Continuous-wave operation of a $(20\overline{2}\overline{1})$ InGaN laser diode with a photoelectrochemically etched current aperture

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Theoretical and experiment analysis have shown that undercut etching of the active region of optoelectronics devices can improve their performance.[1] Reduction of InGaAsP active layer from InP-based laser diode (LD) and modulators has been obtained by selective wet etching.[2,3] Unfortunately, III-nitride materials have shown to be resistant to all of the conventional wet etching techniques and rely mainly on chlorine-based dry etching methods. Although they can achieve a reasonably fast etch rate (up to a few hundred nm/min) and near-vertical sidewall profiles, these techniques can produce sub-surface damage to the epitaxial structure which reduce the performance, reliability and lifetime of the final devices. Moreover, they do not allow any controllable undercut in the lateral direction.

In contrast, photoelectrochemical (PEC) etching has emerged as a promising wet etching technique for III-nitride materials[4], having already been applied successfully to Si and other III-V compounds. Using PEC-Etch, we have fabricated blue edge emitting current aperture $(20\overline{2}\overline{1})$ laser diodes (CA-LD) by selectively undercutting the InGaN/GaN multiple quantum well (MQW) active region. The performance of the current aperture edge-emitting laser diodes (CA-LDs) was compared to shallow etched ridge LDs with a nominally identical epitaxial structure. The threshold current density, threshold voltage, peak output power and series resistance for the CA-LD (shallow etched LD) with a 2.5 μm wide active region were 4.4 (8.1) kA/cm^2, 6.1 (7.7) V, 96.5 (63.5) mW, and 4.7 (6.0) Ω under pulsed conditions and before facet coating. CW operation of a CA-LD with a 1.5 μm wide active region was demonstrated after facet coating.

Measurements of the injection efficiency and loss by sequentially trimming the cavity length by FIB etching cut back, indicate an injection efficiency of ~65% and a differential efficiency of only 13%. These problems can be attributed to excessive losses. These can be attributed partly to un-optimized epitaxial structure and growth conditions (internal loss), partly to leakage current through unetched nanopillars, and partly to scattering losses from rough PEC-etched edges of the active region. Nano-columns, which may be associated with defects and threading dislocations, can act as effective nonradiative recombination centers and locally impede the PEC etching, resulting in current leakage paths. Rough sidewalls, as observed in fluorescent microscopy images, can produce excessive scattering loss caused by the continuous change of the refractive index of the active region along the propagation direction of the light[5]. This effect is particular pronounced in narrow ridge waveguides. Numerical modeling supports this explanation. Further analysis is ongoing.

References

[1] J. E. Bowers, B. R. Hemenway, A. H. Gnauck, T. J. Bridges, E. G. Burkhardt, D. P. Wilt and S. Maynard, *High-frequency constricted mesa lasers*, Appl. Phys. Lett. **47**, 78 (1985).
[2] D. Pasquariello, E. Bjorlin, D. Lasaosa, Y.-J. Chiu, J. Piprek, and J. Bowers, *Selective undercut etching of InGaAs and InGaAsP quantum wells for improved performance of long-wavelength optoelectronic devices*, J. Lightwave Technol. **24**, 1470 (2006).
[3] M. M. Dummer, J. R. Raring, J. Klamkin, A. Tauke-Pedretti, and L. A. Coldren, *Selectively-undercut traveling-wave electroabsorption modulators incorporating a p-InGaAs contact layer*, Opt. Express **16**, 20388 (2008).
[4] M.S. Minsky, M. White, E.L. Hu, *Room-temperature photoenhanced wet etching of GaN*, Appl. Phys. Lett. **68**, 1531 (1996).
[5] F.P. Payne and J. P. Lacey, "*A theoretical analysis of scattering loss from planar optical waveguide*", Opt. Quantum Electron. **26**(10), 977-986 (1994).

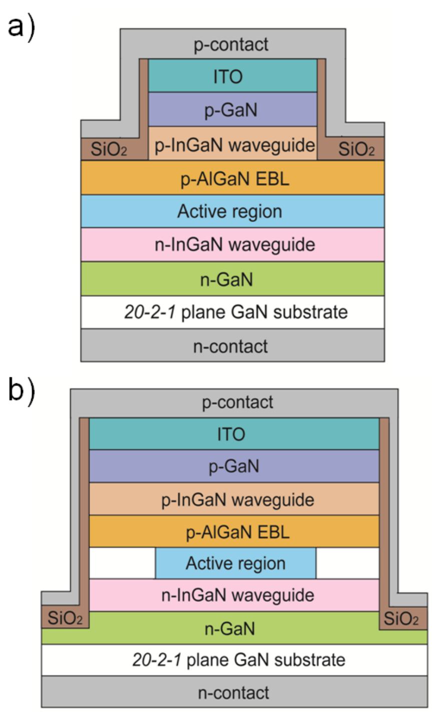

Fig. 1 Schematic of (a) the shallow ridge waveguide LD and (b) the CA-LD.

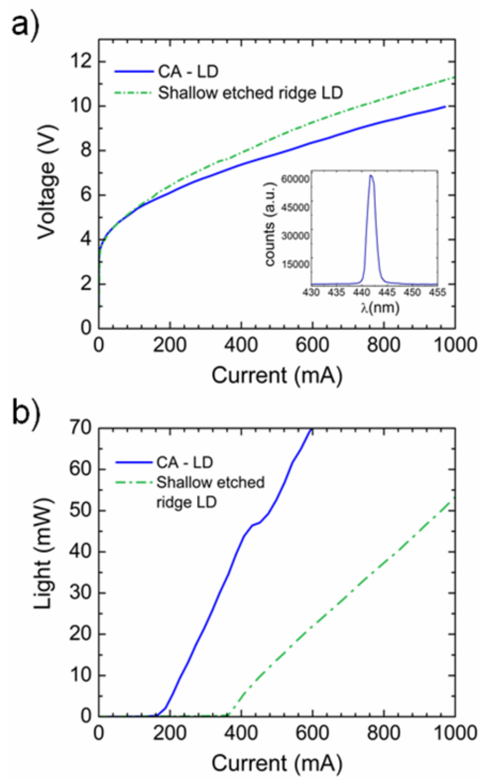

Fig. 2 (a) I-V and (b) L-I characteristics for an 1800 μm long by 2.5 μm wide shallow etched ridge waveguide LD and a 1800 μm long by 8 μm wide CA-LD with a ~2.5 μm wide active region after PEC etching, under pulsed operation. Inset: emission spectrum at 120mA showing lasing operation at 442nm.

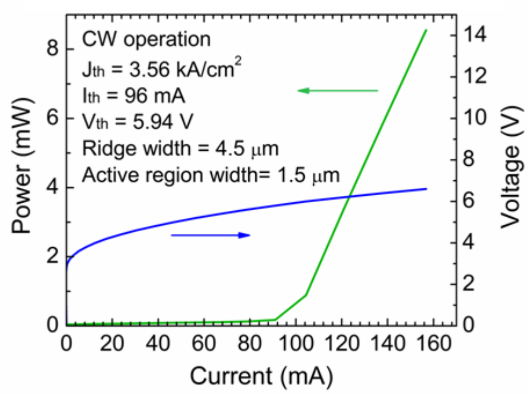

Fig. 3 L-I-V for an 1800 μm long by 4.5 μm wide CA-LD with a ~1.5 μm wide active region after PEC etching under CW operation.

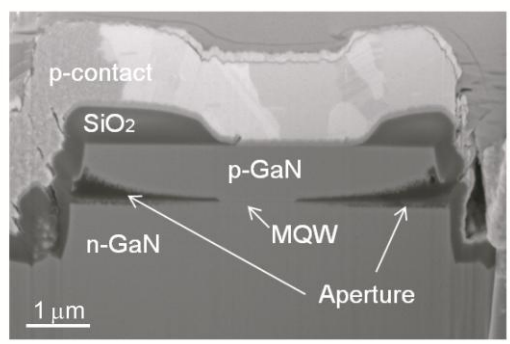

Fig. 4 SEM image of a facet of a CA-LD after FIB.

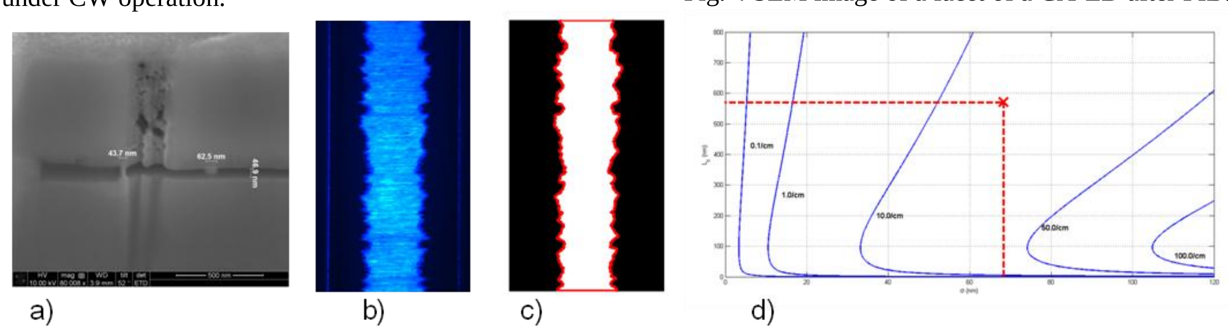

Fig. 5 a) Details of the aperture showing nanopillars, b) and c) Fluorescent image of a PEC etch LD and extraction of the active region contour by image analysis processing, d) Contour map of loss against L_c and σ for PEC etched LD emitting at 440nm and having an active region with cross-sectional dimensions of $\mathbf{1500 \cdot 50}\ \boldsymbol{nm^2}$, the “x” mark indicates the estimated scattering loss.