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Analysis of Nonradiative Carrier Recombination Processes in InN Films by Mid-infrared Spectroscopy

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We investigate the reduction in the efficiency of band-edge radiative recombination in InN by two carrier recombination processes via mid-gap states: radiative recombination via deep states and nonradiative recombination (NR). Because of the small band-gap energy value and the existence of the surface electron accumulation layer, the carrier transition processes via deep states cannot be observed easily. We address this problem by using mid-infrared photoluminescence (PL) measurements, and observe an emission peak around 0.32 eV at room temperature, which we interpret as being caused by transition processes via deep-defect states. Since this emission is weaker than the band-edge emission, the dominant carrier recombination process is concluded to be NR by phonon emission. The NR rate is known to be determined by the NR defect density, carrier transport processes to NR defects, and thermal activation processes of carriers. Carrier transport and capture processes by NR defects are investigated using *p*-type samples for various carrier mobility values. It is concluded that the NR rate is highly affected by the carrier transport, and that the candidates for the NR defect species are point defects and complexes of acceptor nature. We have also observed the correlation between the thermal conductivity and the band-edge PL intensity. As a result, we have found that the NR rate is highly affected by the carrier transport and thermal activation processes in InN.

Key words: InN, nonradiative recombination, deep states, carrier transport process, thermal activation process

INTRODUCTION

InN has attracted considerable interest for its potential applications in high-speed electronic devices and high-output-power infrared light-emitting devices because it has the largest electron mobility (4000 cm^2/Vs to 5000 cm^2/Vs) inside columnar domains and the lowest energy gap (0.63 eV) of all III-nitride materials.[1,2]

The radiative efficiency of InN is the lowest among the III-nitride binary compounds. In unintentionally doped InN (u-InN), we revealed that the photoluminescence (PL) intensity (I_{PL}) at the low-temperature (LT) limit, obtained from the temperature dependence of I_{PL}, strongly correlates with the edge-type threading dislocation density; however, other parameters featuring the temperature dependence show no correlation with dislocation density. On the basis of these results, we estimated that the non-band-edge recombination (NBER) process is the dominant process in carrier recombination, even at LTs, and that NBER occurs via point defects or complexes in the vicinity of edge-type threading dislocations at this temperature. Possible candidates for the thermally activated NBER defects are point defects and complexes.[3] Recently, several groups have reported successful achievement of *p*-type conductivity in InN

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