Waveguide Design and Its Impact on Ultraviolet-A III-Nitride Diode Lasers

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Ultraviolet-A (UV-A) (λ - 375nm - 410nm) laser diodes are extremely important for optical storage, medical, defense, aerospace applications, etc. [1-2]. III-Nitride material system has been utilized to obtain high-performance UV-A lasers [1-2]. The epitaxial material design includes a waveguide, cladding, contact layers, and active region, which form the essential components of a robust, high-performance laser. In this study, we focused on understanding the impact of waveguide thickness on the performance of 390 nm GaN laser diodes.

The device epitaxial structure was grown by MOCVD on a patterned sapphire substrate. Sample A, B and C have the same layer structure except for the waveguide thickness. Sample A and C have a symmetric design with waveguide thicknesses of 500 nm and 100 nm on each side, respectively. Sample B has an asymmetric design where the waveguide on the n-side is 500 nm and the waveguide layer on the p-side was 100 nm. Sample C has a narrow waveguide design with an optical confinement factor of 3.1%, while the broad waveguide designs (Samples A and B) have optical confinement factors of 0.8% and 1%, respectively. The improved confinement factor was obtained at the expense of a higher loss for Sample C (~9x compared to Sample A and Sample B).

We fabricated ridge waveguide laser diodes with varied ridge widths (10 µm to 25 µm) and cavity lengths (250 µm to 1000 µm) on these three epitaxial structures. The devices from three structures were tested under pulsed conditions with a pulse width of 200 ns and a frequency is 20 kHz. The laser behavior was observed from sample C with a threshold current density of ~5 kA/cm^2, while the laser behavior for structure A and structure B was not observed with a current density >15 kA/cm^2. This can potentially be explained by the relatively lower optical confinement factors in the broad waveguide laser structures (Samples A and B), which result in significantly larger threshold material gains in this structure. Mirror coating will be done in the future to bring down the loss to compensate for the lower optical confinement factors.

The devices from sample C have a threshold current density ranging from 5kA/cm^2 to 10kA/cm^2, with a full-width half maximum of the emission spectrum close to 2 nm. The maximum power observed was ~250 mW (both facets) for a cavity length of 500 µm and ridge width of 15 µm. These results are comparable to the laser performance results obtained in the literature with ridge waveguide lasers fabricated on sapphire substrates [3].

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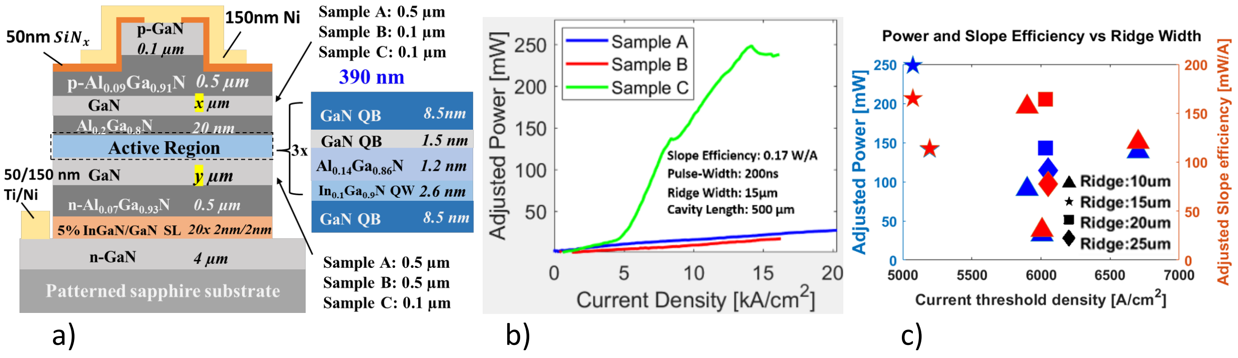

Fig. 1 a) Laser design for Samples A, B and C. b) Adjusted Power (measured power over duty cycle) v/s current density for sample A, B and C. Only sample C demonstrated laser behavior. c) Ridge-width v/s Power (blue) & Slope efficiency (red) for sample C.

References: 1) The 2020 UV emitter roadmap, Hiroshi Amano *et al.* 2020 J. Phys. D: Appl. Phys. 53 503001. 2) Recent development of UV-B laser diodes, Motoaki Iwaya et al 2022 Jpn. J. Appl. Phys. 61 040501. 3) High-power and wide wavelength range GaN-based laser diodes, T. Kozaki, et al., Proc.SPIE 6133, Novel In-plane Semiconductor Lasers V, 613306, 2006