國科會專題研究結案報告

氮化鎵系列材料光電特性與新型製程研究

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中文摘要

我們在氮化銦鎵／氮化鎵量子井內觀察到了兩段螢光衰減的現象，先期較快的衰減斷定是由於載子在不同位能高度侷限能階間之移動所造成。另外，我們也以熱退火方式形成極為規則的氮化銦鎵量子點。

英文摘要

We report the fast and slow decay lifetimes of multi-component photoluminescence intensity decays in the time-resolved photoluminescence measurements at room and low temperatures. The fast decay was essentially due to carrier dynamics.

1. Introduction

Due to the low miscibility between InN and GaN, indium aggregation and phase separation (formation of either InN or GaN clusters) occurred in InGaN/GaN quantum well (QW) structures. Indium-rich clusters in such a QW structure form the localized states, which may trap carriers for radiative recombination. Time-resolved photoluminescence (TRPL) results of InGaN/GaN QW samples have been reported by many groups[1,2,3]. However the decay mechanism in InGaN/GaN QWs has not been well discussed yet, particularly the non-single exponential decay feature[2]. In this paper, we report carrier dynamics of three InGaN/GaN QW samples with varied indium contents. We conducted TRPL measurements at room temperature (RT) and low temperature (LT) at 12K with the same excitation photon energy. Different relaxation behaviors including two-component and one-component decays of PL intensity were observed. We discussed the mechanisms, which are responsible for the observed carrier dynamics.

2. Sample Preparation and Experimental Procedures

The samples were grown in a low-pressure metal-organic chemical vapor deposition reactor. The InGaN/GaN multiple QW samples consisted of five periods of Si-doped InGaN well with 3 nm in thickness. The designated indium compositions of the sample were 11, 16, and 21 % (samples A, B, and C, respectively). The Si doping concentration was 10^{18} cm^{-3}. The barrier was 7 nm GaN. In each sample, the QW layers were sandwiched with a 1.5 μm GaN bufferlayer on a sapphire substrate and a 50 nm GaN cap layer. The growth temperatures were 1050 and 740 ℃ for GaN and InGaN, respectively.

The TRPL measurements were performed with a Hamamatsu streak camera (resolution 4.7 ps). Frequency-doubled optical pulses of about 100 fs width were generated from a mode-locked Ti:sapphire laser for excitation. The pumping photon energy of TRPL was 3.1 eV (400nm). The samples were placed in the cryostat system to measure the low temperature TRPL at 12K.

3. Experimental Results and Discussions

Figure 1 shows the temporal decay profiles of low temperature PL of sample B at different emission photon energy. The temporal behavior on the high-energy side shows a multiple-exponential decay with the fast and slow decays at the earlier and later times, respectively. The fast-decay component tends to disappear when emission photon energy is below a certain value around 2.805eV. For the multi-exponential decays, we fitted the fast and slow decays with individual single exponential for the fast and slow lifetimes. On the other hand, a single decay profile was fitted with a single exponential.

Fig. 2 shows the lifetimes of all the three samples at 12K. On the high-energy side, the fast decay time can be shorter than 300 ps. Such an order of magnitude of decay time can not be

only attributed to radiative carrier recombination. In GaAs/AlGaAs multiple quantum-wells, the non-single exponential decay behavior was also observed. It was attributed to carrier transfer between free-carriers and the bound states. In our system, besides recombination such a short decay time is due to an additional process, i.e., carrier transfer from weak-localized states to strong-localized ones. Therefore, the fast-decay component corresponds to carrier recombination in weakly localized states as well as carrier transfer from weakly localized states to strongly localized ones. Note that carrier dynamics includes carrier transport between different energy levels and different spatial locations. Such a process will disappear after a quasi-equilibrium state is reached. From Fig. 1, one can see that this carrier transport process lasts for several ns. Although carrier transport out from weakly localized states (the high energy level, such as 2.844 eV in Fig. 1) can be completed within about 1 ns, carrier capture of strongly localized states seems to last longer. This process can be seen from the slower single-exponential decays of the strongly localized states (such as the state of 2.737 eV). The decreasing trends of the fast-decay lifetimes, as shown by the empty symbols in Fig. 2, are reasonable because it is easier for carriers in the weaker localized states to relax down to stronger localized states.

As for the slow-decay or long-term decay component, carrier capture of a strongly localized state occurs in a longer time range. This lifetime shows a peak in each of the three samples. For Sample C, this lifetime can be as larger as almost 300 ns. Such a long lifetime is attributed to the quasi-balance of carrier decay due to recombination and net carrier supply due to carrier transport. Thus the decay slope could be considered to be the effective carrier lifetime for the interplay between carrier decay and supply. In each sample, the decreasing trend on the lower energy side of the lifetime peak can be attributed to the relatively higher difficulty for carrier to relax into the deeply localized states. This result may be related to state population distribution among localized states. At a low temperature, without thermal energy carrier relaxation into deeply localized states might be difficult.

To study the effects of thermal energy, we also conducted RT TRPL. Two RT TRPL intensity profiles of two samples at two photon emission energies are shown in Fig. 3. The two-component decay with clear turning point in either profile can be seen. We fitted our data with two-step exponential decay to obtain the fast decay time τ_1 and slow decay time τ_2. The slow decay time of the three samples are shown as functions of emission photon energy in the upper portion of Fig. 4. The decay time τ_2 increases with decreasing photon energy for each of all three samples. This is a typical property of the carrier localization model. The slow decay lifetimes can be regarded as mainly describing the radiative recombination of localized excitons. Note that the comparison between Fig. 2 and the upper portion of Fig. 4 shows that the RT lifetimes are shorter than those of LT. This naturally results from the effect of defect recombination. Also, the monotonic variations of the RT results can be attributed to the fact that at RT it is easier to reach a quasi-equilibrium condition among all localized states because of the thermal energy

For the fast decay part, τ_1 on the high-energy side describes the decay rate of the combined effect of 1) carrier relaxation from weakly localized states to strongly localized states; 2) non-radiative recombination related to defects; 3) radiative recombination of carriers in weakly localized states. On the other hand, τ_1 on the low-energy side describes the decay rate of the combined effect of 1) carrier escape from strongly localized states to weakly localized ones via thermal energy; 2) radiative recombination. Note that carrier escape means the net effect of carrier capture and carrier go-away. The net escaped carriers may end up with non-radiative recombination. With the thermal energy, carrier escape results in insignificant increasing trend of the fast decay time with decreasing photon energy. This is a difference between RT and LT results, as shown by the comparison between Fig. 2 and the lower portion of Fig. 4.

4. Conclusions

In summary, we have demonstrated the fast and slow decay times of multi-component PL intensity decay in the TRPL measurements at both RT and LT. The fast decay was essentially due to carrier dynamics between strongly localized and weakly localized states.

References

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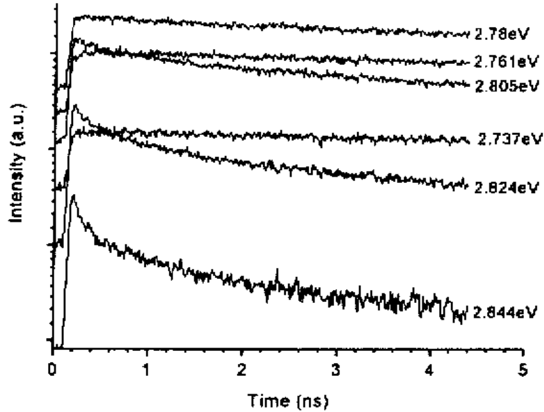

Fig. 1 Temporal PL decay of Sample B at LT.

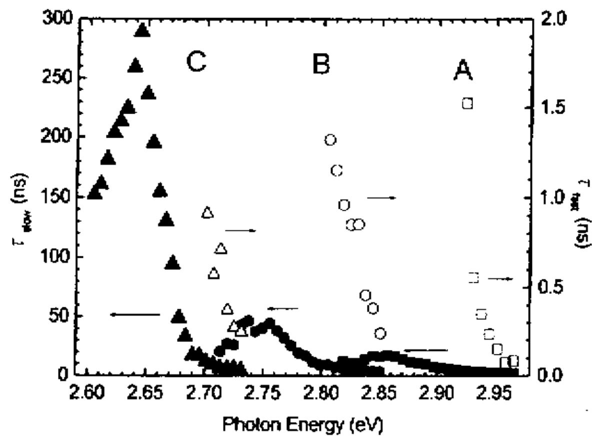

Fig. 2 Slow and fast decay lifetimes at LT.

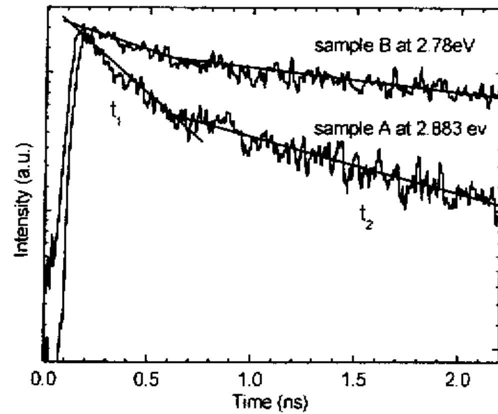

Fig. 3 Typical PL intensity profiles at RT of two samples at two photon energies

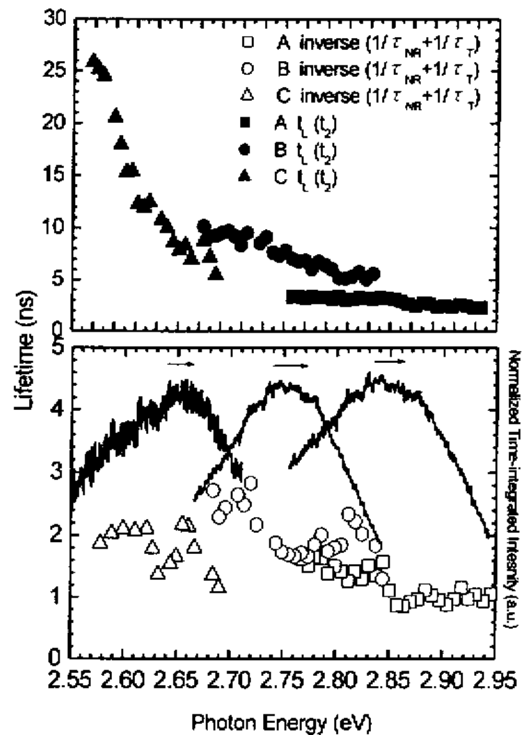

Fig. 4 Slow (the upper portion) and fast decay lifetimes of at RT.