New angle on approach to green lasers

Mike Cooke reports on UCSB's use of 1°-miscut m-plane GaN substrates to develop blue–green lasers with lower threshold current densities than is achieved using on-axis c-plane GaN.

Shuji Nakamura's group at University of California Santa Barbara (UCSB) has reported on a blue–green laser diode (LD) based on a miscut m-plane gallium nitride (GaN) substrate [You-Da Lin et al, Applied Physics Express, vol.2, p.082102, 2009]. Nakamura is responsible for much of the development and commercialization of GaN as a light-emitting material for electronics as part of Nichia Corp in Japan in the late 1980s and all through the 1990s until he became a UCSB professor in 1999. Also involved in the research is a researcher from Mitsubishi Chemical's Optoelectronics Laboratory, Kenji Fujito, who has worked on hydride vapor phase epitaxy (HVPE) of high-quality non-polar m-plane GaN substrates [Fujito et al, physica status solidi (a), vol.205, p.1056, 2007].

While producing red and blue laser light from semiconductors is relatively simple, producing green lasers has been much harder. At present, green laser light (520–570nm) in commercial LD-based systems, such as overhead projectors, is most often produced using conversion from sources emitting another frequency via second harmonic generation (SHG).

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This year has seen a number of groups publish papers describing various approaches to producing green lasers in the III-nitride material system with indium gallium nitride (InGaN) active layers. In February, Rohm pushed InGaN laser wavelengths out to 499.8nm; in March, Osram crossed the 500nm boundary; in May, Nichia reported a 515nm device; and in July Sumitomo Electric Industries reported pulsed lasing at 531nm (see page 46).

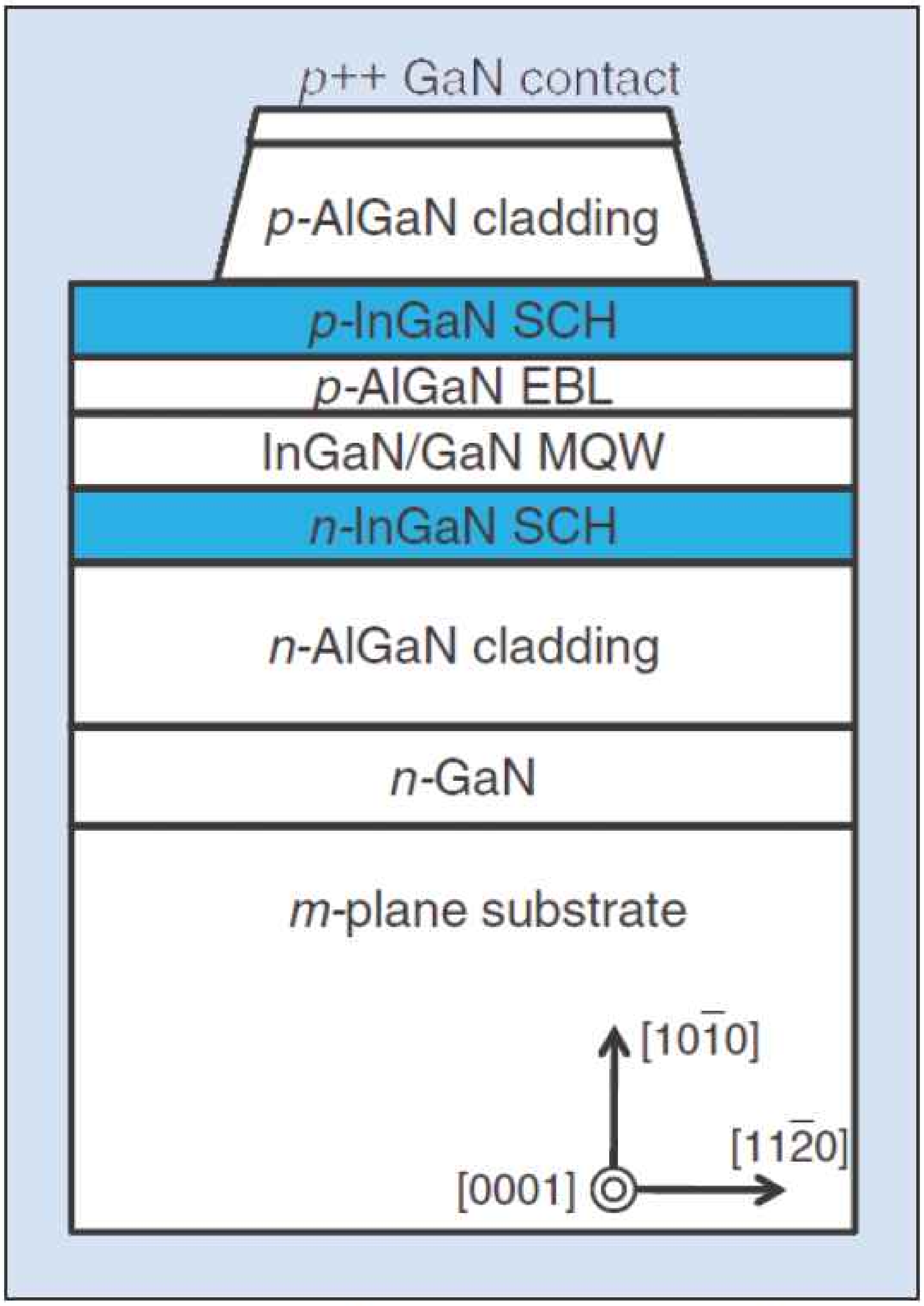

Figure 1. Schematic of laser diode structure used by UCSB. SCH = separate confinement heterostructure; EBL = electron blocking layer.

These developments use various techniques to improve material quality, which is particularly key for the active layer where indium concentrations have to exceed 20% to achieve suitable energy band gaps to produce green light. High-indium-content InGaN is notoriously difficult to grow with the high quality demanded from laser applications.

Although the UCSB work has only reached 481nm so far, the researchers point to improved performance by using miscut non-polar substrates in terms of lasing threshold currents and slope efficiency that suggest moving to longer wavelengths should be 'easy' and a possible route to realizing high-power green laser diodes.

Normally LDs are grown on c-plane GaN, but large polarization fields arise. Such fields separate the electron and hole wave-functions, reducing their ability to radiate light by recombination. An advantage of m-plane GaN is that it is non-polar. Violet m-plane GaN LDs were reported in 2007 and also were the basis of Rohm's work.

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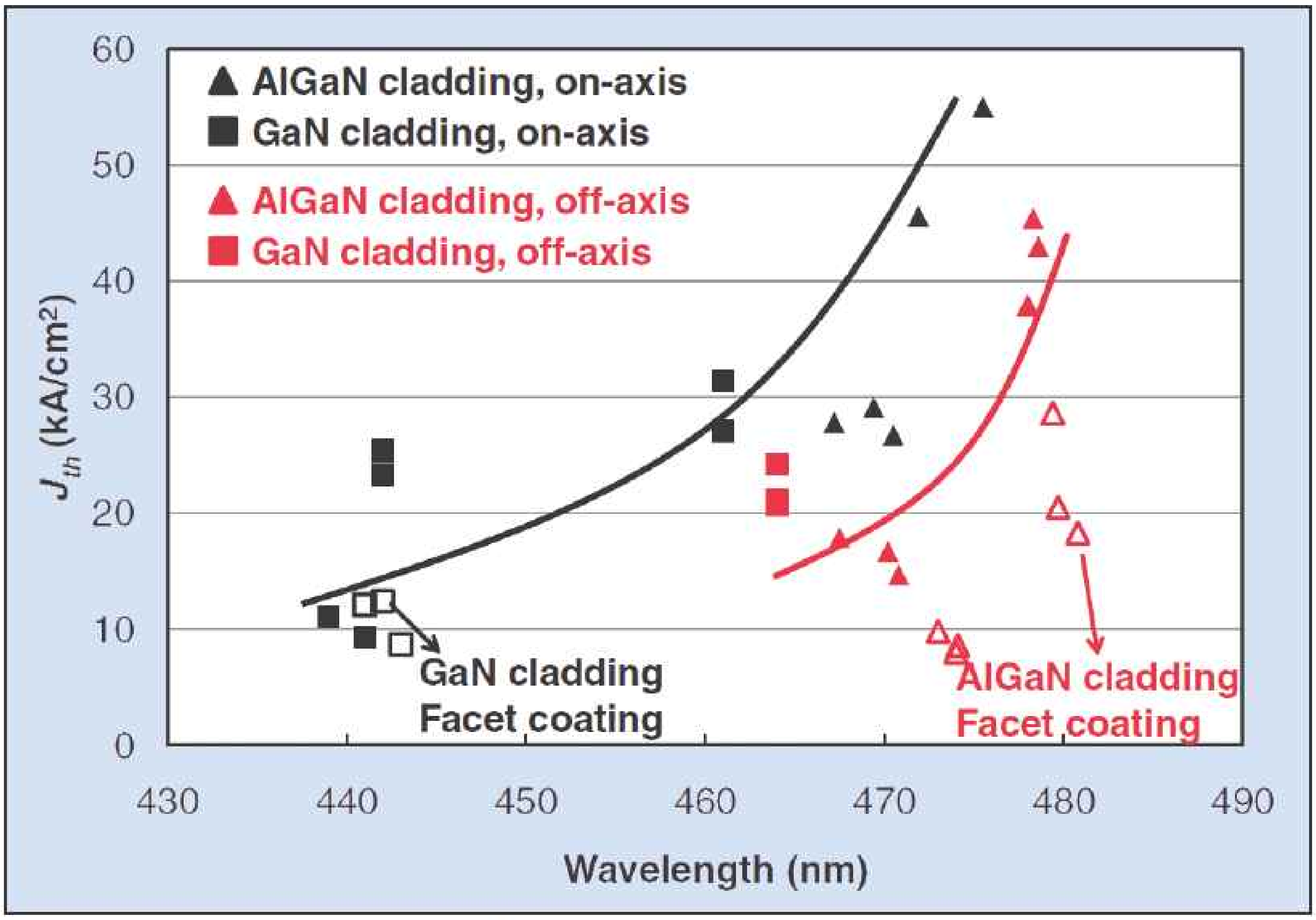

Figure 2. Dependence of threshold current density on lasing wavelength for various laser diodes produced by UCSB using on-axis and 1° towards $[000\bar{1}]$ direction misoriented substrates.

For the UCSB laser diodes, the m-plane GaN substrate was miscut about 1° in the $[000\bar{1}]$ (-c) direction. Miscutting of substrates is commonly used to improve or manipulate material quality on a wide range of substrates. [For a recent example involving improving quantum dot shapes and sizes on an indium phosphide (InP) substrate, see 'Optimizing InP substrate orientation for 1.55µm InAs QD telecom lasers' — www.semiconductor-today.com/news_items/2009/JULY/INP_140709.htm].

UCSB used metal organic chemical vapor deposition (MOCVD) to grow the LD. The active layer was a three-period multi-quantum well (10 nm undoped $In_{0.03}Ga_{0.97}N$ barriers, 3nm InGaN wells with ~26% In estimated through high-resolution x-ray diffraction). Electron blocking layers (EBLs) and separate confinement heterostructures (SCHs) were also used (Figure 1).

Ridge lasers pointing in the c-direction were formed using normal photolithography and etch processes. Nomarski and fluorescence optical microscopy of laser diode surfaces grown on nominal on-axis and miscut substrates showed significantly smoother surface without 'hillocks' for the laser diode on miscut substrate. Also, photoluminescence was much more homogeneous for the miscut substrate device.

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A comparison of 2x500µm laser diodes with uncoated facets in pulsed operation (1% duty cycle) show a lower threshold current (153mA, compared with 413mA for nominal on-axis device) for the miscut substrate. Further, less blue shift was seen in moving from spontaneous to laser emission (~483nm spontaneous wavelength for both miscut and nominal, 471nm miscut lasing, 461nm on-axis lasing). These properties are attributed to larger indium fluctuations in the on-axis samples. A clarification of the mechanisms is promised in a future publication from the group.

The threshold current density tends to increase with wavelength (Figure 2), but with the miscut devices generally reporting a lower value. The longest lasing wavelength found was 481nm (10nm from spontaneous photoluminescence at 491nm) from a coated facet device in 1% duty pulsed operation.

http://apex.ipap.jp/link?APEX/2/082102/
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