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Observation of Slow Carrier Recombination in p-type GaN Epilayers on GaN Substrates

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Abstract

We have investigated carrier recombination processes for p-type GaN epilayers on GaN substrates. The p-type GaN samples show a slow decay component in carrier recombination processes. Based on the temperature dependence of time constants of the slow component, we discuss traps causing the slow decay component.

1. Introduction

Since a GaN has excellent physical properties for not only optical devices but also power devices. To fabricate reliable GaN power devices, it is necessary to evaluate defects in GaN crystal affecting device operation. So far, we have investigated carrier recombination processes for n-type GaN epilayer on GaN substrates to reveal defects capturing minority carriers in the n-type epilayers, and we have found a trap level contributing a slow decay component of carrier recombination processes [1,2]. Although normally-off operation of devices usually requires both n- and p-type regions, the defects in p-type GaN affecting electrical properties are not clarified. Therefore, in the present study, we focus on the carrier recombination behavior in p-type GaN homoepitaxial layers and discuss trap levels contributing carrier recombination processes.

2. Experiments

We prepared two p-type GaN samples named M-1 and M-2 grown by a metalorganic vapor phase epitaxy method. Sample M-1 has an Mg concentration of 2.0×10^{17} cm^{-3} and a film thickness of 2 μm. Sample M-2 has an Mg concentration of 7.0×10^{19} cm^{-3} and a film thickness of 1 μm. We have performed microwave photoconductivity decay (μ-PCD) method and the time-resolved photoluminescence (TR-PL) method to the samples. In both measurements, the excitation light source is a 266 nm pulse laser (pulse width: 1 ns), and the penetration length of this wavelength to GaN is < 100 nm [4]. An injected number of photons per pulse were 1.4×10^{14} cm^{-2}. To perform TR-PL measurements in the range above room temperature, we employed a hot plate to heat for the samples.

3. Results and discussion

Figure 1 shows TR-PL and μ-PCD decay curves observed in sample M-1. In the TR-PL decay curve, there is a fast-initial decay component up to 0.2 μs and a slow decay component after 0.2 μs. The μ-PCD decay curve also shows existence of a slow decay component. Time constants of TR-PL and μ-PCD slow decay components are 4.5 and 1.6 μs, respectively. The μ-PCD signal reflects electrical conductivity and thus such the slow decay in the μ-PCD signal probably induces slow switching characteristics of devices. Because the slow decay component in the TR-PL decay curve is close to that obtained from μ-PCD, the origin of their slow decays in μ-PCD and TR-PL is plausibly due to the same defects. The TR-PL signal shows better signal to noise ratio (in fact, the sample with higher Mg concentration M-2 did not show μ-PCD signal). Hereafter, we focus on TR-PL results for the both samples.

Figure 2 shows the temperature dependence of TR-PL decay curves obtained from sample M-1. The time constant of the TR-PL decay curve decreased with increasing temperature.

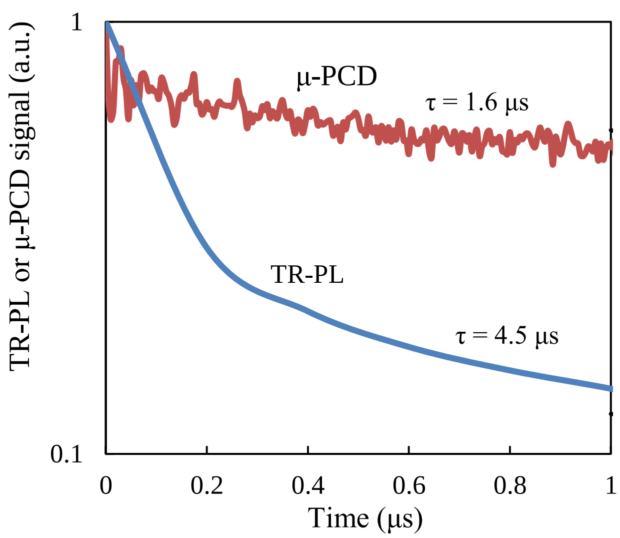

Fig. 1 TR-PL and μ-PCD decay curves for M-1.

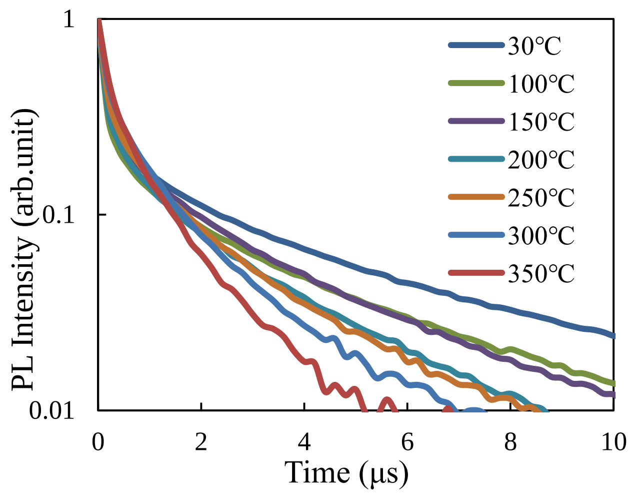

Fig. 2. Temperature dependence of TR-PL decay curves for M-1.

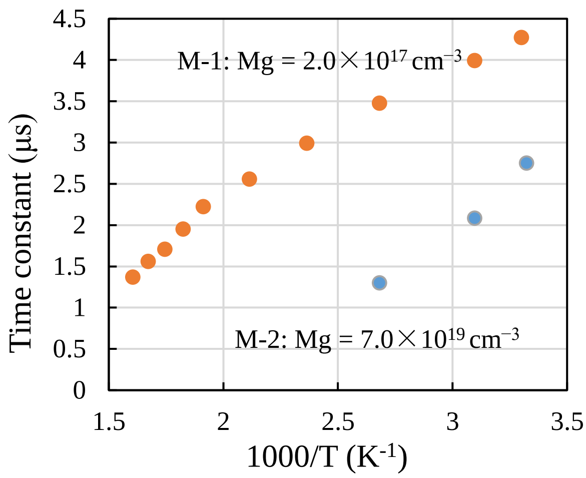

Fig. 3. Temperature dependence of time constant of the slow component in TR-PL decay curves for M-1 and M-2.

Figure 3 shows the temperature dependence of the time constant extracted from TR-PL decay curves. In this figure, time constants obtained from TR-PL for sample M-2 are also shown. The time constants are smaller for sample M-2, and for the both samples, they decrease with temperature increase.

The slow decay component of carrier recombination is generally due to the electron trap in p-type material [5]. Excited electrons are captured into the electron traps immediately after excitation, while holes remain the valence band due to a defect having a small capture cross section for holes of the trap. Decrease of the time constant with temperature increase indicates that the electron emission from the trap is enhanced by increasing temperature, and emitted electrons recombines with holes in the valence band through recombination centers [6].

In n-type GaN epilayer, by comparison with calculation based on the rate equations of capture and emission of carriers, we have found that the H1 trap is a dominant hole trap contributing the slow decay component in TR-PL signal [2]. In this p-type GaN case, we also tried to find an electron trap contributing the slow decay components considering the reported trap levels [7-11]. However, in contrast to the case of n-type GaN, temperature dependence of the time constant is gradual, and this gradual dependence makes difficult to identify the electron trap based on the rate equations with single level.

One possible origin of gradual temperature dependence is temperature dependence of equilibrium hole concentrations. Reported activation energy of holes from the Mg acceptor level is 210 to 245 meV [12], and thus holes are not fully activated at room temperature. In p-type material, the hole capture process is dominant recombination process for the slow decay component at low temperature [2], and the capture rate of holes by the electron trap increases with hole concentration increase. Therefore, increase of hole concentration enhances recombination through the electron trap (the smaller time constants for M-2 than those for M-1 may be due to high hole concentration). Another possible origin is presence of multiple electron traps, which induces multiple activation energies of electrons from the traps resulting in gradual temperature dependence. We are now calculating the rate equations with temperature dependence of the hole concentration and/or multiple electron traps. Then we will find the electron traps contributing the slow decay component of TR-PL which will affect switching performance of normally-off power devices.

4. Conclusions

We have investigated slow decay components in TR-PL and μ-PCD decay curves in p-type GaN epilayers. Such slow decays will induce slow switching characteristics of devices. The slow decay components would be due to electron traps in the p-type GaN. The time constants of the slow decay component depend on temperature. We will identify the electron traps using calculation model based on rate equations with electron traps and temperature dependence of the hole concentration.

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