# Mutual Energy Transfer between Eu Luminescent Sites in GaN under Resonant Excitation

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## 1. Introduction

Rare-earth (RE) doped solids are attractive as a robust material system for population manipulation in a solid for quantum information technology because the intra-4*f* transitions in rare-earth ions are weakly perturbed by the crystalline environment, and they exhibit resonant excitation with a narrow line width [1]. We have reported the growth and luminescence properties of Eu-doped GaN (GaN:Eu) for a novel red light emitter [2]. In this contribution, we have found a pair of Eu luminescent sites which transfer its energy mutually and investigated the population dynamics using the selective excitation of $^7F_0$ to $^5D_0$ transition, particularly focusing on the time constant of the unintentional energy transfer between $Eu^{3+}$ luminescent sites.

## 2. Experimental Approach and Results

GaN:Eu on free-standing GaN (0001) substrates was grown by atmospheric-pressure organometallic vapor phase epitaxy. The sample structure was described in Ref. 3. Combined excitation-emission spectroscopy (CEES) and time-resolved photoluminescence (TR-PL) measurements were performed in a He cryostat at 10 K using a wavelength-tunable dye laser for excitation. The dye laser was modulated by an acousto-optic modulator for TR-PL.

Figure 1 shows an image plot obtained by CEES for the GaN:Eu sample. We found anomalous emission spectra with eleven peaks excited at 2.1086 and 2.1066 eV. We recognized these spectra are caused by the emission from several Eu luminescent sites because the number of emission peaks is too high to originate from a single luminescent site. The inset in Fig.1 shows the spectra excited at 2.1086 and 2.1066 eV. Both spectra have emission peaks with identical energies. Furthermore, the dominant peaks under the excitation at 2.1086 eV become the minor peaks when excited at 2.1066 eV and the reverse is also taking place. These results strongly suggest that energy migrates between Eu luminescent sites. We defined the Eu luminescent sites basically excited at 2.1086 and 2.1066 eV as OMVPE α and OMVPE β, respectively.

We investigated the energy transfer time from OMVPE α to OMVPE β using TR-PL under the excitation of OMVPE α. Figure 2 shows the TR-PL results for peaks α and β which are dominant under the excitation of OMVPE α and β, respectively, which are normalized at saturated intensity. To show the characteristic transients, vertical axis in the laser-on and -off regions are set in liner and logarithmic scales, respectively. In the laser-on region, peak β shows a rise curve of luminescence intensity with inflection point, while peak α exhibits a standard rise transient. In laser-off region, peak β shows an anomalous decay curve with a gradual decrease of luminescence intensity in the initial stage of decay. This gradual decay

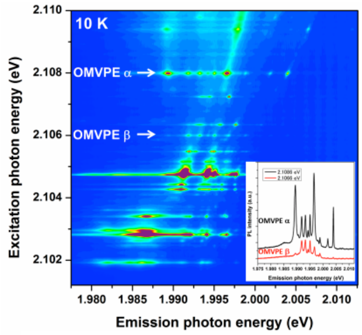


Fig. 1 CEES plot at 10K for GaN:Eu

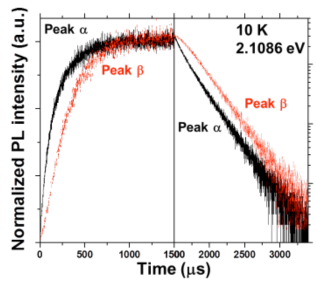


Fig. 2 TR-PL for GaN:Eu excited at 2.1086 eV.

strongly indicates that OMVPE β has the excitation process which is active even after the laser-off.

We also carried out a numerical analysis based on the rate equation to estimate the energy transfer time $\tau_{tr}$ from OMVPE α to β. In the calculated results, TR-PL transient of OMVPE β can be well reproduced when $\tau_{tr}$ is 100 μs order. However, the calculation decay time of OMVPE α is shorter than the experimental result and we could not completely reproduce the excitation power dependence of luminescence intensity. These results indicate that all OMVPE α sites do not contribute to the unintentional energy transfer.

## 3. Conclusions

Using site selective excitation we were able to observe the energy transfer between Eu luminescent sites directly. The numerical analysis based on the rate equations revealed that energy transfer time is 100 μs order.

## 4. Open Questions

- What are the detailed local structures of OMVPE α and β ?
- How can the amount of OMVPE α and β be selectively increased?

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