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3D Four- Three- Two-Photon and Multi-Harmonic Microscopy of Lateral-Over-Grown GaN

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Abstract -- *Complete information regarding the distribution of growth quality, defect state, and piezoelectric field in lateral-over-grown GaN can be obtained simultaneously through multi-photon (4 and 3) and multi-harmonic (3 and 2) microscopy.*

Taking advantage of strong 4-photon absorption of 1eV light in GaN samples, we demonstrated the first ever 4-photon microscopy using GaN material system. Combining with 3-photon fluorescence and second and third harmonic generation microscopies, we studied a lateral overgrown GaN sample with high 3D resolution. Complete information regarding the distribution of growth quality, defect state, and piezoelectric field in lateral-over-grown GaN can be obtained simultaneously through multi-photon (4 and 3) and multi-harmonic (3 and 2) microscopy based on a 1230-nm femtosecond Cr:forsterite laser.

The samples under study include a bulk GaN layer with high quality coalesced lateral epitaxial overgrowth (LEO) [1].

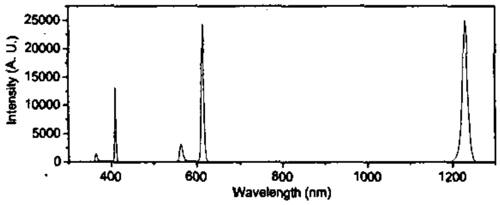

Fig. 1 The nonlinear emission spectrum from a bulk GaN excited by a single Cr:forsterite laser.

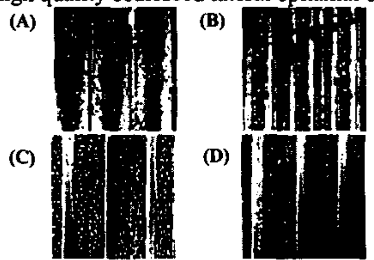

Fig. 2 Plan-view scanning microscopic images corresponding to (A) edge luminescence, (B) yellow luminescence, (C) SHG and (D) THG in a laterally overgrown bulk GaN. Image size: 60x60-μm^2.

Fig. 1 is the nonlinear emission spectrum from the bulk GaN excited by a single femtosecond Cr:forsterite laser centered at 1230 nm. Fig. 2A-2D are plan-view sectioned scanning microscopic images of these nonlinear signals in a LEO bulk GaN. The images were formed by moving the sample perpendicular to laser focusing direction and recording spectrum at each point. The bright bandedge emission at 365 nm corresponding to good GaN edge emission quality in regions above the 15- μm-wide SiO_2 stripes suggests the SiO_2 stripes' ability to block the threading effects. On the other hand, the defect-state-related yellow fluorescence (563 nm) is strongest at the edge of SiO_2 stripes indicating higher deep-acceptor-state density there (Fig. 2B). And strong SHG signal at 615 nm of GaN grown above SiO_2-stripe openings shows the large piezoelectric field induced by unrelaxed strain (Fig. 2C). Moreover, the contrast of THG in Fig. 2D might reveal the interfaces inside the samples and distribution of bandtail states due to their close resonance.

In summary, taking advantage of strong 4-photon absorption of 1eV light in GaN samples, we demonstrated a new approach to mapping LEO GaN structural information combining multi-photon fluorescence (4 and 3) and multi-harmonic (3 and 2) scanning microscopy which provides not only superior 3D (better than 500 nm) resolution but also plentiful information of GaN including growth quality (edge PL), defect state distribution (yellow luminescence), piezoelectric field (SHG) and refractive index change. This study also represents the first ever 4-photon microscopy in history.

REFERENCES

[1] See P. Fini *et al.*, "High-quality coalescence of laterally overgrown GaN stripes on GaN/sapphire seed layers" *Appl. Phys. Lett.*, **75**, 1706-1708 (1999), and the references in it.

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