Surface-Etched Laterally Structured Semiconductor Laser Diodes for Mode Engineering

Pawel Strzebonski*, Katherine Lakomy, Kent Choquette
Electrical and Computer Engineering Department
University of Illinois, Urbana, Illinois 61801 USA
*strzebo2@illinois.edu

Abstract

Various surface-etched, laterally structured waveguide designs were simulated to achieve improved modal discrimination, selection, and direct mode engineering in broad-area diode lasers. These designs have been fabricated in InP/InGaAsP edge-emitting lasers.

Index Terms

Laser modes, Semiconductor waveguides, Semiconductor lasers

I. Introduction

Waveguide index structuring allows for engineering modal discrimination, modal selection, as well as engineering the mode profile and properties directly[1, 2]. In order to engineer the lateral modes of semiconductor edge-emitting lasers we etch ridges within the waveguide region, along the length of the device. These ridges were then filled by deposited a thick layer of contact metal. This introduces a lower-index perturbation along the lateral direction. The width and location of these ridges was determined by two-dimensional simulation of potential transverse index structures, analogously to previous one-dimensional theoretical analysis[3].

II. Lateral Structuring

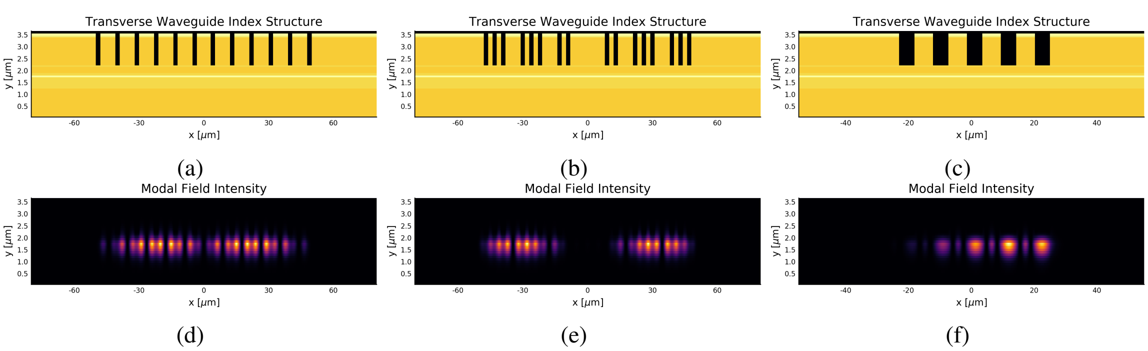

Fig. 1: Transverse waveguide index structure for a 1a) TBR, 1b) "sporadic" grating, and 1c) asymmetric grating designs. The corresponding simulated transverse waveguide modes with the highest field gain-region overlap are plotting in 1d-1f.

Transverse Bragg resonance (TBR) structures can take the form of either a uniform index grating along a transverse direction, or a "defect" ridges sandwiched between a pair of such gratings. Such structures increase the modal discrimination between transverse modes, and by using TBR structures along the lateral dimension of the waveguide may provide a path for creating broad-area, single lateral mode diode lasers[4]. An example of a lateral TBR structure with a defect is shown in Figure 1a, and this structure should select the transverse mode shown in Figure 1d and increase the discrimination between that mode and all others.

We also consider a "sporadic" grating structure, where the lateral waveguide, rather than having a large continuous grating structure has instead multiple smaller grating regions within it. An example of such as structure is shown in Figure 1b, and the preferred mode supported by the structure is shown in Figure 1e.

An asymmetric grating structure, as shown in Figure 1c, compromises of an index grating that is off-center, breaking the lateral mirror symmetry. Such an asymmetric structure should have novel properties with regard to the modes and modal far-fields. The asymmetric index structures enables even-ordered modes, such as the 10^{th} mode shown in Figure 1f, to have on-axis lobes in the far-field (in a symmetric waveguide structure, even-ordered modes have anti-symmetric near-fields, yielding on-axis nulls in the far-field[2]).

III. Fabrication Process

First, SiO_2 hardmask was deposited on top of the InP/InGaAsP edge-emitting laser epitaxy, and then the lateral structures were patterned and etched into the hard mask. Next the lateral structuring was etched into the upper cladding using RIE-ICP. Subsequently, a patterned thick top-side metal contact was deposited over the waveguide region using lift-off process. This thick metal contact then served as a mask for an ion implantation step. Finally, the wafer was thinned, a back-side contact was deposited, and the laser bars were cleaved.

IV. Preliminary Results

(a) (b) (c) (d)

Fig. 2: (2a-2c) Microscope photographs of the fabricated structures based on the structures shown in Figures 1a, 1b, and 1c, and (2d) the preliminary pulsed measurements for those structures.

Various lateral structuring designs were fabricated including those shown in Figures 2a, 2b, and 2c, corresponding to the waveguides shown in Figures 1a, 1b, and 1c. Pulsed light output versus injection current measurements were made of these, as well as of comparable unstructured control lasers. As indicated in Figure 2d, the laterally structured devices lased, albeit with lower efficiency than for unstructured devices. Extensive modal characteristics will be reported at the conference.

V. Conclusion

Edge-emitting laser diodes were fabricating with lateral structuring with the goal of engineering the transverse modes. Preliminary results demonstrate lasing operation of some of these designs. This material is based on work supported by Joint Transition Office Multidisciplinary Research Initiative, Award No. 17-MRI-0619.

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