Photonic Bandgap Microcavity Surface Emitting Electroluminescence Light Source

Pallab Bhattacharya, Weidong Zhou, Jayshri Sabarinathan
Department of Electrical Engineering and Computer Science
University of Michigan, Ann Arbor, MI 48109, USA

A microcavity laser can also operate as a single-mode light-emitting diode (LED), offering the advantages of zero threshold current and very directional output characteristics. Microcavity emitters have been studies with different confinement schemes, such as distributed Bragg reflector (DBR)-based Fabry-Perot microcavities and whispering gallery mode cavities. One promising confinement scheme is to use photonic bandgap (PBG) materials with defect forming the cavity core, which has the potential of creating ultra compact yet high performance lasers with zero threshold and unit spontaneous emission factor β. [1-4] Lasing with optical pumping from a microcavity formed by a single defect in the center of a disc-shaped photonic crystal has been demonstrated. [5,6] We have recently reported a similar device operating at room temperature with current injection, with a large spontaneous emission factor β=0.06. [7]

The device heterostructure is similar to λ-cavity oxide-confined VCSEL structure except no top DBRs. The detailed will be described later. A schematic of the device, incorporating 2D PBG, is shown in Fig. 1 (a), along with the SEM microphotographs showing the etched PBG structure, with air hole radius r=0.13 µm, depth h=0.8 µm, and lattice spacing a=0.4 µm.

The cavity was designed with a 2D PBG crystal encompassing the peak emission wavelength at a normalized frequency of a/λ for the TE modes. In our case the PBG center frequency a/λ =0.426, which corresponds to the quantum well peak emission wavelength of 0.94µm. Mesa-etched devices with p- and n- contacts were first fabricated by optical lithography, dry and wet etching, metallization and polyimide planarization. Lateral wet-oxidation of the $Al_{0.96}Ga_{0.04}As$ layers were used here to funnel the charge carriers more efficiently into the center of the PBG region, which is next formed by e-beam lithography, pattern transfer and deep dry etching techniques. The window inside the oxide ring is measured to be ~ 40µm in diameter. A single defect in the center defines the λ-sized microcavity. The 0.8 µm deep etch goes through the entire cavity region and well into the bottom DBR to ensure a good overlap with the optical field.

The light-current-voltage (LIV) characteristics, spectral properties, near-field, far-field and polarization characteristics of the PBG microcavity devices have been examined. Shown in Fig. 2(a) are the measured and simulated LI curves for our device, which yields a spontaneous emission factor β=0.06, much larger than the value of conventional semiconductor lasers ($\beta \cong 10^{-5} - 10^{-4}$), which indicated the enhanced spontaneous emission in our devices. The spectral output is shown in Fig. 2(b), where multiple peaks are evident due to the inherently multi-mode operation for our device.

The near field image is shown in the inset of Fig. 2(a). It is evident that the mode spreads out even more during its propagation along the vertical direction. The non-uniformity in the mode-profile is possibly due to light scattering in the air holes and diffraction at the surface. Nonetheless, it is important to note that the 4 µm lateral extent of the near field image is much smaller than the oxide window diameter of 40 µm and further helps to exclude the possibility that the entire 2D-PBG crystal beyond the defect microcavity contributes to the observed lasing. Finally, we have also measured the far-field radiation pattern in devices with and without PBG crystal formation. The linewidth (full width at half maximum) of the pattern is ~30^0, in contrast to 90^0 for larger oxide-confined light-emitting diodes, confirming that the observed light output and lasing originates from the single-defect microcavity.

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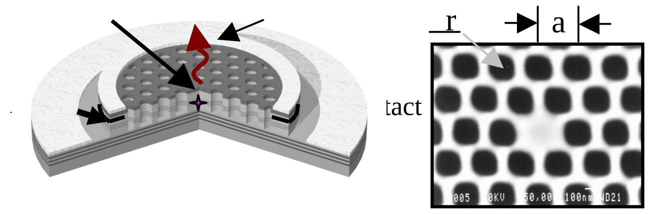
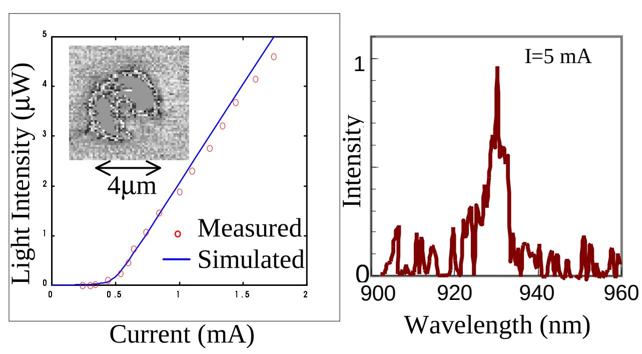


(a) (b)

Fig. 1 (a) Cross-sectional schematic of the electrically injected photonic crystal surface emitting laser with single defect forming the microcavity; and (b) SEM image of top view of the 2D PBG slab with single defect in the center.



(a) (b)

Fig. 2 (a) Measured and simulated light-current characteristics of the single-defect PBG laser at 300K in pulsed mode, with inset shown the measured near-field image; (b) measured spectral output of the single-defect PBG laser.

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