CW electrical operation of single-mode all photonic crystal DFB-like laser

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Abstract. *We present results on room temperature CW electrical operation of an edge emitting, all photonic crystal laser diode. The laser is based on a DFB-like photonic crystal W5 defect waveguide and shows stable single mode emission at 1563 nm. Laser design and performances are discussed.*

Introduction

All photonic crystal (PhC) defect waveguide lasers appear as extremely promising for planar optical integration. Indeed they are by nature fully compatible with already reported integrated compact optical systems based on photonic crystals [1]. In this paper, we present results on the design optimization and CW operation of hexagonal "HW5" defect waveguides lasers showing single mode emission based on 2nd order DFB operation.

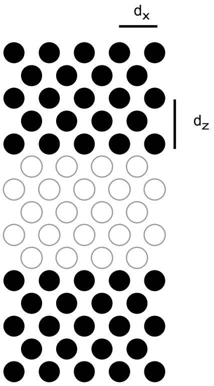

Figure 1: Schematic diagram of the deformed hexagonal lattice used for the "HW5" waveguide.

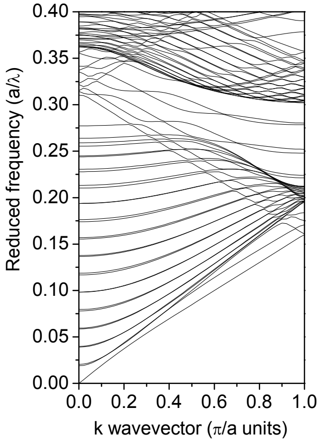

Figure 2: Band diagram of the waveguide with a deformation of -25%. Calculations used 2D PWEM method and an effective index of 3.21.

Laser design

To achieve efficient single mode lasing in the waveguide, we design our PhC waveguide so that the second folding of the first guided mode occurs at the gain peak wavelength. In that way, we plan to achieve stable 2nd order DFB-like emission of our laser [2, 3]. To minimize propagation losses and to minimize the laser threshold, we tried to minimize possible couplings between the DFB mode and the PhC optical modes [4]. To that effect, we introduce an affine deformation of the hexagonal lattice (figure 1) to move the band gap so that the 2nd folding of the guided mode rests into it (figure 2). The final parameters of the lattice are dx = 494 nm and dz = 642 nm, with a hole radius of 123 nm. These values correspond to a deformation of -25%, as a standard hexagonal lattice with the same dx of 494 nm would require dz equal to 856 nm. Due to the deformation, the waveguide width is reduced from 2.5 µm to 1.9 µm. The waveguide is delimited by a cleaved facet on one end and on the other end by a rear hexagonal PhC mirror in the ΓM direction. The lattice constant of the mirror is 403 nm, and the air filling factor is 30%. We designed the PhC mirror so that the emission wavelength of the laser rests at the center of the band gap, to maximize the reflectivity

Results and discussion

Since the main challenge of electrical pumping is heat dissipation, we use what appears to be the most promising route to manage it, the so called "substrate approach". Samples were fabricated at Alcatel Thales III-V lab in the InGaAsP/InP material system. We use an InGaAsP based planar waveguide on InP substrate with 6 compressively quantum wells. The gain curve of the quantum wells is centered around 1.55 µm. The photonic crystal waveguide was defined using e-beam lithography and deep dry etching. The holes depth is around 4 µm, deep enough to achieve 2D like geometry [5]. Metallic contacts were then deposited on the top and bottom surface of the sample, taking care not to fill the holes so as to preserve the quality of the PhC. A gain region of about 10 µm wide was delimited by proton implantation. Samples were then thinned and cleaved into laser bars that we reported on an aluminum submount, in turn mounted on a PCB board for characterization.

Fabricated samples of different lengths ranging from 80 µm to 330 µm were characterized in the continuous regime. Figure 3 shows a typical light-current curve obtained on a 230 µm long laser at room temperature. There is a clear emission threshold around 22 mA with a slope efficiency of 0.07 W/A. The maximum emitted power is around 3 mW and is limited by temperature. As seen on figure 4, the threshold current increases with laser length, whilst the efficiency slowly decreases.

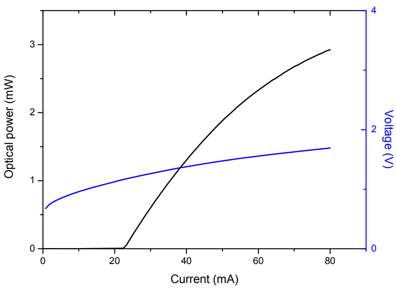

Figure 3: CW Light-current characteristic of a 230 µm long laser at room temperature.

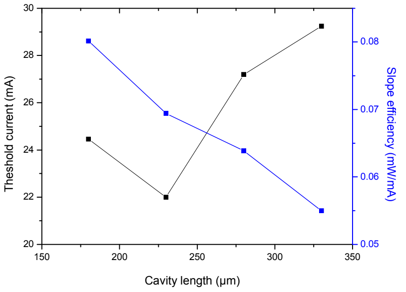

Figure 4: Evolution of the measured threshold current and slope efficiency versus cavity length.

Emission spectra of the lasers were measured using an Ando AQ6315 optical spectrum analyzer. Lasers with lengths ranging from 230 µm to 330 µm showed single mode emission with a side mode suppression ratio (SMSR) larger than 30 dB. The single mode emission is stable with the bias current, as shown on figure 5. For shorter cavity lengths, the Fabry-Perot emission prevailed due to the influence of the rear PhC mirror. DFB operation would be favored by using an antireflection coating on the front facet and moreover the SMSR would be increased. Indeed a 400 µm long laser designed with a cleaved rear reflector showed SMSR as high as 46 dB (figure 6), with a threshold current of only 28 mA.

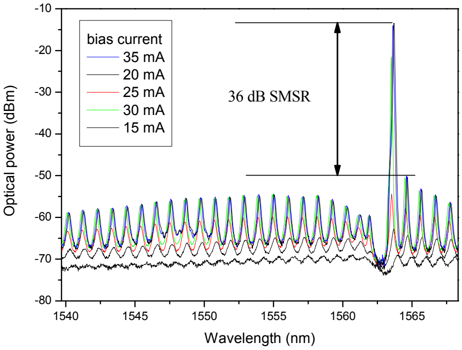

Figure 5: 330 µm long laser spectra for several bias current with a rear PhC mirror.

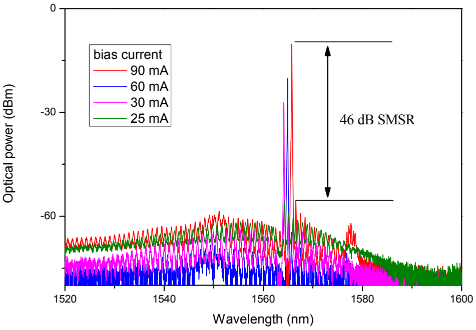

Figure 6: 400 µm long laser spectra for several bias current with a rear cleaved facet.

Similar PhC lasers without affine deformation were fabricated and tested. The crystal lattice constant was 485 nm. Lasers with a rear PhC reflector exhibited threshold current in the same range as deformed lasers and showed multimode Fabry-Perot emission. A 400 µm long laser with a cleaved rear facet presented DFB emission at 1540 nm with a SMSR of about 35 dB, with a high threshold current of 50 mA. These results show the influence of the lateral lattice parameters on the spectral characteristics and the interest in engineering the lateral lattice parameter to design and to achieve a DFB laser with a high SMSR.

Conclusion

We demonstrated CW electrically pumped, 2nd order DFB-like laser emission using an all photonic crystal defect waveguide laser. We introduced an affine deformation to limit the coupling of the DFB mode with the PhC optical modes and to force the emission in the bandgap. Experimental results show that DFB operation is improved by introducing an affine deformation in lateral dimension of the lattice. This approach will allow to achieve DFB lasers operating with high SMSR values.

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References

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