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High Efficiency Oxide Confined Vertical Cavity Surface Emitting Lasers*

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Abstract: Optical loss is studied in devices with either two aligned apertures above and below the active region or with a single effective aperture above the active region. The latter exhibit slope efficiencies of up to 1 W/A.

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DISCLAIMER

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This year, structures based on aluminum-oxide layers have led to dramatic improvements in VCSELs such as power conversion efficiencies in excess of 50%[1] and threshold currents below 10 μA[2]. The low index, insulating aluminum-oxide (presumably similar to alumina in composition), formed by selective wet thermal oxidation of AlGaAs, serves as an effective index guide[3] as well as a current injection aperture. A substantial amount of design freedom exists with respect to the number and placement of apertures with published structures varying from single apertures[1-5] to one per mirror period[6]. In this paper we present data on devices with either two aligned apertures above and below the active region or with a single effective aperture above the active region leading to slope efficiencies of up to 1 W/A.

The schematic device structure is shown in Figure 1. The epitaxial structure includes a triple InGaAs quantum well active region in a graded AlGaAs one-wave cavity with 19 top and 38 bottom GaAs/AlGaAs mirror periods. The composition of the $Al_xGa_{1-x}As$ in the mirror periods immediately above and below the cavity is x=0.98 while the remainder of the mirror has a maximum of x=0.96. The selective oxidation[5] fabrication begins with a plasma etch of varying size square mesas to different depths depending on the desired aperture profile which translates from the etch profile. A deep etch results in aligned apertures while a shallow etch results in a larger bottom aperture. The samples are later prepared for a one-hour wet thermal oxidation at 425°C by removing any unwanted surface oxidation using a 10 second phosphoric-peroxide-water etch immediately prior to loading into the equilibrated furnace.

Figure 2 presents room temperature, cw effective threshold current densities and slope efficiencies for devices with varying size square active regions. For large devices, the threshold current density approaches a constant value of ~800 A/cm^2. We attribute the slight decrease in slope efficiency for the largest devices to increased temperature as well as current crowding at the periphery of the device which becomes more significant at higher currents. For the smallest devices, the effective threshold current density increases rapidly and the slope efficiency falls. This initial data does not clearly identify any significant difference in the scaling of the threshold current density between the two aperture structures although more complete work is in progress. Several mechanisms including scattering or diffraction loss, carrier diffusion into the perimeter, and non-radiative recombination associated with the oxide may cause the rise in threshold current for small devices. The highest slope efficiencies are obtained for intermediate sized devices. Higher efficiencies for the single aperture device indicates reduced optical losses as compared to the double aperture structure. Figure 3 presents data on the differential quantum efficiency as a function of wavelength. The peak gain wavelength is ~965 nm, longer than the maximum efficiency wavelength. This is consistent with loss mechanisms that decrease with decreasing wavelength such as free-carrier absorption and diffraction, although it could also be attributed to variation in mirror reflectivity. Slope efficiencies of greater than 1 W/A are observed.

[1] K. L. Lear et al., Electron. Lett. **31**, 208 (1995).
[2] G. M. Yang et al., Conf. on Lasers and Electro-Optics, CPD4-1 (1995)
[3] K. L. Lear et al., Appl. Phys. Lett. **66**, 2616 (1995).
[4] D. L. Huffaker et al., Electron. Lett. **30**, 1946 (1994).
[5] K. D. Choquette et al., Electron. Lett. **30**, 2043 (1994).
[6] Y. Hayashi et al., Electron. Lett. **31**, 560 (1995)
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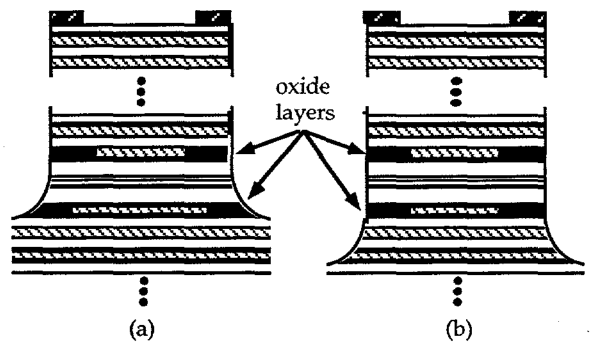

Figure 1. Schematic cross section of the two structures studied in this paper: (a) an effective single oxide aperture due to a shallow etch and (b) an aligned double aperture structure due to a deeper etch.

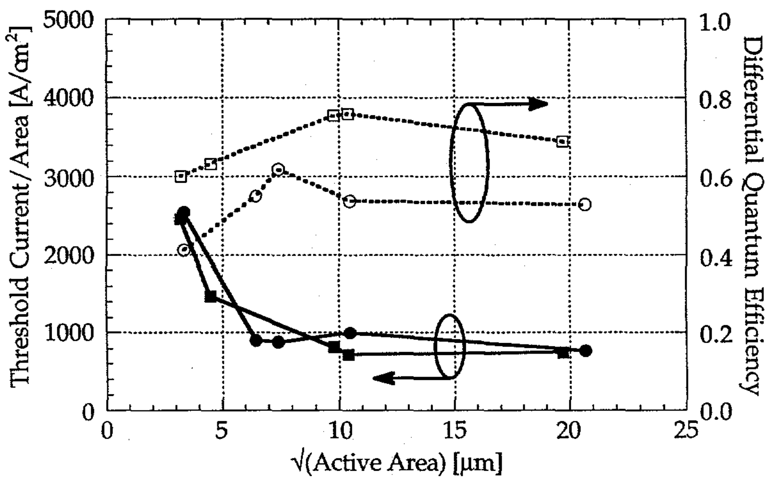

Figure 2. Differential quantum efficiency and threshold current density for single effective aperture (circle) and double aperture (square) versus size. The active areas are roughly square.

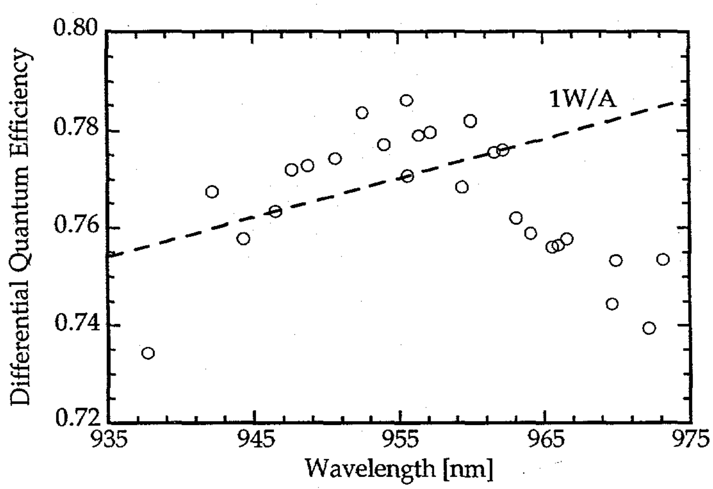

Figure 3. Differential quantum efficiency as a function of wavelength for ~10x10 μm^2 single oxide aperture VCSELs. Devices have slope efficiencies of up to 1 W/A.