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Two-component Photoluminescence Decay and Carrier Localization in InGaN/GaN Multiple Quantum Well Structures

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Abstract

Localization energies of localized states of InGaN/GaN quantum well structures were obtained by fitting the data of photoluminescence (PL) and amplified spontaneous emission. The two-component decay times in time-resolved PL show consistent results.

I. Introduction

Because of indium aggregation and phase separation in InGaN, localized states for carriers are formed in such a compound. Different from free-carrier states, carriers trapped in the localized states cannot move freely. However, thermal excitation can let carriers escape from the localized states. In this paper, we present the results of energy gap between these two groups of states by fitting the data of photoluminescence (PL) and amplified spontaneous emission (ASE) with models. We also measure time-resolved PL (TRPL) to study carrier dynamics.

II. Sample Preparation

The InGaN/GaN quantum well samples, grown with MOCVD, consisted of five periods of Si-doped (10^{18} cm^{-3}) InGaN well with 3 nm in thickness. The designated indium compositions were 15, 20, and 25 % (samples A, B, and C, respectively). The barrier was 7 nm GaN. The QW layers were sandwiched with a 1.5 μm GaN buffer layer on a sapphire substrate and a 50 nm GaN cap layer.

III. Fitting and Analysis

The temperature-dependent peak positions of PL and ASE are shown with filled and empty symbols, respectively, in Fig. 1. Because ASE is supposed to originate from free carrier recombination, its peak positions, $E_f(T)$, should follow Varshni's equation: $E_F(T) = E_F(0) - \alpha T^2/(T+\beta)$. The dash-dotted curves stand for the fitting results with Varshni's equation and Table 1 lists the fitting values of α and β. Because PL comes from the recombination of both free and localized carriers, the formula for characterizing its curves is as follows [1]: $E_L(T) = E_L(0) - \alpha T^2/(T + \beta) - \sigma^2/K_B T$. With the same values of α and β for fitting the ASE data, we can obtain $E_L(0)$ and σ, as shown in Table 1. Keeping the same α and β in the last formula without the contribution of the localized states term $\sigma^2/K_B T$, we can reproduce the pure effect of the free-carrier states, as shown with the short-dashed curves in Fig. 1. As a result, the energy difference between the PL peak position at the lowest temperature and the intercepted point of the short-dashed curve at 0 K roughly corresponds to the energy difference between the localized and free states, i.e., localization energy. A larger nominal indium content leads to higher localization energy that is consistent with the extent of composition fluctuation.

Fig. 2 shows the integrated ASE intensity as functions of pumping power. The threshold of sample B is smaller than those of samples A and C.

The TRPL decay profile is shown in the inset of Fig. 3 and the profile is two- component decay. We fitted the profile and obtained the first-component decay time t_1 and second-component decay time t_2. Fig. 3 shows the decay times t_1 and t_2 as functions of emission energy for the three samples. The decay time t_2 increases with decreasing energy for all three samples. This is a typical property of the localization model [2]. The increasing trend of t_2 with increasing indium content is consistent with the previous arguments, which predicted that a larger localization energy resulted in a longer radiative lifetime. On the other hand, t_{1B} is longer than t_{1A} and t_{1C}. We suppose that t_1 is the decay time for carriers to relax into localized states. During the relaxation process, carriers may be captures by defects. Therefore, sample quality has an important impact on the size of t_1. A longer t_1 stands for better sample quality. The longer t_{1B} is consistent with the lower ASE pumping threshold of sample B.

V. Conclusion

In conclusion, we have presented the results of calibrating the localization energy between localized and free-carrier states of InGaN/GaN multiple quantum well structures by fitting the data PL and ASE with models. The two-component decay times t_1 and t_2 in TRPL are consistent with the observations of PL and ASE.

References:

1. P. G. Eliseev, P. Perlin, J. Lee, and M. Osinski, Appl. Phys. Lett. 71, 569 (1997).
2. Y. Narukawa, Y. Kawakami, Sz. Fujita, Sg. Fujita and S. Nakamura, Phys. Rev. B55 (1997) R1938.

	A	B	C
Localization energy(meV)	18.3	31.4	33.27
$E_L(0)$ (eV)	2.905	2.773	2.7
α (meV/K)	0.37	0.39	0.65
β (K)	324.6	550	760.7
σ (meV)	22	22.5	37.64

Table 1. Fitting results in Fig. 1.

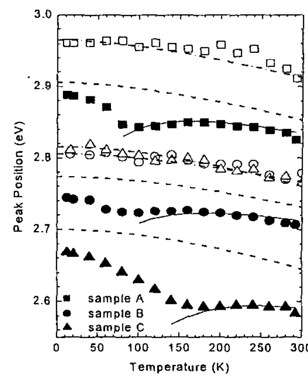

Fig. 1 PL (filled symbol) and ASE (empty symbol) peak positions of the three samples as functions of temperature.

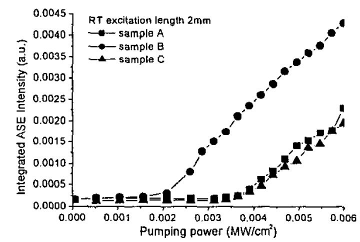

Fig. 2 The integrated ASE intensity as functions of pumping power.

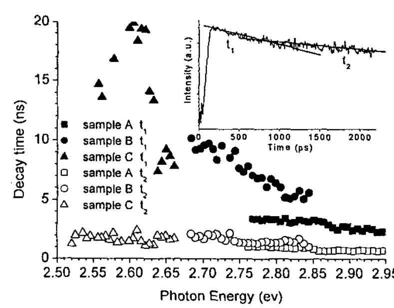

Fig. 3 Decay times t_1 and t_2 as functions of emission energy for the three samples. Inset shows a profile and fitting.