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Deep Oxidation of AlGaAs Heterostructures for Strongly-Confined Optical Waveguides

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Impurity-induced layer disordering (IILD), when used in conjunction with wet thermal oxidation to first intermix fast (high x) and slow (low x) oxidizing layers, has been shown to enable deep oxidation through a conventional $Al_xGa_{1-x}As$ quantum well heterostructure (QWH) for the fabrication of low-loss, high-index-contrast, tightly-curved buried channel waveguides (WGs).[1] Without the IILD step, higher x confinement layers typically oxidize laterally beneath the mask, pinching off the current path to the active stripe before oxidation can proceed downward through the lower x WG layers. Photon-enhanced anisotropic oxidation along *p-n* junctions has also been observed, presenting an additional obstacle to deep oxidation of non-disordered heterostructures.[2] We report here the achievement of deep-oxidation, avoiding these problems *without use of the IILD process*, by applying a process gas modification which substantially decreases the oxidation rate selectivity between high and low Al composition AlGaAs.

Normally, ultra high purity (UHP) N_2 is used as the H_2O carrier gas during the wet thermal oxidation of AlGaAs. We have previously investigated in detail how oxidation rates, oxide refractive index and surface roughness depend upon added O_2 concentration (0-5% O_2 to N_2 ratio) during the wet oxidation of $Al_xGa_{1-x}As$ ($x\leq0.8$).[3] Due to a proportionately greater rate enhancement for low x materials, the rate selectivity between high and low x AlGaAs is substantially reduced. For example, at 450 °C the rate selectivity R(x=0.8)/R(x=0.3) decreases from (30.2 nm/min)/(1.77 nm/min)=17.1X in UHP N_2 to 43.2/17.9=2.4X with the addition of 7000 ppm O_2 to N_2. We present here the application of this rate selectivity modification to the fabrication of buried-channel index-guided WGs. We utilize a conventional separate-confinement QWH laser diode structure grown by MOCVD: a 10 nm GaAs QW sandwiched by two undoped 75 nm $Al_{0.20}Ga_{0.80}As$ waveguiding layers and p-type upper and n-type lower $Al_{0.80}Ga_{0.20}As$ current confinement layers of thickness around 1 µm, with a 50 nm p^+ cap layer. Wet oxidation of this heterostructure at 451 °C is compared for different times with both ridge and planar geometries and with both UHP N_2 and 7000 PPM O_2+N_2. For planar structures, a 7-8 µm Si_3N_4 masking stripe is used to protect the GaAs cap layer. With UHP N_2, SEM micrographs reveal that in 90 min the oxidation front progresses laterally 2.1 µm under the mask, but barely penetrates into the upper x=0.2 WG layer. In contrast, in 50 min. with added O_2 and lateral oxidation of 2.6 µm, the oxide penetrates through the WG to a depth of 1.3-1.5 µm, simply forming an index-guided WG with strong optical confinement. Penetration is deeper under the nitride mask edge, suggesting a stress or defect-related oxidation enhancement. For both planar and ridge geometries, with and without O_2 addition, we observe little to no anisotropic oxide "spike" formation as seen in Ref. [2], suggesting that effect may be growth dependent and not a fundamental limitation for formation of deep-oxide waveguides. The ability to oxidize through a complete AlGaAs heterostructure WG with a simple one-step process enables new possibilities for III-V integrated optics and optoelectronics.

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