# HL 80: Focussed Session: Novel Green Laser Diodes

Time: Thursday 14:30–17:15 Location: POT 51

**Invited Talk** HL 80.1 Thu 14:30 POT 51

**GaN-based green laser diodes grown on c-plane GaN substrate** — •Shinichi Nagahama — Nitride Semiconductor Research Laboratory, Nichia Corporation, 491 Oka, Kaminakacho, Anan, Tokushima 774-8601, Japan

We have succeeded in developing the GaN-based green laser diodes (LDs) with an emission wavelength of 510-515 nm and output power of 50 mW for the green light source in the small laser projectors.The green LDs structures were grown on conventional c-plane GaN substrates by metal organic chemical vapour deposition. The operating current and threshold voltage with an output power of 50mW were 200 mA and 5.0 V, respectively. The lifetime test of these LDs was carried out under high driving temperature up to 60 °C in cw operation. Lifetime was estimated to be over 10,000 h with an optical output power of 50mW. These results ensure that GaN-based LDs is the best candidate for the green light source in the future small laser display applications.

**Invited Talk** HL 80.2 Thu 15:00 POT 51

**Room-temperature CW operation of BeZnCdSe green laser diode** — •shigehisa tanaka[1], jun-ichi kasai[2], sumiko fujisaki[1], ryouichi akimoto[2], takeshi kikawa[1], shinji tsuji[1], haruhiko kuwatsuka[2], toshifumi hasama[2], and hiroshi ishikawa[2] — [1]Hitachi Central Research Laboratory, Kokubunji-shi, Tokyo, Japan — [2]National Institute of Advanced Industrial Science and Technologies, Tsukuba-shi, Ibaraki, Japan

Recently, green laser diodes have been received much attention because they enable novel devices such as micro-projectors or vivid color displays when used in combination with red and blue laser diodes. Although several approaches using III-nitride-based semiconductors and their successful laser operations with wavelength of over 500 nm have already been reported, their threshold currents still increase as their lasing wavelengths approach to the pure green region. ZnSe based compound semiconductors are also promising materials for the green laser diodes. In particular, Be containing ZnSe based mixed crystals are expected to overcome the problem of limited lifetime of II-VI-based laser diodes.

In this study, a room temperature continuous-wave operation at 545 nm was demonstrated with a BeZnCdSe quantum-well laser diode. Its threshold current density was as low as 1.7 kA/cm2. This result indicates this material system is advantageous in realizing a green laser diode with low power consumption.

**Invited Talk** HL 80.3 Thu 15:30 POT 51

**Growth and properties of semi-polar GaN on patterned silicon substrate** — •Nobuhiko Sawaki — Aichi Institute of Technology, Yakusa, Toyota 470-0392, Japan

Growth and properties of semi-polar and non-polar GaN on Si substrate is reviewed. Particular attention is paid on selective MOVPE on patterned substrates. By tilting the c-axis of the GaN on the silicon surface, the thermal expansion coefficient mismatch and the threading dislocation density were much reduced to improve the crystalline quality. By the virtue of self-organized growth mode on a facet, we achieved excellent surface morphology. The incorporation of carbon and magnesium were investigated in (1-101)GaN which is terminated by nitrogen. We found that the sample doped with carbon shows p-type conduction. Optical spectra and Hall measurements suggested the formation of shallow acceptor levels in the sample.

**Coffee Break**

**Invited Talk** HL 80.4 Thu 16:15 POT 51

**Advantages of Using Semipolar Orientation for Making Green InGaN QW Laser Diodes.** — •Dmitry Sizov, Rajaram Bhat, Kechang Song, and Chung-en Zah — Corning Incorporated, One Science Center Dr., Corning, NY, 14831, USA

During recent years, several research groups demonstrated a steady progress in increasing InGaN quantum well (QW) laser diode lasing wavelength. Using c-plane substrates has been a preferred approach for it, thanks to established growth and fabrication techniques and available 2-inch substrates. More lately, semipolar substrates became available enabling faster progress in this field. Theoretical and experimental studies show that in green spectral range, because of lower built-in electric fields, the differential gain of semipolar QW is much higher than in c-plane if the stripe direction is properly chosen. For this, one needs to take into account that emission polarization depends not only on QW plane orientation, but also on pumping level. Another advantage of semipolar orientation is easier carrier transport in green semipolar multiple-QWs due to smoother band profile resulting from reduced pizeoelectrical effect, allowing uniform carrier injection among QWs when using more QWs to increase net optical gain. While having the improved optical gain, we found that the internal optical losses are not a strong function of substrate orientation, but rather depend on acceptor concentration in p-layers. Both quantum efficiency and optical gain can however be altered by strain relaxation, which is prone in the semipolar system, but can be avoided via proper strain management.

**Invited Talk** HL 80.5 Thu 16:45 POT 51

**Optical gain of green (Al,In)GaN laser diodes** — •Ulrich Schwarz — Fraunhofer IAF, Freiburg, Germany — IMTEK, University of Freiburg, Germany

To achieve lasing in the green spectral region with group III-nitrides, InGaN quantum wells with Indium content larger than 25% are necessary. It is extremely difficult to find growth conditions which are producing homogeneous InGaN quantum wells without dark spots at this high Indium content. Both, the density of nonradiative recombination centers and the width of inhomogeneously broadened photoluminescence spectra increase with Indium content. The consequences are broadened optical gain spectra and lower differential gain. For green laser diodes amplified spontaneous emission sets in far below lasing threshold due to the low differential gain. Going from c-plane to semi- and non-polar oriented quantum wells the differential gain as function of carrier density increases. However, the carrier liefetime decreases, lowering the differential gain as function of current density. The orientation of the quantum well has also an impact on the width of the gain spectra, both through intrinsic band structure effects and through dependency of the growth conditions and Indium fluctuations on the individual growth plane. For semipolar quantum wells also the effect of birefringence on the waveguide modes and optical gain has to be considered.