SAND2015-5420C

INVITED PRESENTATION

IEEE Photonics Society 2015 Summer Topicals Meeting,

Nassau, Bahamas

July 13-15, 2015

350-nm-band edge-emitting laser diodes enabled by low-dislocation-density AlGaN templates

Mary H. Crawford, Andrew A. Allerman, Andrew M. Armstrong, Jonathan J. Wierer, Weng W. Chow, Michael W. Moseley, Michael L. Smith and Karen C. Cross

Sandia National Laboratories, Albuquerque, NM, USA

Overgrowth of submicron-patterned AlGaN epilayers was applied to achieve crack-free templates with 10x reduction in threading dislocation density. This approach enabled low-threshold 346 nm optically-pumped lasers and room-temperature, pulsed-current UV laser diodes at 352 nm.

350-nm band edge-emitting laser diodes enabled by low-dislocation-density AlGaN templates

Mary H. Crawford, Andrew A. Allerman, Andrew M. Armstrong, Jonathan J. Wierer, Weng W. Chow, Michael W. Moseley, Michael L. Smith and Karen C. Cross

Sandia National Laboratories, Albuquerque, NM, USA

Realization of efficient laser diodes with ultra-violet (UV) emission from ~260-360 nm would enable many applications including fluorescence-based biological agent detection, sterilization, and portable water purification. While InGaN-based laser diodes are well developed down to ~370 nm, achieving shorter UV wavelengths requires higher Al-content AlGaN alloys with increasing challenges in achieving p-type doping, strain-management, and low threading-dislocation-density (TDD) AlGaN templates. Given these challenges, few groups have reported AlGaN-based edge-emitting laser diodes (LDs) with emission < 355 nm.[1, 2] Most recently, random lasing *via* Anderson localization in AlGaN nanowire structures has demonstrated a novel approach to realizing deep-UV laser diodes.[3]

With bandgaps that are tunable from ~210-365 nm, AlGaN alloys have emerged as highly promising materials for realizing UV laser diodes. However, a key challenge has been achieving low threading dislocation densities; an essential feature to realizing high performance, reliable laser diodes. This challenge arises from the lack of a lattice-matched substrate for mid-range compositions (~0.2 < x ~0.8) which makes it difficult to grow thick epilayers without out cracking and with TDD less than 10^9 cm^{-2}. Previously, $Al_xGa_{1-x}N$ templates (x = 0.18-0.3) with TDD in the low 10^8 cm^{-2} were reported for AlGaN overgrown on faceted GaN (11-22) pyramids [2] and on etched trenches in GaN [1] or AlGaN [4].

Here, we report a distinct method for fabricating crack-free AlGaN templates with TDDs in the low 10^8 cm^{-2}. Using an approach similar to Tsuzuki *et al.* [4], we employ AlGaN overgrowth of patterned AlGaN templates as a dislocation reduction strategy. However, unlike previous reports, our starting patterned $Al_{0.3}Ga_{0.7}N$ template employs very narrow and high density features, namely submicron-wide-mesas on a 2 μm pitch. Overgrowth of narrow mesas yields spatially-uniform TDDs of 2-3 x 10^8 cm^{-2}, eliminating the need to align laser diodes to lower-defect striped regions. Unlike previously-reported faceted GaN templates which absorb λ < 365 nm [1], these AlGaN templates have an AlN buffer layer and thus are also suitable for bottom-emitting UV LEDs. We further employed 1.3 mm-thick sapphire substrates (3x thicker than standard for 2-inch wafers) for epi-growth. These substrates eliminated layer cracking and reduced wafer bow to less than 15 μm, enabling fabrication of narrow (2 μm) ridges over the wafer. Using this approach, we have demonstrated similarly low TDDs in $Al_{0.7}Ga_{0.3}N$ epilayers which are relevant to the UV-C region.

We applied this AlGaN template approach to achieve room-temperature, pulsed-current operation of AlGaN-based UV laser diodes with emission at 352 nm. The resulting ridge-waveguide lasers have threshold current densities of ~22 kA/cm^2 and were operated to peak output powers to > 2.5 mW per facet. Lasers were fabricated with 2-4 μm-wide ridges, 0.7 to 1.3 mm-long cavities and etched facets. The heterostructure design differed from previous reports [1, 2] by utilizing doped waveguide layers and an electron blocking layer between the MQWs and p-waveguide layer. Optical pumping of undoped heterostructures employing GaN/AlGaN MQWs, $Al_{0.2}Ga_{0.8}N$ waveguides, a $Al_{0.3}Ga_{0.7}N$ bottom cladding and etched facets on low-TDD AlGaN templates yielded room-temperature lasing at 346 nm with a threshold of 50 kW/cm^2. This low optically-pumped lasing threshold suggests that optimization of the p-type cladding and waveguide doping profiles to minimize optical loss while maintaining effective current injection will lead to lower threshold current densities in laser diode structures.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

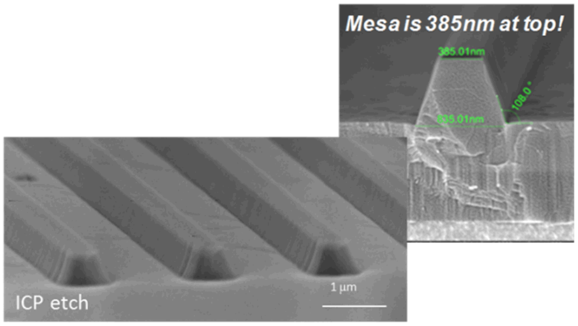

Figure 1. SEM images of trenches and mesas in an $Al_{0.3}Ga_{0.7}N$ template prior to overgrowth. The submicron mesa width and narrow trenches are key to reducing dislocations in the overgrowth layer.

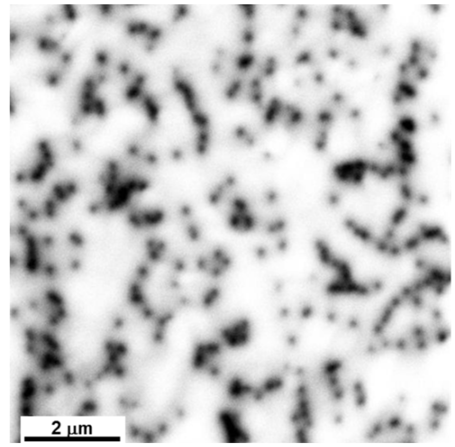

Figure 2. Cathodoluminescence image from MQWs grown on an $Al_{0.3}Ga_{0.7}N$ overgrowth / patterned template. (TDD is approximately 2-3 x10^8 cm^{-2})

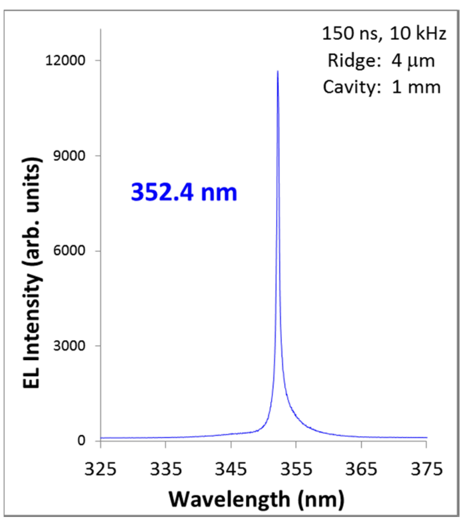

Figure 3. Room-temperature, pulsed-current laser emission at 352.4 nm from an AlGaN-based ridge waveguide laser diode.

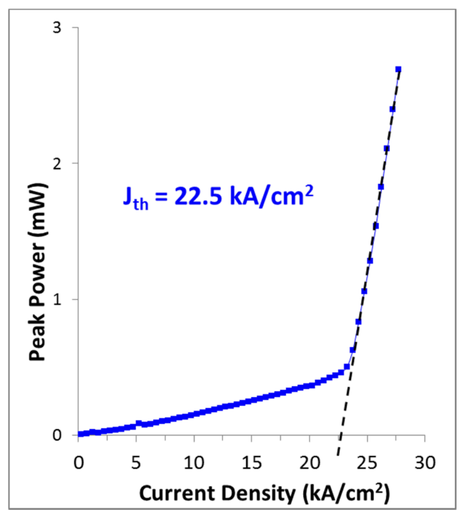

Figure 4. L-I characteristics under pulsed-current injection with a lasing threshold current density of 22.5 kA/cm^2.

[1] Iida, *et al.* Jpn. J. Appl. Phys. **43** L499 (2004).
[2] Yoshida, *et al.* Jpn. J. Appl. Phys. **46** 5782 (2007).
[3] Li *et al.,* Nat. Nanotechnol. 10, 140 (2015).
[4] Tsuzuki, *et. al.* Phys. Stat. Sol. (a) **206** 1199 (2009).