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High-Power Single Mode Operation of Hybrid Ion-Implanted/Selectively-Oxidized VCSELs

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Abstract

We report the design and testing of a novel 850nm hybrid vertical cavity laser employing ion implantation and selective oxidation to independently define the gain region and mode size for optimal high-power single-mode operation.

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Selectively-oxidized vertical-cavity surface-emitting lasers have demonstrated record performance. However, due to the strong index confinement created by the low-index oxide layers, devices with large enough diameter to produce significant power virtually always operate in multiple transverse modes[1]. High-power single-mode operation is desirable in many applications such as optical storage and printing due to the ability to tightly focus the laser output. One method of providing the mode selectivity necessary to insure single mode operation in a large diameter VCSEL is to independently control the size of the gain region and that of the optical mode[2]. We first present numerical simulations that quantify this approach by predicting lateral mode discrimination for different sized gain apertures. These calculations are experimentally confirmed by the fabrication and testing of 850 nm VCSELs employing hybrid ion implantation/selective oxidation that produce a single-mode output of more than 5 mW.

We performed VCSEL simulations using a 2D axisymmetric finite-difference code that solves for cavity eigenmodes including both mode shape and energy loss rate for a realistic VCSEL structure that includes gain and loss in the quantum well(s). We chose a VCSEL comprised of a 1-λ cavity containing a single 100 A quantum well with 34 DBR pairs below and 21 above the cavity. Optical mode confinement resulted from two quarter-wave oxide layers positioned just above and below the cavity with fixed 10 μm diameter. Gain in the quantum well was made uniform within some aperture radius and given a large negative value outside the aperture to simulate the unpumped quantum well. For each aperture diameter, the gain was set so that the fundamental mode was at threshold, and the modal loss of the most competitive higher-order modes computed. In Fig. 1, the loss has been normalized by the cold-cavity loss of the fundamental mode. Symbols plotted along the vertical axis correspond to the first-order radial mode having m=0. These results show clearly that with a 10 μm gain aperture there is virually no mode discrimination, but that as the diameter is reduced below the oxide diameter significant mode discrimination appears. Gain aperture reduction is of course limited by the resulting severalfold threshold increase predicted by the model (and observed experimentally).

This concept was realized in the laboratory by using conventional proton implantation to define a gain region independently from the size of the oxide aperture, as shown in Fig. 2. Devices with equal gain and oxide apertures lased multimode as expected. However, when the gain aperture was decreased to about half the oxide aperture, single mode operation ensued up to the device's peak output, in agreement with the simulations. For example, VCSELs with 6 μm implant diameter and 12 μm oxide diameter display the output characteristics shown in Fig. 3. This device lased single mode with 30 db of side mode suppression up to its maximum output power of 5.2 mW. Higher single-mode output power is expected from similar devices designed with more aggressive output coupling. Sandia is a multiprogram lab operated by Sandia Corporation for the U.S. Dept. of Energy under Contract DE-AC04-94AL85000.

References

[1] K. D. Choquette and K. M. Geib, "Fabrication and Performance of Vertical Cavity Surface Emitting Lasers", Chap. 5 in *Vertical Cavity Surface Emitting Lasers*, ed. C. Wilmsen, H. Temkin and L. Coldren, Cambridge University Press (Cambridge, UK) 1999.

[2] K. D. Choquette, A. A. Allerman, K. M. Geib and J. J. Hindi, "Lithographically-Defined Gain Apertures Within Selectively Oxidized VCSELs", CLEO2000, paper CtuL6, San Francisco, CA (May 2000).

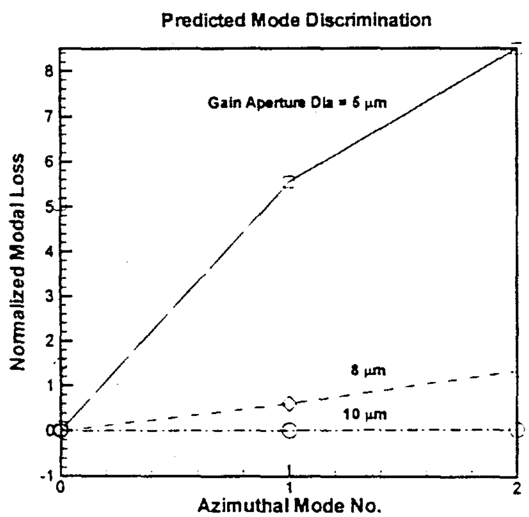

Fig. 1 Predicted modal loss for different high-order modes and gain apertures

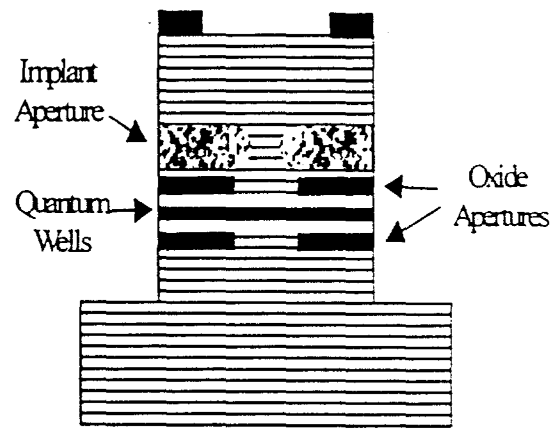

Fig. 2 Hybrid VCSEL schematic

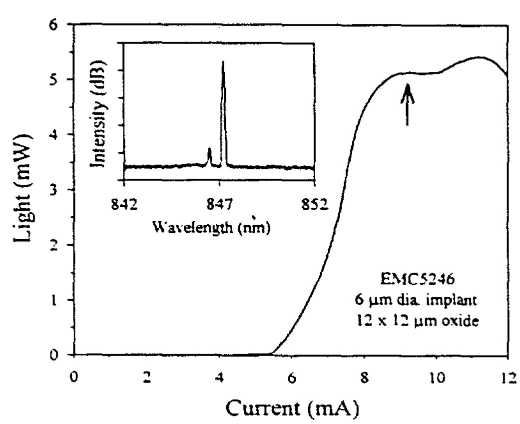

Fig. 3 Measured LI curve for 6 μm gain aperture and 12 μm oxide aperture. Inset shows side-mode-suppresion at current indicated by arrow.