Inclusive and exclusive analyses of non-radiative sites/processes in rare-earth doped semiconductors: Unignorable quenching factors behind luminescence

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1. Introduction

For commercialization of light emission devices using rare-earth doped semiconductors, the luminescence efficiency should attain the level with recent high-intensity devices on the market. For the purpose, it is necessary to minimize non-radiative sites/processes involved in the developmental materials. Although novel luminesce mechanisms always fascinate us, it is non-radiative sites/processes which should be taken notice. In this study, we discuss an "*inclusive*" analysis in which non-radiative charge decay and reflection can be evaluated as well as emissive charge transfer. Moreover, a site-selective spectroscopy of luminescent rare-earth dopants is performed as an "*exclusive*" analysis of non-radiative sites.

2. *Inclusive* analysis: Vector analyses of frequency response of charges

Basically, optical measurements cannot observe non-radiative processes directly. Considering that the non-radiative processes are caused by decay or reaction of injected charges and that luminescence is induced by charge trapping and recombination, these non-radiative and radiative processes can be inclusively evaluated by electric measurements rather than optical measurements. We demonstrated a vector analysis of charge responses to AC electric field for various photoexcited materials. [1-3]. Figure 1 shows charge responses of Si nano-crystal with Er dopants (Si-nc:Er). From comparison with responses of the Si-nc without Er, it can be understood that the charge response at 45 μs is intrinsic to the Er doping. We found that various rare-earth doped semiconductors have similar responses related to the dopants in the range from μs to ms. Interestingly, the response time is synchronized with luminescence properties such as temperature quenching.

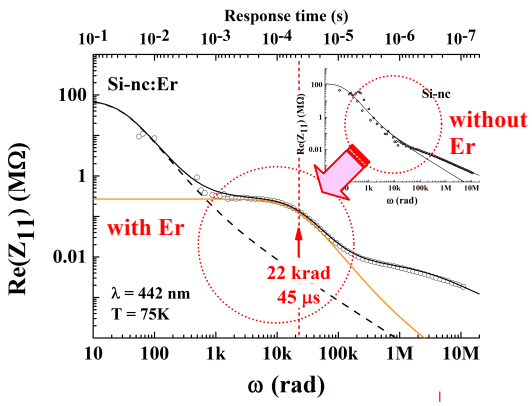

Fig. 1 *Charge response of intrinsic to doped Er. Inset indicates a Si-nc sample without Er dopants.*

3. *Exclusive* analyses: Site-selective XAFS using XEOL

As an exclusive analysis, we observed a site-selective X-ray absorption fine structure (XAFS), which is derived from X-ray-excited optical luminescence (XEOL). In this technique, only the luminescent dopants contribute to the measurement; thus, only their local structure can be selectively revealed. The sample for the site-selective XAFS was Sm-doped titanium dioxide (TiO_2:Sm) deposited on a Si(100) substrate. Figure 2(a) shows the Sm L3-edge spectrum obtained with conventional fluorescence XAFS which provides an average local structure including optically inactive sites. In contrast, the XEOL-XAFS spectrum of Fig. 2(b) clearly shows different fine structures from Fig. 2(a). From theoretical simulations of the near-edge structure, we concluded that a SmO_6 cluster with a C_{4v} symmetry formed by compressive Sm–O bond realizes the intra-4*f* transition.

4. Open Questions

- Do faster electric responses in *microwave region* clarify charge dynamics directly related to the intra-4*f* transition?
- What is the purity of site-selectivity in Optical-Detection-type measurements such as XEOL-XAFS and OD-ESR?

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References

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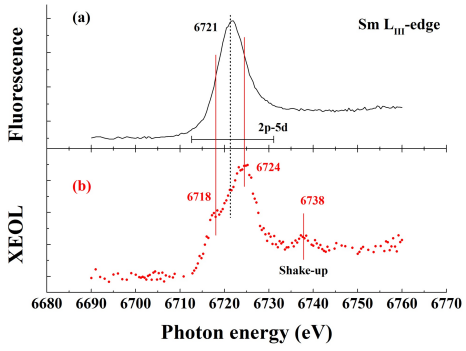

Fig.2 *Sm L3-edge XAFS spectra of (a) conventional XAFS and (b) site-selective XAFS using XEOL.*