Recombination Dynamics In III-Nitride Semiconductors With Carrier Localization

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Ternary nitride alloys, such as InGaN and AlGaN, provide a natural means of tuning band gap and other material parameters enabling the band gap engineering and the wider application of semiconductor devices. However, the inevitable spatial fluctuations of alloy composition as well as quantum well (QW) width result in the strong influence of carrier localization on optical properties. The photoluminescence (PL) spectra of such materials generally include contributions both from the free and localized carriers. Therefore, to adequately model the recombination dynamics of such complex system both contributions have to be considered. Typically, the problem is simplified at certain conditions, e.g., only localized carriers are considered at low temperatures and/or low excitations, while only the free carrier system is analysed at high temperatures and high excitations.

In this report, we propose a model of carrier dynamics which takes into account both free and localized carriers. The main idea of this model is using energy–dependent PL decay time function to calculate the PL spectrum. We assume that the luminescence intensity at certain energy is proportional to the density of carriers and the PL decay time. The shape of the decay time function is obtained from the time–resolved PL measurements. In the samples with considerable carrier localization, this function is usually constant in the low–energy region (corresponding to the localized carriers) and decreases with energy on the high–energy side (corresponding to the free carrier system) of the PL spectrum. Meanwhile, the energy dependence of carrier density is determined by the density of states, which is calculated by taking into account the localizing potential profile, and the Fermi–Dirac distribution, where carrier temperature is retrieved from the high-energy slope of the PL band.

Using this model, we calculated the PL spectra under different excitation and temperature conditions and a good agreement with the experimentally measured PL spectra was obtained. The decrease of integrated PL intensity with increasing carrier density coincides for experimentally obtained and calculated results. The results show that the significant decrease in luminescence efficiency, which is observed at low temperature to occur already at quite low carrier densities, can be explained just by population of localized states.