Nepusiausvirųjų krūvininkų tyrimas nepoliniame InGaN kvantiniame lakšte

Study of excess carrier dynamics in homoepitaxial m-plane InGaN quantum well

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Efficiency droop is a phenomenon that diminishes the radiative efficiency of III-nitride based light emitting diodes (LED) at sufficiently high carrier densities. However, most of the reported efficiency droop studies are performed in polar InGaN multilayered structures, where carrier delocalization and state filling effects are obscured by the presence of internal electrical fields. Here, we present an analysis of carrier recombination and diffusion processes in *nonpolar single* InGaN quantum well (QW) sample by means of several time- and spectrally-resolved all-optical techniques at room temperature over a wide carrier density range ($2x10^{17}$ – $4x10^{20}$ cm^{-3}), which marks the onset of droop.

The investigated $In_{0.15}Ga_{0.85}N$ 10 nm width single QW sample was grown by MOCVD on a low dislocation density m-plane GaN substrate with a 1^0 miscut towards the $(000\bar{1})$ direction. To study excess carrier dynamics time resolved photoluminescence (TRPL) spectroscopy (pump at 355 nm) was combined with two pump-probe techniques (selective excitation of QW by 250 fs pulses at 386-392 nm): (i) spectrally-resolved differential transmission (DT); (ii) light-induced transient grating (LITG). Quantum efficiency (QE) was estimated using PL and integrating sphere.

The peak PL QE value reaches only ~7%, which confirms the dominance of nonradiative carrier recombination at room temperature. While the shape of QE curve is rather typical, the onset of efficiency droop happens at carrier density as low as 8×10^{17} cm^{-3}.

The PL and DT spectra consist of broad and asymmetrically shaped bands that change and blue shift with excitation (Fig. 1). The large spectral line widths are typical for nonpolar InGaN quantum wells and are attributed to strong carrier localization [1]. To explain the asymmetrical shape of PL spectra at high carrier density, we assumed that the spectra are a result of superposition of different spectral components. In total, four (P1 – P4) Gaussian components were used to fit the TIPL, TRPL, and DT spectra at all photoexcitations. P1 being of the lowest photon energy (2.8 eV), P2 (2.9 eV), P3 (3 eV), and P4 – of the highest energy (3.1 eV); here we assume that spectral components in different techniques but at overlapping spectral position correspond to the same electronic transition.

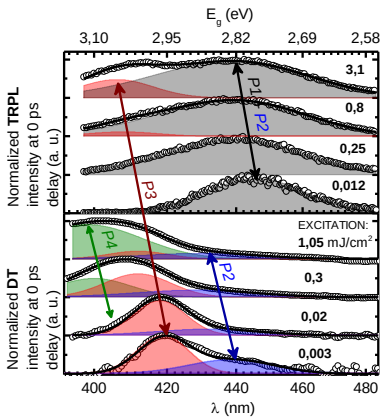

Fig. 1. Instantaneous PL (top) and DT (bottom) spectra measured at various excitation energy fluencies.

Additionally, comparison between integrated and time-/spectrally-resolved PL and DT measurements reveals that spectral components P1 – P4 have different decay times (τ_{slow}, τ_{med}, and τ_{fast}) that become shorter with increasing component photon energy. τ_{slow} was related to peaks P1 and P2, τ_{med} – to P3, and τ_{fast} – to P4. The decay time constant dependences on carrier density show unusual trend (Fig. 2), which cannot be explained by using general ABC model. The LITG technique was used to assess the decay time τ_R and ambipolar diffusivity D of the entire free carrier population as functions of carrier density. An opposite dependence of τ_R and D versus excitation was seen (not shown). That suggests delocalization effect relation with increased nonradiative recombination.

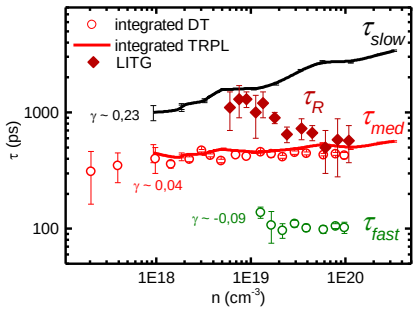

Fig. 2. Decay times of different components as a function of carrier density.

To conclude, the change in state occupancy manifests in emergence of higher energy components in spectra that in turn correlates with the decrease in overall carrier lifetime and increase in diffusion coefficient. Therefore, the delocalization effect is proposed as a significant cause of efficiency droop.

Reference

[1] P. Dawson, S. Schulz, R.A. Oliver, M.J. Kappers, and C.J. Humphreys, J. Appl. Phys. 119, 181505 (2016).