Lateral mode control in edge-emitting lasers with modified mirrors

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Abstract. We present a study on lateral mode control in edge-emitting lasers with profiled mirror reflectivity. The object was to eliminate high-order lateral modes in conventional ridge-waveguide InAs/InGaAs QD (quantum dot) lasers with the stripe width of 10 μm. We have used a FIB (focused ion beam) technique to selectively etch windows in the AR (anti-reflection) facet coatings in order to introduce extra mirror losses for the high order modes. This approach allowed us to eliminate the first-order mode lasing without deterioration of the laser parameters. We suppose that further optimisation of the laser heterostructure and window designs may lead to a pure lateral single-mode lasing in the broadened ridge waveguides.

1. Introduction

Today high-power diode lasers are essential for various applications due to their energy efficiency, reliability, compact size, and low cost. However, increasing optical power in conventional ridge-waveguide laser diodes inevitably requires the waveguide expanded in the lateral direction resulting in multi-mode lasing. A number of approaches has been developed to ensure oscillation on a fundamental mode in broadened ridge-waveguides. Among them are tapered waveguides, external cavities, phase-locked arrays, and profiled mirror reflectivity. The reflectivity profile in semiconductor edge-emitting lasers is formed with partial high-reflection (HR) or AR coating of the laser output mirrors. Lateral modes are differ in their spatial distribution, thus, partial coating may be used to create additional loss for high-order modes and to change the lasing conditions in favor of the fundamental mode. Previously several techniques have been used to create modulated reflectivity mirrors in broad-area lasers, and single lobe far-field patterns where demonstrated [1,2]. Nevertheless, obtaining pure single-mode lasing in broadened ridge-waveguides is still a challenging task. In this work, we present a study on the lateral mode control in edge-emitting InAs/InGaAs quantum dot lasers with modulated reflectivity mirrors.
2. Experiment and results

The laser wafer was grown by molecular beam epitaxy. Ten layers of InAs quantum dots capped with InGaAs and separated by 35 nm GaAs where sandwiched between 1.5 μm Al_{0.35}Ga_{0.65}As claddings. The wafer was processed into 10 μm wide shallow mesa ridge-waveguide lasers using standard photo-lithography. All studied devices where mounted on copper heat sinks using indium solder in order to minimize overheating in continuous wave (cw) regime. The 2 mm long devices showed the threshold current density of 100 A/cm² and the lasing wavelength of 1.26 μm in cw regime, which corresponds to the lasing via the QD ground state. Plotting reciprocal differential quantum efficiency versus cavity length yielded the internal quantum efficiency of 77% and internal loss of 2.8 cm⁻¹.

![Figure 1. SEM (scanning electron microscope) photograph of the laser with etched mirror.](image1)

![Figure 2. Light output vs. injected cw current of the initial (red triangles), coated (black squares), and etched (blue dots) devices. The inset shows the laser parameters and estimated output losses.](image2)

Coatings where deposited on the both facets of the 2 mm long devices. The HR coating consisted of 5 pairs of SiO₂/Ta₂O₅ with the thicknesses of 217 nm and 157 nm, respectively. Another facet was coated with single 157 nm Ta₂O₅ AR layer which was partially removed (figure 1) using FIB. Opening width was designed to eliminate lasing of the first-order lateral mode.

To ensure that the devices did not degraded after the coating and FIB etching, we measured cw light-current characteristics at each step of fabrication of the modified mirrors (figure 2). The inset in figure 2 shows the laser parameters and estimated output loss. One can see that the threshold current increased twofold after the coating and the differential efficiency increased accordingly due to increased output loss. After the FIB etching threshold current remained unchanged but differential efficiency decreased. We attribute the latter to the lower output loss for the fundamental mode resulted from partial removing of the AR coating.

![Figure 3. Experimental setup used for the measurement of spectrally resolved lateral far-fields.](image3)

To confirm elimination of the first-order mode lasing in the devices with modified mirrors, we studied spectrally resolved far-fields. Figure 3 shows a layout of the experimental setup used for these measurements. A 200 μm fiber was used to collect chopped far-field emission. A lens was used to
focus the fiber output to the 0.5 m monochromator. The output emission from the monochromator was detected with an InGaAs photodiode connected to a lock-in amplifier. Spatial and spectral resolutions were 0.06° and 0.4 nm respectively.

Figure 4 shows typical spectra and spectrally resolved lateral far-fields of the uncoated laser (figure 4a) and laser with modulated reflectivity mirror (figure 4b). Fundamental mode lasing took place around 1265 nm in the both types of the devices. The far-field patterns taken at 1265.2 nm (red lines in figure 4a,b) prove it. We attribute the small fringes around ±8 deg. in the far-field pattern of the device with modified mirror to the diffraction at the AR opening but not to the presence of the first-order mode.

![Figure 4. Lasing spectra (left hand side) and spectrally resolved lateral far-fields (right hand side) of the uncoated laser (a) and laser with modulated reflectivity mirror (b) measured in cw regime at 300 mA pump current.](image)

First-order mode lasing appeared around 1258 nm in the uncoated device (blue line in figure 4a). In contrast, the device with modified mirrors showed no lasing at this wavelength. However, an additional group of lines emerged in the lasing spectra around 1244 nm (left hand side of figure 4b). We attribute these lines to the second-order mode. This speculation is in agreement with the far-field pattern taken at 1244.3 nm (blue line in figure 4b). We assume that at the high currents the waveguide effectively expands in the lateral direction due to the current spreading. Therefore, the second-order mode could be eliminated with deeper ridge etching or with optimization of the AR opening width.

3. Conclusion

In conclusion, having used profiled reflectivity mirror we were able to selectively eliminate the first-order mode lasing in the conventional InAs/InGaAs QD laser with 10 μm ridge waveguide without noticeable deterioration of the device performance.

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References

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