Electrically pumped, edge-emitting, large-area photonic crystal lasers with straight and angled facets

Lin Zhu, Philip Chak, Joyce K.S. Poon, Guy A. Derose, Amnon Yariv and Axel Scherer

Department of Electrical Engineering, Department of Applied Physics, California Institute of Technology, Pasadena, California 91125

linz@caltech.edu

Abstract: We propose and demonstrate electrically pumped, edge-emitting, large-area photonic crystal lasers. Effective index-guided and Bragg-guided lasing modes are obtained depending on the design of photonic crystal and facets.

©2007 Optical Society of America

OCIS codes: (140.5960) Semiconductor lasers; (250.5300) Photonic integrated circuits

1. Introduction

It is well known that photonic crystal waveguiding structures can support two different kinds of modes: Bragg-guided and effective index-guided. For Bragg-guided modes, light is confined by Bragg reflection arising from a photonic bandgap in the transverse direction. Electrically pumped semiconductor photonic crystal lasers with Bragg-guided modes have been demonstrated in surface emitting structures [1, 2]. For effective index-guided modes, in photonic crystal fibers for example [3], confinement in the transverse direction is due to the index difference between the core and the effective medium formed by the periodic structure in the cladding.

In this work, we present photonic crystal lasers with small index contrast that operate under a pulsed electrical current injection. These are edge-emitting devices and well suited for planar integration. We show single-mode lasers with a large modal volume by combining effective index guiding and Bragg reflection in two dimensional photonic crystals. We also demonstrate Bragg-guided lasing modes in devices with an angled facet design.

2. Single-mode photonic crystal lasers based on effective index guiding

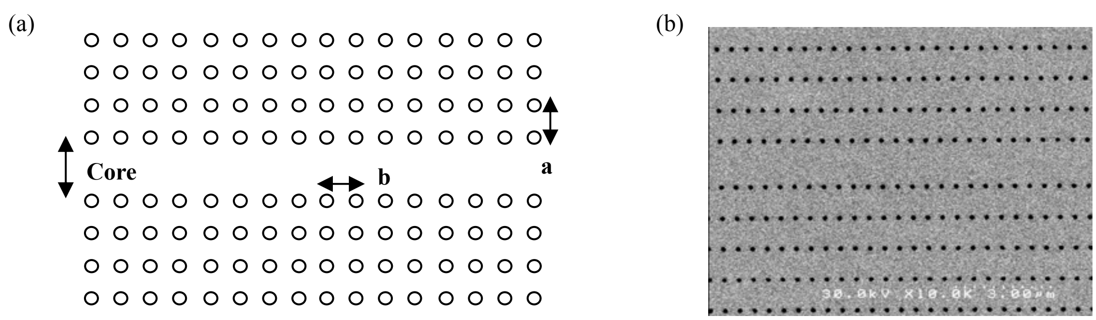

Fig.1. (a) Schematic diagram of our two dimensional photonic crystal lattice. (b) SEM image of our photonic crystal laser.

Figure 1(a) shows the schematic of our photonic crystal structure. The laser consists of a rectangular lattice array of ~10^6 polymer filled holes with one waveguide core on the wafer surface. The transverse lattice constant a is 1µm and the longitudinal lattice constant b is 400nm. The core width is 1.5µm. The hole radius and etch depth are 100 nm and 410nm, respectively. Figure 1(b) shows a scanning electron microscope (SEM) image of a photonic crystal laser before contact deposition.

The laser operates in a single-mode with a single peak in the spectrum, a single lobe in the near-field profile, and a diffraction-limited far-field pattern. The experimental results are summarized in Fig.2. Fig. 2(a) shows the laser optical spectrum with a single peak at 1.543µm. The single-mode behavior is maintained until I=1.5Ith. Fig. 2(b) shows the near-field profile of the single-mode laser with a single lobe centered at the core in the middle of the metal contact, which suggests that only one transverse mode exists. The $1/e^2$ modal width is ~25µm. The laser also possesses a diffraction-limited single-lobed far-field pattern with a divergence angle of 2.9^o as shown in Fig. 2(c).

©OSA 1-55752-834-9

The far-field pattern is similar to that of a large-area index-guided ridge waveguide mode. This implies effective index, rather than Bragg reflection is the main waveguiding mechanism for the lasing mode.

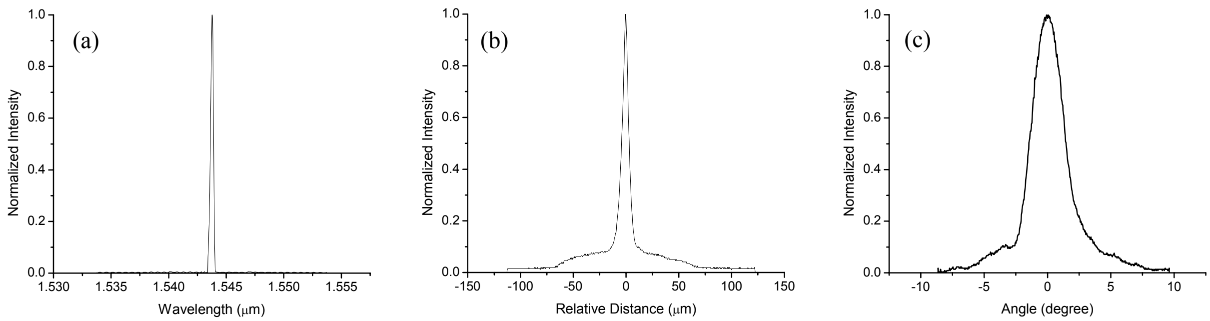

Fig.2. (a) The laser spectrum. (b) The near-field profile. (c) The far-field pattern. All experiment data are taken at I=1.1Ith.

3. Bragg-guided photonic crystal lasers in angled facet geometry

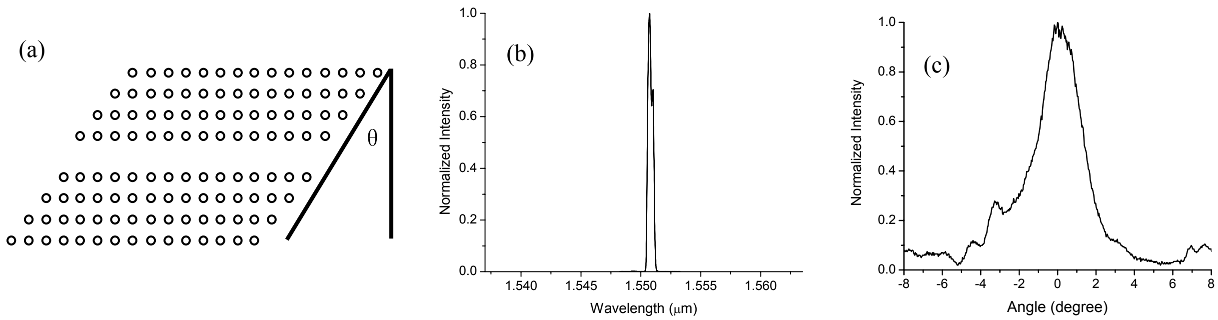

Fig.3. (a) Photonic crystal laser with angle facets (b) The laser spectrum at I=1.5Ith. (c) The far-field pattern at I=1.5Ith.

Figure 3(a) shows the schematic of our photonic crystal laser structure with angled facets. The transverse lattice constant *a* is 1μm and the longitudinal lattice constant *b* is 490nm. The core width is 1.5μm. The hole radius and etch depth are 100 nm and 360nm, respectively. The facet angle, θ, is 13.8^{o}. Angled facets give preferential feedback to Bragg-guided modes and suppress the effective index-guided modes [4,5]. The laser can provide diffraction-limited far field pattern even at high power. The longitudinal periodicity reduces the threshold and provides additional longitudinal modal control.

Figure 3(b) shows the laser spectrum at I=1.5Ith. Although single-mode lasing is not obtained, the spectrum linewidth of 0.5nm is much narrower than previously demonstrated edge-emitting lasers with angled facets by five times [6]. In the corresponding near-field profile, the $1/e^2$ modal width is ~30μm. Figure 3(c) shows the far-field pattern which has a diffraction limited divergence angle of 2.4^{o}.

4. Conclusion

In summary, we have demonstrated electrically-pumped, edge-emitting, large-area photonic crystal lasers. Based on effective index guiding, single-mode operation is achieved under pulse current injection for photonic crystals with straight facets. With the angled facet configuration, we demonstrate Bragg-guided lasing modes with a large modal volume in two dimensional photonic crystals.

References:

[1] H.G. Park et al, "Electrically driven single-cell photonic crystal laser," Science 305, 1444-1447 (2004).

[2] S. Noda et al, "Polarization mode control of two-dimensional photonic crystal laser by unit cell structure design," Science 293, 1123-1125 (2001)

[3] T. A. Birks et al, "Endlessly single-mode photonic crystal fiber," Opt. Lett. 22, 961-963(1997).

[4] R. J. Lang et al, "Theory of grating-confined broad-area lasers," IEEE J. Quantum Electron. 34, 2196-2210 (1998).

[5] A. M. Sarangane et al, "Spectral properties of angles-grating high-power semiconductor lasers," IEEE J. Quantum Electron. 35, 1220-1230 (1999).

[6] C.S. Kim et al, "Broad-stripe near-diffraction-limited mid-infrared laser with a second-order photonic-crystal distributed feedback grating," IEEE Photon. Tech. Lett., 16, 1250-1252 (2004)