

# Vertical conduction and ultraviolet laser diodes on bulk gallium nitride

Hamamatsu's 356.6nm UV laser diode has a bulk GaN substrate that also enables cleaving, improving far-field pattern.

**H**amamatsu Photonics K. K. of Japan has developed 356.6nm-wavelength ultraviolet laser diodes (LDs) on bulk gallium nitride (GaN), allowing a vertical conduction scheme [Yuta Aoki, Appl. Phys. Lett., vol107, p151103, 2015]. The researchers say that there has been no previous report on aluminium gallium nitride (AlGaN) UV LDs on bulk GaN.

Instead, devices grown on sapphire have to adopt a lateral conduction scheme where the electrodes must reach the contact layers from the same side, since the substrate is electrically insulating.

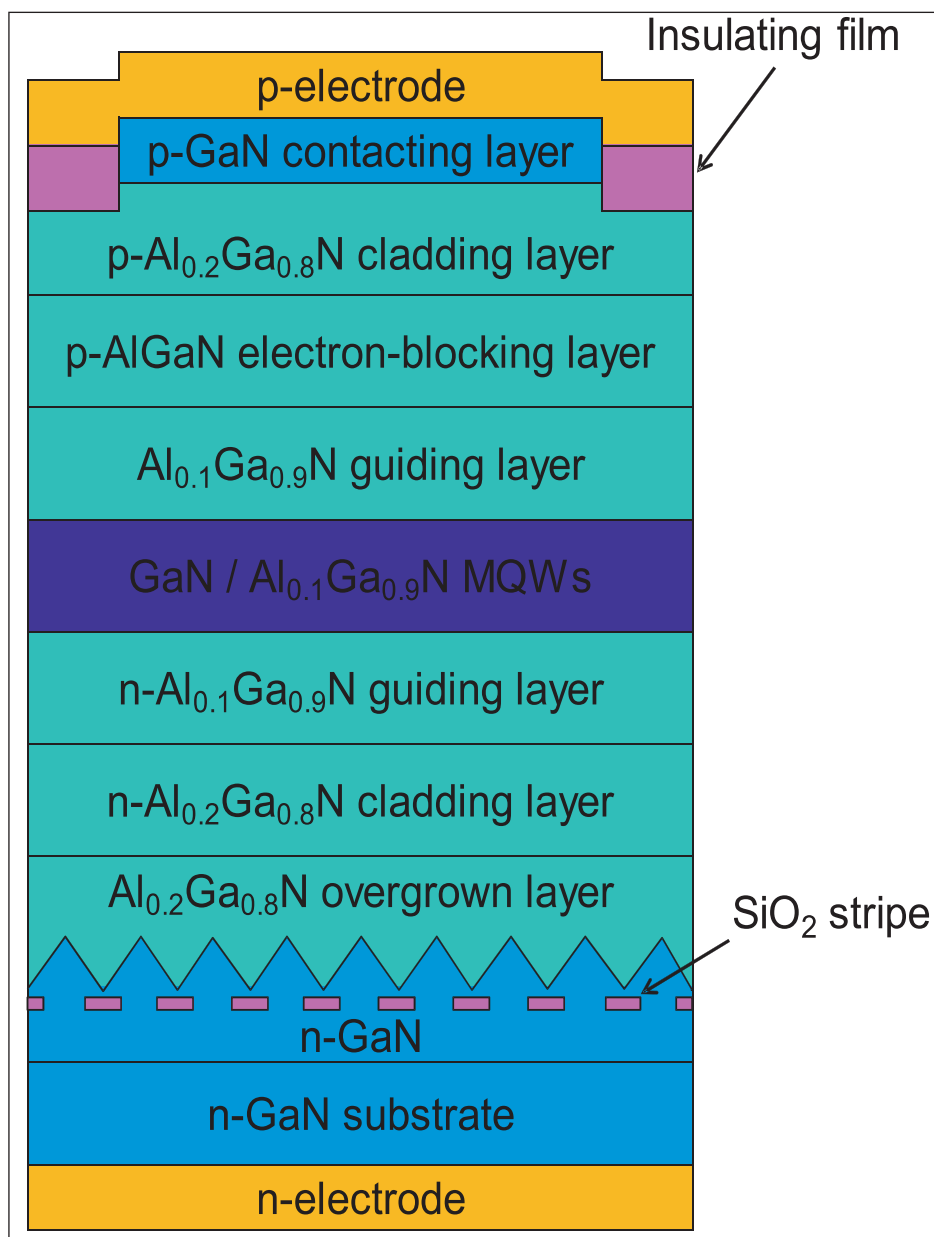
The researchers comment: "The vertical conductive structure is expected to open the path to high-output-power laser diodes." They see potential application in broad-area striped configurations and arrayed as multiple emitters for material processing.

The vertical conduction scheme could also allow junction-down assembly for improved thermal management.

The use of bulk GaN and a vertical conduction scheme also enables cleaving of the crystal wafer to give smooth reflecting facets for the laser cavity. Sapphire substrate laser diodes are difficult to cleave and dry etching is usually adopted, which results in poor shaping of the emitted laser light.

UV LDs are of interest for chemical analysis and material processing. The alternatives such as gas or solid-state lasers suffer from problems with energy efficiency, stability, warming-up time, and compactness.

The epitaxial structure (Figure 1) was grown on bulk n-GaN using metal-organic chemical vapor deposition



**Figure 1. Schematic cross-sectional diagram of GaN/AlGaN multiple quantum well (MQW) UV-LD fabricated on GaN substrate.**

(MOCVD). Lateral overgrowth was used to improve crystal quality. This involved creating periodic silicon dioxide stripes and then growing inclined-facet

GaN seed crystals in the region between the stripes. This allowed overgrowth of high-quality, crack-free  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ , which formed the template for subsequent layers. The researchers expected the crystal quality to be similar to overgrown layers on sapphire.

The target wavelength was around 350nm, comparable to recent work on sapphire substrates.

The material was fabricated into 1.5 $\mu\text{m}$  ridge waveguide laser diodes. The dry etching for the ridge also exposed the p-GaN contact layer for p-electrode deposition. The n-electrode was applied after thinning of the n-GaN substrate to 100 $\mu\text{m}$  thickness by grinding and polishing. The mirror facets for the 300 $\mu\text{m}$ -long laser cavity were created by cleaving the device wafers. The facets were not coated to increase reflectivity.

The devices were tested at room temperature using 10ns pulses with 5kHz repetition. The threshold current was 250mA (56kA/cm<sup>2</sup>). A 359.6nm laser diode on sapphire has achieved 8kA/cm<sup>2</sup> threshold. The Hamamatsu researchers believe that lower thresholds for their device on GaN could be achieved by optimizing the crystal growth and laser design.

The laser output power reached 10mW from one facet at  $\sim 300\text{mA}$ . The slope efficiency and external quantum efficiency (EQE) were estimated at 0.24W/A per facet and 14% for both facets, respectively.

The threshold voltage was around 20V, similar to the values obtained on sapphire. The researchers attribute the high voltage to the narrower ridge and short cavity compared with reported sapphire devices.

The spectrum of the emission peak had a full width at half maximum (FWHM) of  $\sim 6\text{nm}$  below threshold (190mA) and 0.4nm above threshold (275mA). The above threshold value was close to the resolution limit of the spectrometer. The radiation was strongly transverse electric polarized, as expected from the optical gain characteristics of GaN/AlGaIn MQWs and the reflectivity of the facets.

The far-field pattern (FFP) of the laser radiation was Gaussian-like in the horizontal and vertical directions, unlike devices on sapphire, which suffer from severe distortion (Figure 2). The researchers comment: "The deteriorated FFP of the UV-LD on sapphire substrate is considered to be caused by the interference between the direct beam from the mirror facet and the reflected beam from the residual terrace lying down in front of the etched mirror facet. The cleaved mirror facets provide the highly improved FFP." ■

<http://dx.doi.org/10.1063/1.4933257>

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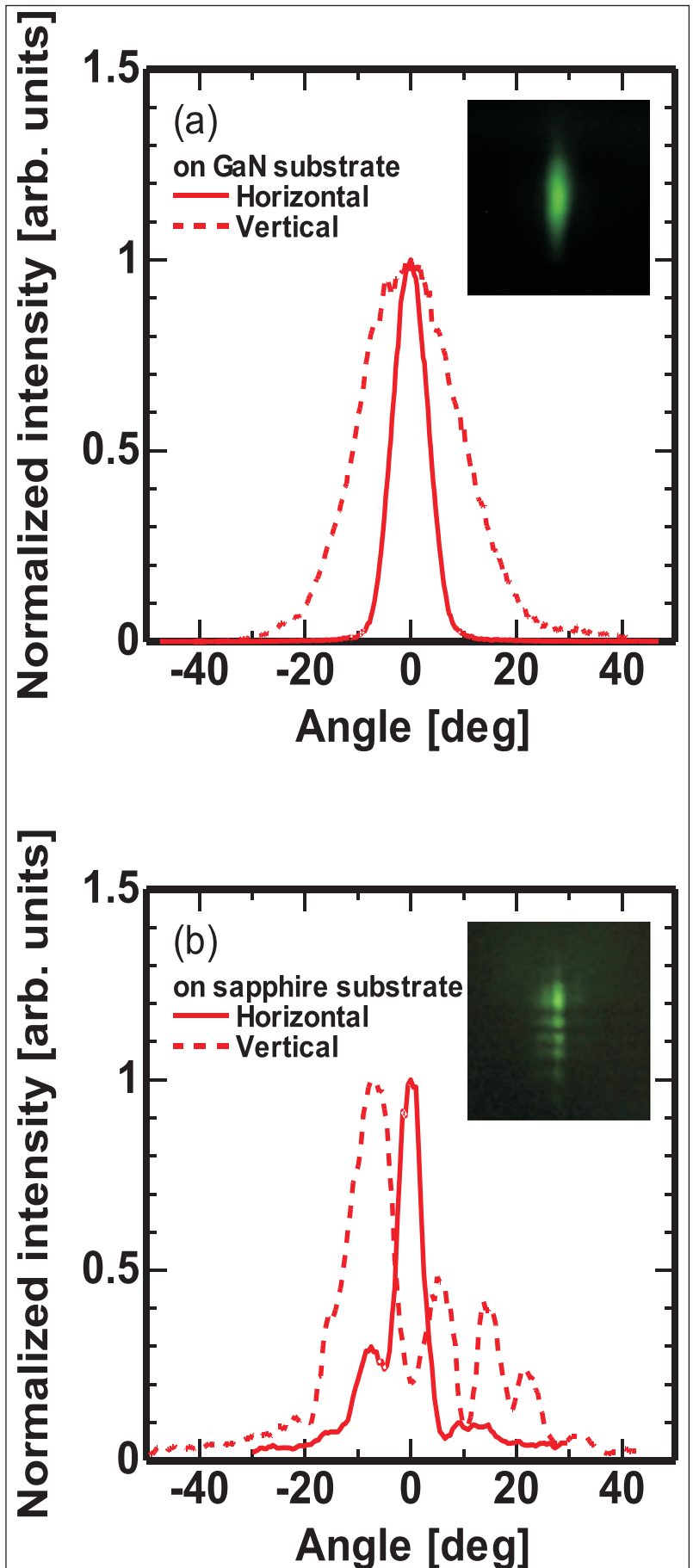


Figure 2. FFPs of UV-LD on (a) GaN substrate (with cleaved mirror facets) and (b) sapphire substrate (with etched mirror facets). Inset: photos of each FFP.