Coordination Geometry of Praseodymium Ions Implanted in Gallium Nitride and Its Sensing Application

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Introduction

Isolated rare-earth (RE) ions in crystals are promising candidates for quantum bits and single-photon sources—key components of emerging quantum technologies. In this study, we focus on gallium nitride (GaN) semiconductors, which enable electrical control of RE ion photon emission at room temperature. Specifically, we investigate the photon emission characteristics of RE ions implanted into GaN and explore the emission enhancement via coupling with nanostructures [1]. Ion implantation is a critical technique in quantum device fabrication, as it allows for the precise placement of a specific number of RE ions at nanoscale resolution. However, this process introduces lattice damage, necessitating post-thermal annealing to restore. Despite its importance, experimental insights into the electronic state and local coordination geometry of implanted RE ions remain limited. We recently reported that the optimal annealing temperature for optical activation depends on the implantation concentration, suggesting changes in the local structure around RE ions at higher temperatures [2]. In this work, we investigated the electronic state and coordination geometry of praseodymium (Pr) ions implanted in GaN using X-ray absorption fine structure (XAFS) analysis conducted at the SPring-8 BL14B1.

Results

Figure 1 shows the X-ray absorption near-edge structure (XANES) spectra at the Pr LIII-edge for Pr-implanted GaN samples before and after cap-annealing at 1200 °C. Comparison with reference spectra from Pr_2O_3 and Pr_6O_{11} confirms that the implanted Pr ions are trivalent regardless of annealing. The post-annealing spectra exhibit increased peak intensity and reduced peak width, indicating improved local symmetry around Pr ions. These findings suggest that the enhancement in photon emission intensity following annealing is primarily due to the reduction of non-radiative transitions caused by residual lattice damage, rather than changes in the charge state of the Pr ions.

In the presentation, we will further discuss extended X-ray absorption fine structure (EXAFS) analysis and its correlation with the photon emission properties of Pr ions, including results from samples subjected to ultra-high-pressure annealing. Additionally, we will introduce a temperature sensing technique based on the temperature-dependent photon emission of Pr ions.

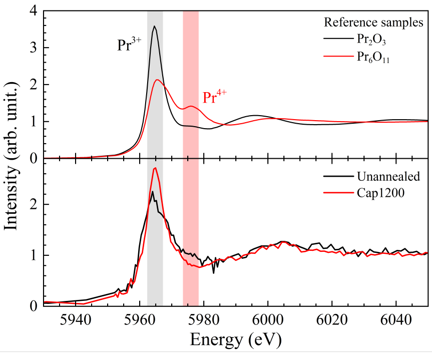

Figure 1 Pr L_{III}-edge XANES spectra of Pr-implanted GaN (black: as implanted, red: 1200 ℃ cap annealing). The spectra of Pr_2O_3 and Pr_6O_{11} are shown as reference.

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References

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