Reducing LED droop at high current with nitrides

UCSB and Mitsubishi Chemical produce first blue-violet LEDs on (20$\bar{2}\bar{1}$) GaN.

University of California Santa Barbara (UCSB) and Japan's Mitsubishi Chemical Corp have produced blue-violet light-emitting diodes (LEDs) with high output power and low droop by using (20$\bar{2}\bar{1}$) indium gallium nitride (InGaN) structures "for the first time" [Yuji Zhao et al, Appl. Phys. Express, vol4, p082104, 2011].

The reduced droop of the device up to injection current of 200A/cm^2 is described as "outstanding" (Table 1), being only 14.3% at the upper limit. "To the best of the authors' knowledge, such a low droop has not been reported at current densities of 200A/cm^2," the team comments.

The researchers are working to improve the performance of LEDs for general lighting. This requires more cost-efficient devices with higher output power. Unfortunately, nitride-based LEDs have a tendency to be less efficient at higher injection currents/output power — a phenomenon often referred to as 'droop'.

Although UCSB's own theoretical team under professor Chris Van de Walle blames an indirect Auger recombination process for droop (www.semiconductor-today.com/news_items/2011/APRIL/UCSB_200411.html), other research groups continue to dispute this.

One approach that might ameliorate the droop effect is to use nitride semiconductors oriented in semi-/non-polar directions, rather than the usual c-plane crystals that have strong polarization fields. These polarization effects lead to electric fields in the active region of the device, which tend to separate the electrons and holes that researchers want to recombine as light emission.

The semi-polar (20$\bar{2}$1) orientation has recently been investigated for producing longer-wavelength green-emitting devices, including lasers. The UCSB devices use the opposite orientation of (20$\bar{2}\bar{1}$) (Figure 1).

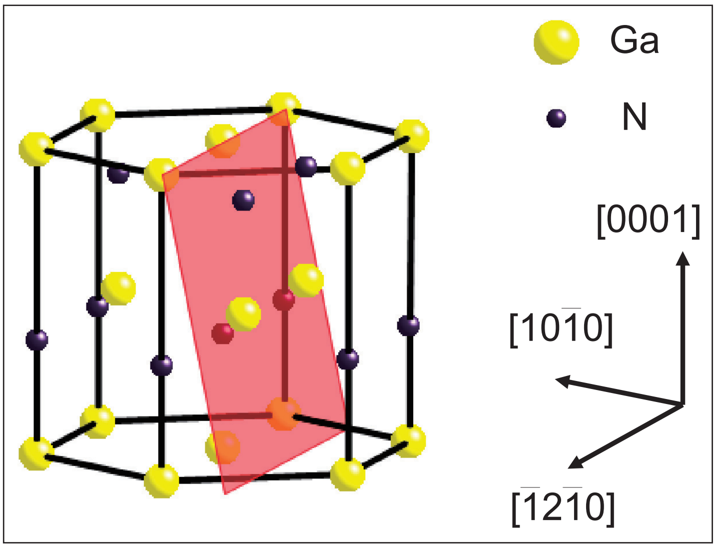

Figure 1. Schematic view of semi-polar (20$\bar{2}\bar{1}$) plane in the wurtzite crystal structure.

Table 1. EQE and droop performance of semi-polar blue-violet (20$\bar{2}\bar{1}$) LED at various current densities.

Current density (A/cm^2)	35	50	100	200
EQE (%)	52.6	50.7	48.4	45.3
Droop (%)	0.7	4.3	8.5	14.3

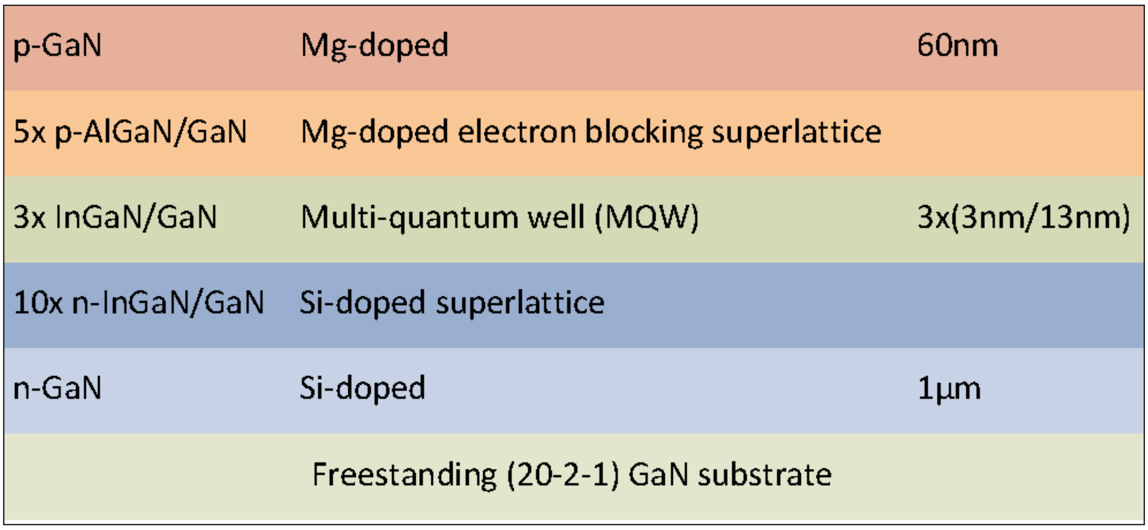

Figure 2. Epitaxial structure used in UCSB LEDs.

Mitsubishi Chemical supplied the free-standing $(20\bar{2}\bar{1})$ GaN substrates on which the epitaxial structures (Figure 2) were grown using MOCVD.

To make the LEDs, the epitaxial material was covered with an indium tin oxide (ITO) current-spreading layer before rectangular mesa structures were etched with chlorine-based inductively coupled plasma and then metal contacts and pads were applied (Figure 3). Backside roughening of the LED structure was performed to enhance light extraction by reducing reflection back into the device at the GaN–air interface due to refraction index differences. The devices were packaged in transparent vertical-stand structures.

Room-temperature pulsed electroluminescence measurements with 1% duty cycle were carried out up to injection current densities of 200A/cm^2 (Figure 4). The researchers comment that the 20mA output power of 30.6mW and external quantum efficiency (EQE) of 52% "are comparable to the best values ever reported for semi-polar or non-polar LEDs". These 'best values' were reported in 2010 by UCSB and Mitsubishi themselves [http://apex.jsap.jp/link?APEX/3/102101/] as being 31.1mW and 54.7%, respectively.

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The spectral properties of the emissions at different injection currents were also investigated. The peak wavelength shift up to 200A/cm^2 is described as 'negligible', "indicating greatly reduced polarization-related electric fields inside the QWs [quantum wells]". The peak wavelength is about 423nm. The 'very small' full-width at half maximum (FWHM) of the emission peak varies in the range 16–21nm, which suggests "good compositional and structural uniformity for the InGaN QWs".

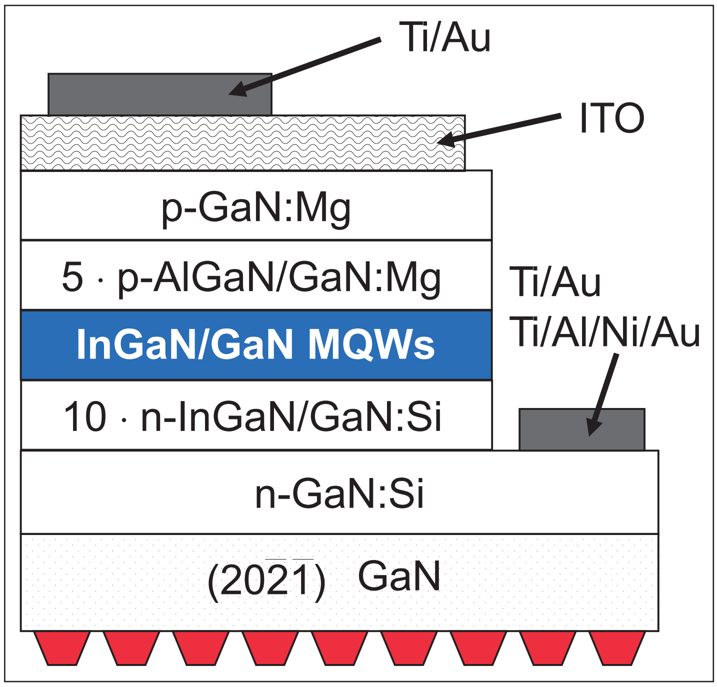

Figure 3. Schematic of semi-polar $(20\bar{2}\bar{1})$ LED device with backside roughening structures.

The researchers are still investigating the underlying cause of the low efficiency droop on semi-polar $(20\bar{2}\bar{1})$ LEDs. ■

http://apex.jsap.jp/link?APEX/4/082104

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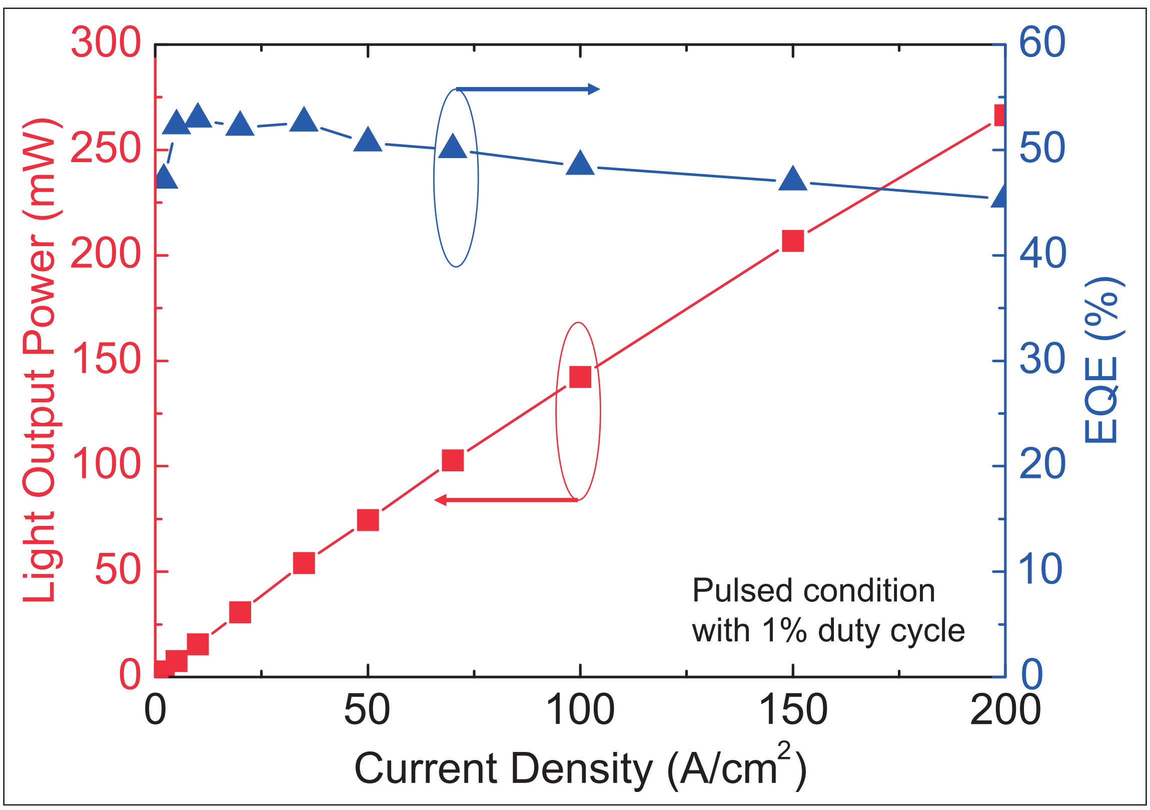

Figure 4. Light output power vs current density and EQE vs current density curves for a packaged $(20\bar{2}\bar{1})$ LED under pulsed operation.