Highly-Efficient Laser with Self-Aligned Waveguide and Current Confinement by Selective Oxidation

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We report highly efficient, low-threshold-current edge-emitting lasers where both the optical waveguide and lateral current confinement are achieved by lateral selective oxidation of AlGaAs. External differential quantum efficiency in excess of 95% and 40% wall-plug efficiency are demonstrated in 600 μm -long devices without facet coatings. Shorter, 300- μm -long, uncoated devices have <6 mA threshold currents. This high-performance is a combined result of placement of the oxide layers so as to achieve the minimum optical mode volume and bi-parabolic grading of the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ heteroepitaxy for minimum height potential barriers, less than 15 meV, created by the wide-energy-gap layers required for selective wet oxidation.

Since the initial development of wet AlGaAs oxidation methods, a number of oxidized edge-emitting laser concepts have been tried. The most successful of these have used lateral selective oxidation of AlGaAs layers between 100 and 300 nm thickness. These layers have been used as current restricting apertures^{1,2} or for both current restriction and lateral waveguiding.^{3,4} Use of an oxide layer above and below the laser active region offers the ability to create a self-aligned waveguide with current apertures on both sides of the pn-junction in a process requiring only one epitaxial growth step. Previous use apertures for these dual purposes resulted multi-moded lasers with reduced efficiency and elevated threshold current density due to non-ideal formation of the waveguide and possibly excess stress caused by the thick (300 nm) oxide layer.³

We present a highly efficient, low-threshold-current edge-emitting laser with dual oxide waveguiding apertures. The Buried Oxide Waveguide (BOW) laser is shown in Fig. (1) as a numerical simulation of the optical mode overlaid onto the layer structure of the guide. The BOW laser design has high optical and current confinement resulting from optimized placement of the oxide layers and selection of the aperture width. This has been achieved by 2D simulation of the waveguide as shown in Fig. (1). Oxidation-induced stress is minimized by the use of thin, 40 nm, oxidation layers. A key aspect of design of a BOW laser for high efficiency is the potential barrier created by the heterojunction offset between the oxidation layer, having as much as 98% Al content, and the surrounding waveguide cladding, where Al content does not usually exceed 60%. Reduction of these barriers through engineered grading of the heterojunction has improved vertical-cavity laser performance but these techniques have

not been used in edge-emitters prior to this work. In fact, edge-emitters present a much larger design space for use of graded interfaces allowing for greater reductions in barrier height. Using 1D simulations of the heterojunction band structure, the potential barrier height of these new BOW lasers has been reduced to less than 15 meV for both the p-type and n-type high-

Fig. 1: Schematic of the BOW laser waveguide with superimposed numerical simulation of the laser optical mode. Selectively-oxidized layers forming the lateral waveguide and current aperture are shaded in gray.

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Al-content layers. This low barrier is a consequence of using fully bi-parabolic graded interfaces and is more than an order of magnitude smaller than barriers typically built into uni-parabolic graded VCSEL interfaces.

Lasers were fabricated using MOCVD (Al,Ga)As on n-type-doped GaAs substrates. Waveguide material is 60% Al with 175 nm thick grade between 60% and 30% Al forming a separate confinement heterostructure waveguide around a 10 nm GaAs quantum well active region. 98% Al AlGaAs layers for selective oxidation are located on both sides of the graded waveguide. Mesas between 20 and 40 μm wide were etched through to the substrate and steam oxidation at 420° C used to create oxide layers leaving apertures between 2.3 μm and 25 μm in width. SiO_2 was deposited between the mesas to insulate the n-type material from the top ohmic contact and the entire mesa surface was used to form the upper p-type ohmic contact. Fig. (2) is and SEM cross section of a completed laser. The gap between the darkest gray laterally oxidized regions is clearly seen.

Lasers were tested p-side up without heat sinking or facet coatings using 1 μs pulses at 10 kHz repetition rate. Fig. (3) shows pulsed light-versus-current data for 300- μm - and 600- μm -long BOW lasers with 4- μm -wide waveguide apertures. The 300 μm laser (top) has a threshold current, I_{th} , of <6 mA and a threshold density, J_{th} , of 486 A/cm². The slope efficiency is constant at 1.15 W/A for all tested currents. The 600 μm laser (bottom) has I_{th} = 8.7 mA, J_{th} = 307 A/cm², and slope efficiency of 1.48 W/A (assuming equal power from rear facet.) At the operating wavelength these devices have external differential quantum efficiencies of 0.79 (short laser) and >0.95 (long laser). Wall-plug efficiency of the long laser peaks at 40%.

In summary, we have demonstrated a highly efficient BOW laser using dual selectively-oxidized AlGaAs layers to form both the optical waveguide and the current confinement regions. Optimization of the waveguide design, oxide layer placement, and bi-parabolic grading of the heterointerfaces on both sides of the AlGaAs layers for oxidation has yielded 95% external differential quantum efficiency and 40% wall-plug efficiency from a laser that is very simple to fabricate and does not require epitaxial regrowth of any kind.

- 1) Y. Cheng, G. Yang, M. MacDougall and P. Dapkus, IEEE Phot. Technol. Lett. 7, 1391-1393 (1995).
- 2) W.-J. Choi and P. D. Dapkus, IEEE Phot. Technol. Lett. 11, 773-775 (1999).
- 3) S. A. Maranowski, A. R. Sugg, E. I. Chen and N. Holonyak, Appl. Phys. Lett. 63, 1660-1662 (1993).
- 4) J. Heerlein, M. Grabherr, R. Jager and P. Unger, IEEE Phot. Technol. Lett. 10, 498-500 (1998).

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Fig. 2: SEM cross-section image of completed BOW laser.

Fig. 3: Output power per facet and total wall-plug efficiency of two lengths of BOW laser.