

**By Thaira Zakaria Al-Tayyar . Design and Simulation of a PC-VCSEL Diode .
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Abstract

On-chip, single-mode semiconductor lasers are usually fabricated using conventional vertical cavity surface emitting laser (VCSEL) structures. Due to the limitation of index guiding in the transverse direction, the width of these lasers has to be less than a few microns. This thesis reports on achieving the single-mode operation of vertical emitting semiconductor lasers using the photonic crystal (PC) Bragg structure (two-dimensional distributed feedback structures). Theoretical results are presented to support such achievement.

The design issues for a current injection VCSEL operating at 1550 nm is presented using PC technology. The design is based on PC slab containing multihole rings with a single defect is introduced at the center which acts as a waveguiding core. Three-dimensional finite difference time domain (FDTD) method and MATLAB program are developed to analyze and design the PC Bragg structure. It is shown that the single-mode lasing can be obtained by satisfying both the transverse and longitudinal Bragg conditions and a single lobe, diffraction limited far field can be obtained by optimizing the coupling coefficient of the PC. The effect of the radius of the inner hole ring is investigated. The results indicate that the hole radius must be controlled carefully to achieve a single-longitudinal lasing mode with a high intensity due to the light confinement improvement.

The frequency modulation response of a PC-VCSEL is investigated under direct-modulation scheme. The analysis is based on small-signal analysis of laser rate equations. A simplified cavity modal is developed here for the PC cavity. The cavity is treated as a semiconductor defect cavity surrounded by two air/semiconductor distributed Bragg reflectors (DBRs). The results indicate that a 45 GHz resonance frequency can be achieved with a PC-VCSEL compared with 23 GHz for a conventional VCSEL which means a speed enhancement in device operation.

Electrically pumped, small-area ($0.36 \mu\text{m}^2$), single mode semiconductor photonic crystal Bragg lasers are theoretically demonstrated with single lobe, diffraction limited far fields. Two dimensional lasing wavelength tuning is demonstrated, which proves that the lasing mode is truly defined by the photonic crystal lattice. Furthermore, a wavelength tuning sensitivity about 12.4 times smaller than a conventional VCSEL is also achieved, allowing for more accurate control of the lasing wavelength.

A three-dimensional FDTD method is used to calculate the mode profile and the quality factor (Q). Device parameters are optimized to increase Q . The results provide important guidelines for device fabrication.

Keywords: PC-VCSEL, FDTD, DBR, Quantum well.