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Mode-Expanded Semiconductor Laser with Tapered-Rib Adiabatic-Following Fiber Coupler

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Expanded-mode semiconductor lasers are of great interest due to the benefits of reduced far-field divergence and improved coupling efficiency to optical fiber.[1,2] We present a new diode laser using a Tapered-Rib Adiabatic-Following Fiber Coupler[3] (TRAFFiC) to achieve 2D mode expansion without epitaxial regrowth or sharply-defined tips on tapered waveguides, Fig. (1). The expanded mode size would allow 0.25 to 1 dB coupling loss to standard telecommunications fiber making smaller-core specialty fibers unnecessary, increasing misalignment tolerance, and eliminating the need for coupling optics.

The TRAFFiC laser uses lateral tapering in an AlGaAs/InGaAs rib waveguide to convert the rib mode to the fundamental mode of a larger underlying mesa guide. Progressive narrowing of the etched rib has the effect of squeezing the optical mode out of the rib and down into the larger mesa waveguide thereby expanding the fundamental optical mode size. Due to the adiabatic nature of the mode expansion, light reflected by the cleaved facet at the expanded-mode output couples back into the fundamental mode of the active rib waveguide. This is the first demonstration of a TRAFFiC mode expander in an active device.

The laser is a strained-quantum-well separate-confinement heterostructure type employing two $In_{0.20}Ga_{0.80}As$ quantum-well (QW) active layers within a $GaAs/Al_{0.1}Ga_{0.9}As$ double-heterostructure waveguide. A 2 μm-wide rib waveguide is etched in the cladding region above the QWs to define the active lasing section in a region of high vertical confinement factor. A TRAFFiC output coupler is formed at one end of the laser by tapering the rib waveguide width from 2 μm to 0.4 μm over a length of 0.5 mm. A second 10 μm-wide outer mesa provides lateral confinement of the expanded optical mode propagating within the 8-μm thick lower cladding. A layer of $Al_{0.4}Ga_{0.6}As$ is used to isolate the expanded mode from the GaAs substrate. Overall length of the lasers is 1.25 mm of which 1 mm is contacted for electrical current injection. The TRAFFiC section is electrically injected only where where significant overlap of the optical mode and QWs exist.

Lasers were fabricated using two lithography-and-etch steps. The tapered rib waveguide was defined using electron-beam direct-write lithography. Both rib and mesa were formed using dry etching. Although these devices were patterned with direct-write techniques, the 0.4 μm minimum width of the waveguide taper could be defined using optical methods. After etching, ohmic contacts were applied to the rib top and wafer bottom. Final lasers were tested using pulsed current without facet coatings or heatsinking. Threshold current of the TRAFFiC laser, Fig. (2), is 160 mA compared to 82 mA for the uniform 2-μm wide control. Output matches that of the control laser at the maximum tested current of 300 mA. This suggests that these first TRAFFiC lasers have increased optical losses or saturable absorption in regions of low injection current along the taper which might be reduced with optimized processing and electrical contacting.

Near-field images, Fig.(3), of the TRAFFiC laser show it to have a much larger fundamental optical mode as compared to the 2 μm control device. The back facet emission image of the TRAFFiC laser is indistinguishable from that of the control laser. No evidence of high-order modes is seen at any tested current level. Measurements of 7° and 6° FWHM along the two principal axes of the far-field emission pattern further support the conclusion that the TRAFFiC structure is expanding the output mode as expected. The only evident deviation from expected behavior is seen in the height of the output mode. As seen in Fig. (1), the output mode is intended to be roughly as tall as it is wide. These first TRAFFiC lasers have a rectangular output mode filling the etched mesa but not extending significantly into the cladding beyond the vertical extent

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observed well above lasing threshold. This new TRAFFiC laser is suitable for use where low optical fiber coupling loss or low beam divergence are desired. Such applications include pump sources for Er^{+}-doped fiber amplifiers and optical range sensing.

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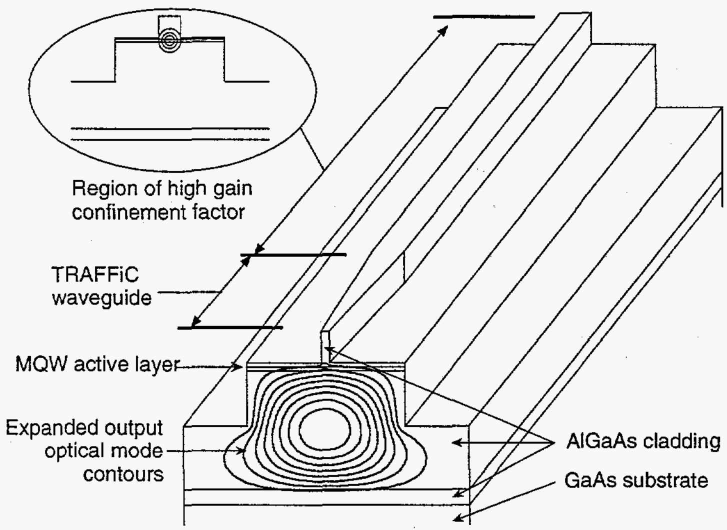

Figure 1: Representation of the TRAFFiC laser showing the tapered-rib upper cladding shape and the approximate form and size of the optical mode in the active gain section of the wide rib region (inset) and the expanded size and shape of the output optical mode at the cleaved end where the rib is most narrow.

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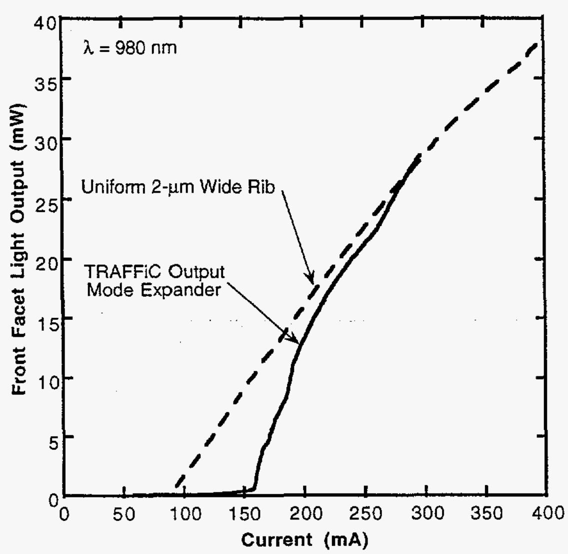

Figure 2: Threshold characteristics of TRAFFiC and 2-µm wide control lasers. Data is for 1 µs pulses at 1 kHz repetition rate.

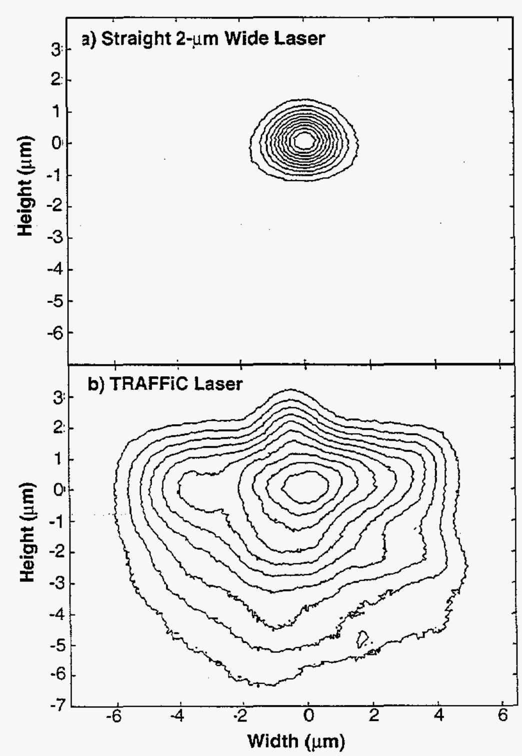

Figure 3: Contour plots of measured near-field emission intensity pattern of expanded-mode TRAFFiC laser and 2-µm-wide control laser.