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Nanoscale photoluminescence mapping for MOVPE InN films using scanning near-field optical microscopy (SNOM)

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Abstract

This paper reports for the first time the scanning near-field optical microscopy (SNOM) analysis of MOVPE InN. A near-field PL spectrum and its intensity mapping for MOVPE InN are obtained successfully at room temperature. The near-field PL spectrum has a smaller FWHM and a little higher peak energy compared with the conventional macroscopic PL spectrum. Near-field PL images are used to know the effects of GaN buffer layer on in-plain optical uniformity in MOVPE InN. A large non-uniformity is seen in the image for the sample grown without GaN buffer. Compared with the film grown without buffer, the film grown with a GaN buffer has a better uniformity. Although the use of buffer improves the apparent in-plane uniformity, a fine structure is found in both the PL and topographic images. The fine structure seems to be related to the small grains of InN grown on the GaN buffer composed of small grains.

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Keywords: Photoluminescence; SNOM; ImN; MOVPE

1. Introduction

The interest in InN as a highly potential material for high-speed electronic devices has been markedly increased because of the small electron effective mass and the high theoretical maximum electron mobility in InN. Optical devices operating in the wavelength region from ultraviolet to infrared, including a tandem solar cell, can be made in the use of InGaN, InAlN and InGaAlN alloys, since InN has a direct band gap of 0.7 eV. Although significant improvements in the growth of InN films have been attained recently by using molecular beam epitaxy (MBE) or metalorganic vapor-phase epitaxy (MOVPE), films applicable to device fabrication have not yet been grown. Further studies on InN, especially from the standpoints of growth and characterization, are needed to realize InN-based devices. It should be pointed out that most of electrical and optical data obtained for InN films are analyzed based on the assumption that those films are homogeneous. However, there are some evidences, which show inhomogeneities in InN. The 'surface electron accumulation layer' reported for MBE samples [1] is one of the typical examples. A large difference between PL peak energy and absorption edge for MOVPE InN [2] compared with that for MBE samples [3] seems to show that MOVPE InN films have a relatively larger inhomogeneity in their properties. Therefore, studies on inhomogeneities in InN are highly required to improve the film quality for device applications. In this work, we employ the scanning near-field optical microscopy (SNOM) to analyze non-uniformity in MOVPE InN films. The study is focused on the comparison of non-uniformity between InN films grown without and with GaN buffer.

2. Experimental

Atmospheric-pressure MOVPE method is used to grow InN films. The films are grown on nitrided (0001) sapphire substrates at 600 °C in the pressure of 800 Torr. A 20 nm thick GaN layer grown at 550 °C is used as a buffer. Samples without buffer are also prepared for the comparison. The carrier concentration in the samples used for the study is 5×10^{18} to 3×10^{19} cm^{-3}. The setup of SNOM system (Type NFS-220FK, JASCO Corp., Japan) is schematically shown in Fig. 1. In the SNOM system, a green laser ($\lambda=532$ nm, $P=100$ mW) is used as an excitation source. A scanning probe with an aperture size of 100–500 nmϕ is used to excite the sample surface and collect near-field emission

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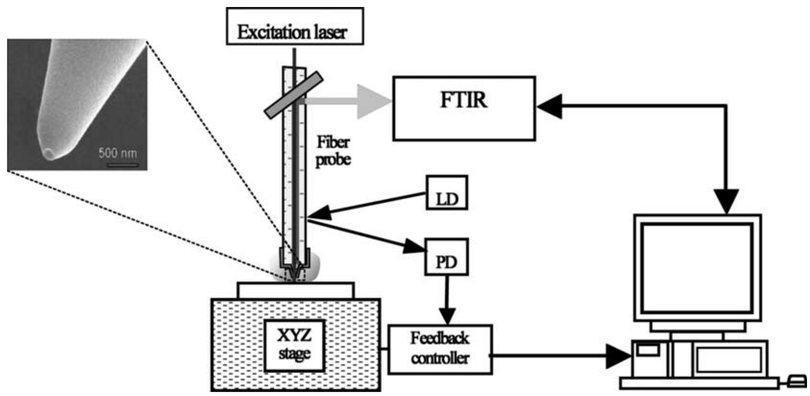

Fig. 1. System diagram of SNOM.

(illumination–collection mode). The measurement is made at room temperature. The emission is analyzed using FTIR spectrometer with two different types of InGaAs pin photodiode; One (Detector I; Type 220FK-01, JASCO) has a cut-off wavelength 1600 nm and the other (Detector II; Type G7754-01 (LN-cooled), Hamamatsu Photonics) 2300 nm. The scanning probe is vibrated at its resonance frequency by the piezoelastic ceramic transducers. The photodiode detects vibration amplitude of the probe. With decreasing sample–probe separation, the amplitude of the probe is decreased because shear force interaction between the probe and the sample surface is increased. By monitoring vibration amplitude, the sample–probe separation is kept at a constant value. When we scan the sample while shear force feedback is working, the sample position (height) changes depending on the sample topography. Thus, sample topography can be mapped by monitoring the stage movements at each point of measurement. A conventional macroscopic PL spectrum is also measured at room temperature by using a grating monochrometer, a He–Cd laser ($\lambda = 442$ nm, $P = 300$ mW) as an excitation source and an InGaAs pin photodiode (Type G7754-01 (LN-cooled), Hamamatsu Photonics) as a detector. The detector used here is of the same type as the Detector II in the SNOM measurement. All spectra shown in this paper are corrected using the spectral response of each detector. In order to check the effects of wavelength dispersion of the spectrometers (FTIR and grating monochrometer), a macroscopic PL spectrum is also measured using the FTIR system with the Detector II. In this measurement, the fiber probe is not used and, therefore, the excitation light is not focalized into a small size (−500 nm) and a far-field PL is recorded. Fig. 2 shows the comparison of the macroscopic PL spectra measured with the FTIR and with the grating monochrometer. As shown in the figure, no difference is found between the both. Therefore, we can compare the near-field PL measured with the Detector II with the conventional macroscopic PL.

3. Results and discussion

Fig. 3 shows the near-field PL spectra measured with the different detector (Detector I or II). A scanning probe with an aperture size of 500 nmϕ is used in this case. Also shown in Fig. 2 is the macroscopic PL spectrum for the comparison. Even at room temperature a near-field PL spectrum is measured successfully as seen in Fig. 3. The emission mechanism of PL with the peak energy around 0.7 eV is known to be the recombination between degenerate electrons and free holes [4]. Therefore, the PL peak energy is increased with increasing

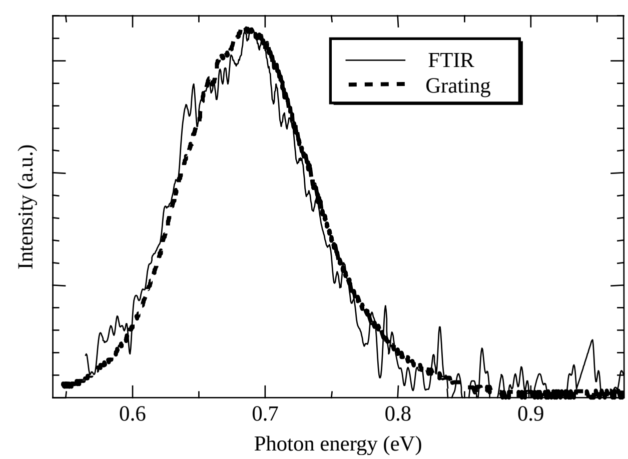

Fig. 2. The comparison between the macroscopic PL spectra measured with the grating system and with the FTIR system without the fiber probe. The detectors used here are of the same type.

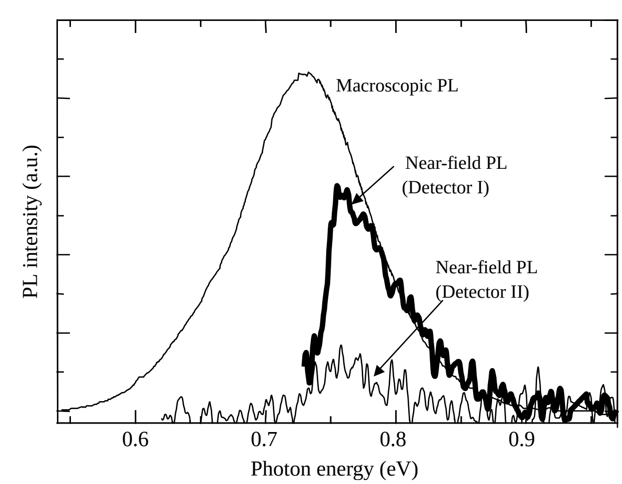

Fig. 3. Near-field PL spectra measured with different detectors and conventional macroscopic PL spectrum for a MOVPE InN at room temperature.