Effects of dislocation density on injection and temperature sensitivity of InGaN LED emission spectra: a combined experimental and simulation approach

Effects of Dislocation Density on Injection and Temperature Sensitivity of InGaN LED Emission Spectra: a Combined Experimental and Simulation Approach

M. Goano[‡], S. Chiaria[‡], M. Calciati[‡], F. Bertazzi[‡], G. Ghione[‡], M. Meneghini[*], M. Ferretti[*], G. Meneghesso[*], E. Zanoni[*], E. Bellotti[¦], D. Zhu[†], C. Humphreys[†]

[‡]Dipartimento di Elettronica, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
[*]Department of Information Engineering, University of Padova, Via Gradenigo 6/B, 35131 Padova, Italy
[¦]Boston University, 8 Saint Mary's Street, Boston, MA 02215, USA,
[†]Department of Materials Science and Metallurgy, University of Cambridge, Pembroke Street, Cambridge CB2 3QZ, UK United Kingdom

The aim of this paper is to describe a combined simulation and characterization activity carried out on blue LEDs grown on templates with different threading dislocation densities (TDDs). The study was carried out on identical structures grown on GaN templates having TDDs ranging from $3{\cdot}10^{8}$ cm^{-2} to $8{\cdot}10^{9}$ cm^{-2}. The active region includes five $In_{0.15}Ga_{0.85}N$/GaN quantum wells, with no electron/hole blocking layers. The *p*-type top layer is covered with a uniform, non-roughened semitransparent square contact with 0.5 mm side length. The *IV* and *LI* characteristics, quantum efficiency, and electroluminescence spectra were measured under pulsed excitation over a controlled temperature range between 15 °C and 120 °C. Experimental results indicate that:

i) LEDs with low TDD have a significantly higher efficiency; ii) low-TDD devices exhibit a much smaller temperature sensitivity of both peak emission wavelength and quantum efficiency. For an injection current I = 100 mA, a temperature increase ΔT = 105 °C corresponds to a reduction in the emitted optical power equal to 50% and just 10% in high- and low-TDD LEDs, respectively (Fig. 1); iii) low-TDD devices exhibit also a remarkable improvement in the stability of the peak emission wavelength over the injection current, as predicted by numerical simulation.

Self-consistent numerical simulation of the electrical and optical characteristics of the measured devices was performed with Crosslight APSYS. The main outcomes of this analysis are:

i) numerical simulation can be used to minimize the significant uncertainties on profile and ionization of acceptor impurities, heterointerface polarization charges, and QW thicknesses;

ii) in agreement with experimental data, the stability of the peak emission wavelength over injection current and temperature can be greatly improved by reducing TDD;

iii) an accurate inclusion of many-body Coulomb effects, usually neglected in LED simulation, is essential for a correct prediction of device performance (Fig. 2).

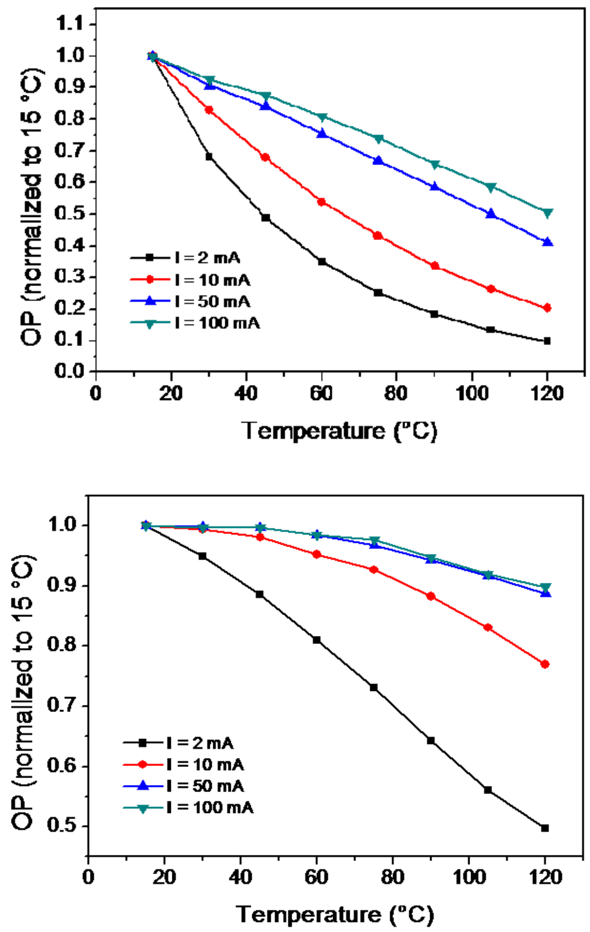

Fig. 1. Measured optical power as function of the temperature for different injection currents in a LED with high (top) and low (bottom) TDD.

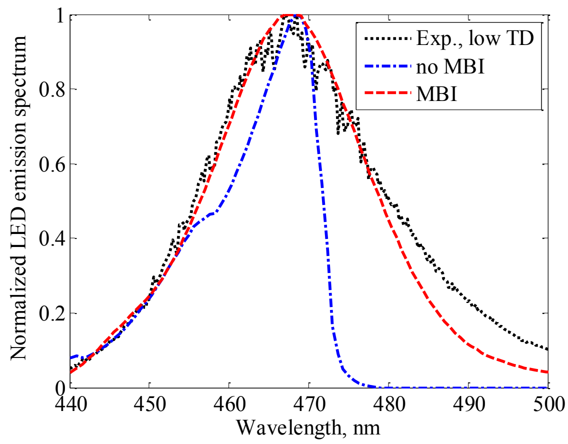

Fig. 2. Measured electroluminescence spectrum (T = 15 °C, I = 100 mA) compared with simulations neglecting and including many-body Coulomb interactions.