Photoluminescence frequency domain technique – a tool to investigate InGaN LED structures in a wide range of excitation and time

I.Reklaitis[1], R.Kudzma[1], R.Tomasiunas[1,*], I.Pietzonka[2], M.Strassburg[2]
[1] *Institute of Applied Research, Vilnius University, Sauletekio 10, 10223 Vilnius, Lithuania*
[2] *OSRAM Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany*
*Email: rolandas.tomasiunas@ff.vu.lt

To the best of our knowledge, it is the first time yet to use the photoluminescence frequency domain technique for the InGaN multi-quantum well (MQW) light emitting diode (LED) structure investigation. We applied both, LED and laser diode (LD), to excite resonantly the structure of a blue and green LED with modulated light and exceeded to cover a broad range of photoexcitation power density (1-500 mW/cm^2). The oneness of this method is to study the transient processes under very low non-equilibrium charge carrier density and non-saturated recombination channel condition. By this, we were complementing our results with those obtained using conventional time-resolved photoluminescence spectroscopy with usually relative high/medium photoexcitation power density. The photoexcited charge carrier lifetime dynamic was analyzed while applying a model with single and stretch exponential decay depended on the sample and on the measurement condition. The extracted lifetimes range straight from nanoseconds up to tens of microseconds and in some case even more. To analyze the activation mechanisms measurements down to 10 K temperatures were performed.

The LED or LD emission intensity was modulated in the frequency range from 1 Hz to 100 MHz. The time evolution was extracted using Fourier-transform analysis. The investigated InGaN/GaN LED structures with characteristic wavelength 460, 500 and 530 nm were grown on sapphire by MOCVD consisting of a standard sequence of epilayers: buffer layer – unintentionally doped GaN, *n*-type GaN, active layer – MQW of a typical 3 nm width and >20% In, *p*-type GaN.

Analysis revealed a shift toward long lasting charge carrier localization, in particular for the blue structure expressed by very long lifetime values reaching 15-25 mks for 200 K temperature and with a gradual increase till 20% of the fractional input in the kinetics for the room temperature. The single exponential decay time indicated on a characteristic localization site. Extremely large decay times up to 120 mks were extracted also for the green structure using LED excitation, though with a minor fractional input and difficulty to interpret. Stretched exponential behavior surprisingly appeared for the relative fast decay time range. The stretching parameter for the fast and medium decay time range corresponded well to those obtained by the conventional time resolved photoluminescence and were attributed to indium phase segregation and the associated spatial fluctuations of the local indium concentration in the well or well thickness fluctuation.

Recombination rate activation energies were extracted and dependencies vs. photoexcitation power density drawn. The decrease of activation energy with photoexcitation power density appeared to be in-line with the delocalization effect observed in the literature for the InGaN/GaN MQW structures.

The complementarity of the frequency domain measurements with other measurements carried out under high excitation power density regime will be presented.

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