Form 2

Dissertation Abstract

Report no.	(Course-based) No. 1032	Name	MD. JULKARNAIN
Dissertation title	Characterization of GaN Based Light Emitting Semiconductors by Two-wavelength Excited Photoluminescence (２波長励起フォトルミネッセンス法によるGaN系発光半導体の評価に関する研究)		

Abstract

A spectacular technological development in growth and commercialization of gallium nitride (GaN) based optoelectronic devices has already been achieved, but still now lacking the native lattice-matched substrate produces high densities of threading dislocations and point defects which act as nonradiative recombination (NRR) centers or trap centers in the crystal. Moreover, the origin of below-gap radiative channels like yellow luminescence (YL), green luminescence (GL), and blue luminescence (BL) in GaN is a matter of hot debate. The defect mediated NRR centers are the killer of carrier lifetime and responsible for the low efficiency of the devices. To relieve these problems, not only a fundamental understanding of the basic mechanism of grown-in defects and imperfections in these materials, but also correlations of these defects to the performance and reliability limiting problems, and ascribe them to their physical origin is required.

In this study, various GaN-based samples like undoped GaN, Si-doped GaN, and AlGaN/AlGaN multiple quantum wells (MQWs) have been investigated by two-wavelength excited photoluminescence (TWEPL) method. The inductively coupled plasma (ICP) etching induced defects in n-type GaN and its recovery by subsequent annealing in N_2 have also been studied by TWEPL. In the TWEPL, an intermittent below-gap excitation (BGE) source whose energy is lower than the band-gap ($h\nu_{BGE}<E_g$) is superposed on a constant above-gap excitation (AGE) source ($h\nu_{AGE}>E_g$). The intensity change in photoluminescence (PL) due to the addition of a BGE light on an AGE light implies the presence of NRR levels in the energy position corresponding to the photon energy of the BGE.

The below-gap recombination bands of MOCVD grown undoped GaN have been studied by TWEPL. The intensity of donor-acceptor pair (DAP) and YL decreases while it increases for I_{OX} (oxygen impurities to valence band transition) after irradiation of the BGE. Both the enhancing and quenching of emission intensities under the irradiation of the BGE have been interpreted by a recombination model. The YL band centered at around 2.3 eV is a result of the shallow donor to the deep state transition. The YL band has been allocated at about 1 eV above the valence band maximum (VBM) which is one of the direct experimental evidence indeed, and it will be a clue to find out the specific origin of YL band in this energy level. Excitation-induced spectral characteristics also investigated for below-gap bands. A sub-linear dependence of YL intensity with excitation power reflects the shallow donor-to-deep state transitions. The excitation induced blue-shift of emission energy justifies the DAP characteristics. A set of

defect related parameters that give a qualitative insight in the samples has been evaluated by systematically solving the rate equations and fitting the result with the experiment. Comparison of the experimental results with the theoretical reveals reasonable agreement of the dependencies and validates our model consideration.

The Si-doped GaN (n-type GaN) samples have been studied to elucidate the damages induced by Inductively Coupled Plasma (ICP) etching and the effect of subsequent annealing in N_2. The intensities of near-band-edge (NBE) and donor-acceptor pair (DAP) emission decreased while the intensities of I_1 (~3.41 eV) and yellow luminescence (YL) remained constant after irradiation of the BGE. The BGE effect of the NBE peak increased after ICP etching and subsequent annealing at 800 and 900°C, which signifies the inclusion of NRR levels on the sample after ICP etching and even subsequent annealing. The integrated PL intensity without the BGE decreased by ICP etching and gradually increased after annealing in N_2. Thus, the annealing of ICP etched samples in N_2 effectively removes the ICP induced defects, leading to the enhancement of the PL intensity, but introduces and/or reforms another type of defects in the sample which are responsible for the BGE effect.

Two different AlGaN MQWs samples with varying Al-concentration have also been investigated. The two-channel Arrhenius fitting gives thermal activation energy of about 100 meV for both samples. The PL intensity of quantum well emission decreased in both cases after irradiation of the BGE which can be interpreted by two levels model. Based on the defects present in the GaN and using the vacuum referred binding energy model, the origin of these two defect levels is tabulated. The rate equations have been extracted from the model and analyzed based on the SRH statistics for $Al_{0.55}Ga_{0.45}N/Al_{0.72}Ga_{0.28}N$ MQWs. A set of defect related parameters that give a qualitative insight in the samples has been evaluated by systematically solving the rate equations and fitting the result with the experiment.