Spatio-time-resolved cathodoluminescence studies on freestanding GaN substrates grown by hydride vapor phase epitaxy

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The results of macroarea measurements such as photoluminescence (PL), time-resolved photoluminescence (TRPL), and postion annihilation on the low defect density polar c-plane and nonpolar m-plane freestanding GaN (FS-GaN) wafers grown by hydride vapor phase epitaxy (HVPE) will be presented to quantitatively establish the relation between the point defect concentration and the nonradiative luminescence lifetime ($\tau_{nr}$) for the near-band-edge (NBE) emission at room temperature. We also show the results of temperature-variable spatio-time-resolved cathodoluminescence (STRL) measurements, visualizing the spatial distributions of luminescence lifetime ($\tau$) and equivalent value for the internal quantum efficiency ($\eta_{eq}$) in the vicinity of an inversion domain boundary (IDB). A record-long positron diffusion length and a record-high $\eta_{eq}$ value under a weak-excitation regime for three-dimensional bulk GaN will be presented.

As a solution to concerns about energy crisis, exploitation of high-efficiency power-switching devices using AlGaN/GaN heterostructure-field-effect-transistors and solid-state-lighting using InGaN quantum well LEDs is one of the significant ways for drastically decreasing total energy consumption [1]. Although InGaN LEDs fabricated on defective GaN templates exhibit reasonably low defect density polar c-plane and nonpolar m-plane FS-GaN samples of gaseous HCl was flowed on heated Ga, and NH3 was supplied from a separate gas line. Typical growth temperature and pressure were 1050 °C and atmospheric pressure, respectively. Details of the growth and fundamental properties have been given in Refs. 2 and 3.

The results obtained are as follows: the $\eta_{eq}$ value for the NBE exciton emission at 293 K increases with (i) decreasing $S$ parameter for the positron annihilation and (ii) increasing postion diffusion length ($L_p$); i.e., decreasing the concentration of Ga vacancies ($V_{Ga}$) and gross concentration of charged and neutral point defects and complexes. The concentration of $V_{Ga}$ in the best unintentionally doped FS-GaN sample is below the detection limit, namely lower than 10$^{13}$ cm$^{-3}$. This particular sample exhibits a record-long $L_p$ being 116 nm. The fast component of the PL lifetime for its NBE emission increases with temperature rise up to 100 K and levels off at approximately 1.1 ns. The result implies saturation in thermal activation of nonradiative recombination centers (NRCs).

Representative SEM image and monochromatic CL intensity images monitoring the NBE emission in the vicinity of an IDB for one of the c-plane FS-GaN samples are shown in Fig. 1. Because the room temperature $\tau$ value measured within the bright areas, for example positions labeled 5 and 6, differs place to place, ultimate $\tau_{nr}$ and consequently $\eta_{eq}$ are limited by the concentration of NRCs originating from $V_{Ga}$-complexes [6]. As the measurement temperature decreases, the dark-line width decreases. The result reflects the decrease in minority carrier diffusion length and freeze-out of NRCs at low temperature. Details will be presented at the conference.

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References