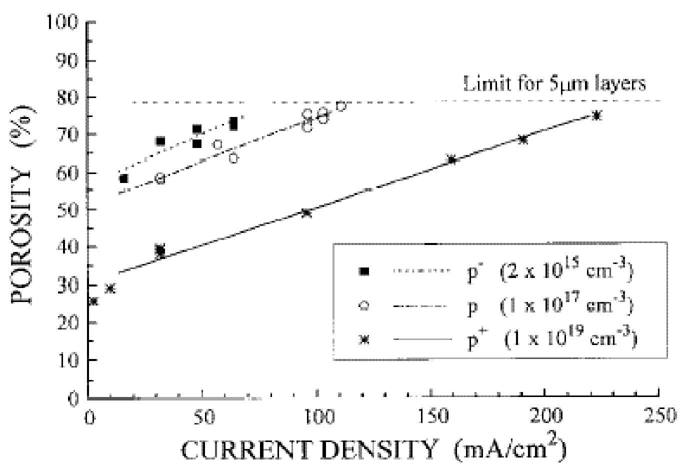


Fig. 2. Porosity as a function of current density for different substrate doping levels. The upper porosity limit is given by the mechanical stability of the layers.

virtually all luminescent porous Si layers exhibit some degree of inhomogeneity with depth; i.e., a finite porosity gradient exists. This arises more from the very nature of the electrochemical etching process itself, than from the anodization equipment used. Most porous Si layers exhibit a negative porosity gradient, i.e., the porosity decreases with increasing depth within the layer, and is highest at its surface. In thin layers the pore nucleation process itself gives rise to such an inhomogeneity. In thick layers, secondary chemical etching can be the dominant factor since the top of layer is exposed to the etchant longer than the bottom of the layer. The use of excessively long anodization times, chemically aggressive electrolytes or light assisted etching will all act to raise the magnitude of the latter effect. Only electrolyte depletion 140 or capillary-force-induced collapse act to generate positive porosity gradients within such layers[2].

1. St.Frohnoff et al, Formation techniques for Porous Silicon Superlattices, Thin solid films, 255 1995 pg 59
2. The structural and luminescence properties of porous silicon, Applied Physics Rev, Vol 82 No1 August 1 1997 pg 909