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 positron annihilation on the non defective GaN templates exhibit reasonably high purity bulk crystals. Also, because the present FS-GaN has very low density TDs, the influence of a TD on the local luminescence spectrum and lifetime can be studied using such low structural defect density, high-purity 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 bright emission, fabrication of high-purity large-area FS-GaN wafers with low threading dislocation (TD) density is desirable for achieving high-performance and reliable devices. For example, suppression of the efficiency-droop phenomenon is predicted by using heat-conducting FS-GaN substrates. Accordingly, fabrication of InGaN LEDs on c- or m-plane FS-GaN could be a straightforward way in realizing compact high-power LED bulbs.

Recently, reduced TD and basal-plane stacking fault (BSF) density c- and m-plane FS-GaN wafers [2,3] sliced from a certainly bowed (c-axis-tilted) bulk GaN boule grown by HVPE [2] have been distributed. From scientific point of view, fundamental influences by point defects on the electronic and optical properties can be studied using such low structural defect density, high-purity bulk crystals. Also, because the present FS-GaN has very low density TDs, the influence of a TD on the local luminescence spectrum and lifetime can be studied using a spectroscopy technique of sufficient high spatial resolution.

To probe local carrier dynamics in GaN, a scanning near-field optical microscopy (SNOM) equipped with a femtosecond laser has been widely used. On the other hand, the use of a scanning electron microscopy (SEM) equipped with a femtosecond electron beam (e-beam) gun makes it possible to measure the local time-resolved cathodoluminescence (TRCL) signal at the point defined precisely by the secondary electron image [4]. To construct a STRCL system, we first developed the femtosecond laser-driven photoelectron gun [5], and installed it on a SEM.

The samples investigated were grown using a vertical-flow HVPE apparatus [2,3]. Appropriate amount 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 τNR value for the NBE excitonic emission at 293 K increases with (i) decreasing S parameter for the positron annihilation and (ii) increasing positron diffusion length (Lp): i.e. decreasing the concentration of Ga vacancies (Vga) and gross concentration of charged and neutral point defects and complexes. The concentration of Vga in the best unintentionally doped FS-GaN sample is below the detection limit, namely lower than 10¹⁵ cm⁻³. This particular sample exhibits a record-long Lp, 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 in one of the c-plane samples measured at (b) 293 K and (c) 20 K.

References