Distribution of below-gap states in GaN-based quantum wells revealed by two-wavelength excited photoluminescence

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One of the key steps for realizing optimum growth of high efficient blue-UV light emitters is to disclose the microscopic origin of defect-related below-gap states peculiar to GaN-based materials. By means of an improved two-wavelength excited photoluminescence (PL) [1], we have resolved the distribution of below-gap states in bulk GaN, InGaN/GaN and GaN/AlGaN quantum well structures (QWs) grown by TF-MOCVD technique (Fig. 1). The resultant energy distribution of these states and its concentration decrease with increasing the number of wells revealed a multi-levels dynamics, which consistently explained the behavior of both band-edge emission and the yellow luminescence (YL) [2].

The experimental method utilizes a time chopped below-gap excitation (BGE) superposed on a conventional above-gap excitation (AGE), both focused on the sample surface. An energy matching of BGE and below-gap states unbalances the equilibrium of carrier recombination attained under only AGE, thus changes PL intensity I_{AGE} to $I_{AGE+BGE}$. The effect of BGE is expressed by the normalized PL intensity defined as $I_{AGE+BGE}$ / I_{AGE}. Performed at 77K with a single-photon counting system, the method permits to discern the energy distribution of below-gap states and a selection of the layer under study by appropriately choosing the wavelength of BGE and AGE respectively [3].

In an InGaN/GaN QWs, below-gap states were detected in the GaN buffer layer as shown by the decrease in the normalized PL intensity in Fig. 2, where identical results for bulk GaN are also included. We interpret this by a multi-levels model (Fig. 3) which consists of a state (*Deep Level 1*) and a distribution of levels spreading from the conduction-band edge down to 1 eV inside the forbidden gap. The collection of levels underneath the conduction band allows nonradiative recombination (NRR) followed by YL. Deep Level 1 provides a path for NRR and acts also as the final state of YL.

We measured the normalized PL intensity change of a set of three GaN/AlGaN QWs having 5, 10 and 30 GaN wells as a function of both the AGE and the BGE power, as depicted in Fig. 4. The decrease of PL reveals the presence of trap centers; the reduction of its absolute value as the well number is increased is in concordance with the reduction of below-gap states density due to a terminating effect on dislocations at heterointerfaces.

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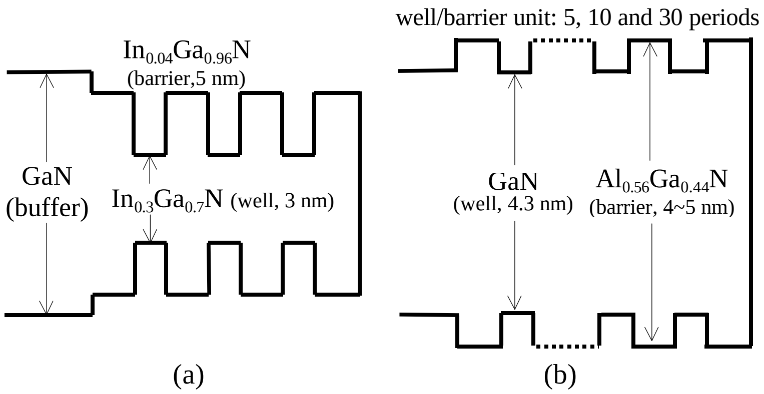

Fig. 1 Structures of GaN-based QW samples.

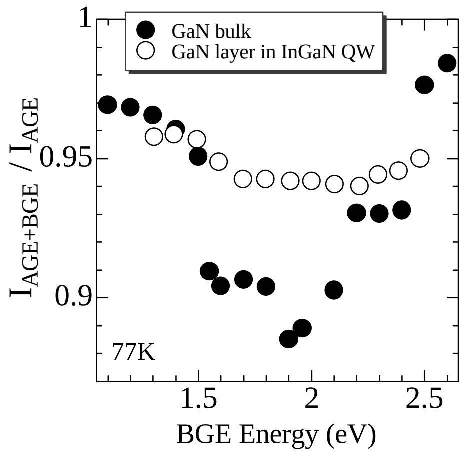

Fig. 2 The normalized PL intensity as a function of BGE energy.

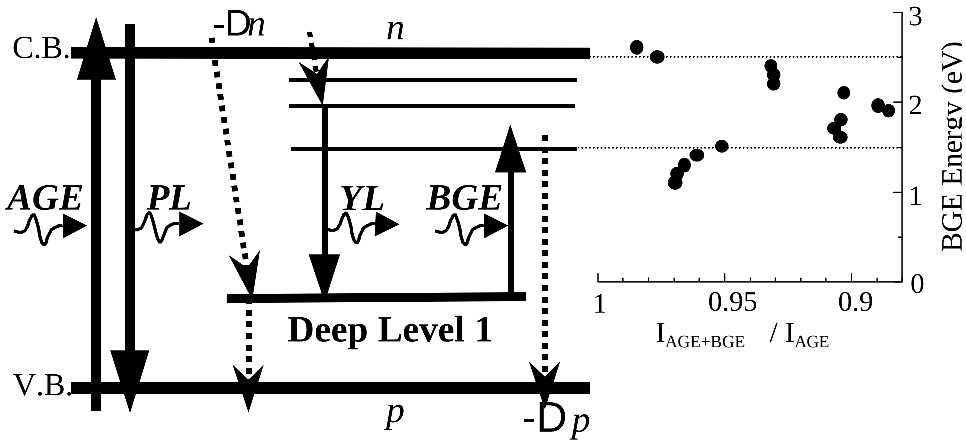

Fig. 3 A multi-levels model explaining the behavior of both, band-edge luminescence and YL in response to BGE.

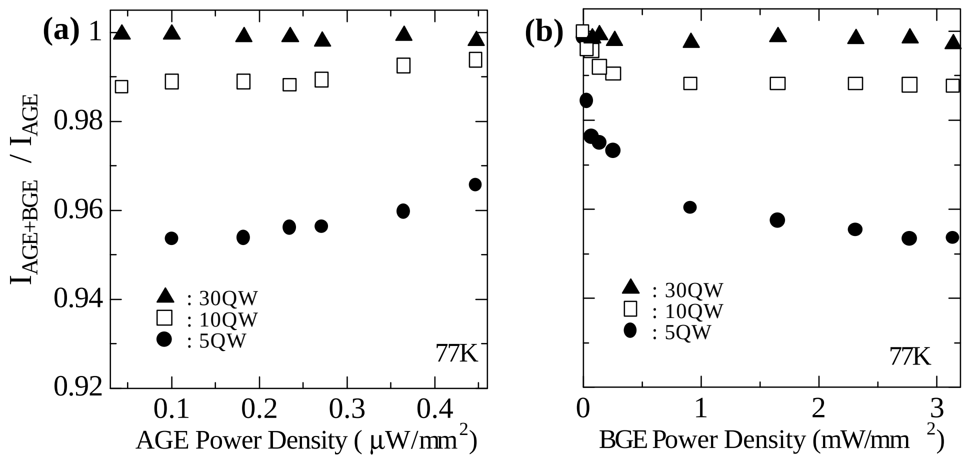

Fig. 4 AGE and BGE power dependence of the normalized PL intensity for GaN/AlGaN QWs.