RAMAN SPECTRA OF LOW AND HIGHLY DEGENERATE InN FILMS

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Abstract: The Raman spectra of low and highly degenerate InN films with optical bandgaps ranging from 0.7 to 1.9 eV have been studied. The observation of unscreened LO-phonon, and the absence of the coupled plasmon LO-phonon modes have been attributed Landau damping of higher coupled mode and the emergence of A_1(LO) mode from the electron-hole pair spectra.

InN has attracted much attention because of its excellent electrical and optical properties [1-2]. As a result InN has been extensively investigated due to its potential applications to a wide range of fast and high frequency electronic devices. Recently, the optical bandgap of InN films has been shown to be ~ 0.7 eV rather than the long believed and generally accepted value of 1.9 eV [3-5]. This is has been attributed to the improvements in the thin-film fabrication techniques leading to higher quality InN films with relatively less disorder. The optical absorption edge in InN films has been shown to be highly dependent on the carrier concentration, n_e [6]. For example, samples with $n_e \leq 1.0 \times 10^{19}$ cm^{-3} show a bandgap absorption edge of ~ 0.6 - 0.7 eV, whereas highly degenerate films with $n_e \geq 3 \times 10^{20}$ cm^{-3} show ~ 1.5 - 1.9 eV. Here, we present the Raman spectra of degenerate InN thin films with n_e varying from 7×10^{17} to 9×10^{20} cm^{-3} and discuss the behaviour of LO-phonon mode.

InN films were grown by conventional Molecular Beam Epitaxy (MBE) and Plasma Source Molecular Beam Epitaxy (PSMBE) at ~ 470 ^{o}C on c-plane sapphire substrate. Sample thickness varied from 0.6 to 2 μm. Details of the experimental details are given in references 5 and 7. Figure 1 shows the Raman spectra of low and highly degenerate InN films recorded in backscattering geometry using a 514.5 nm excitation line.

Raman spectra of low degenerate InN films (Fig. 1a) show sharp A_1(LO) and E_2 modes whereas spectra of highly degenerate InN films (Fig. 1b) show rather broad features indicating the presence of a large number of structural defects. These observations are consistent with the x-ray diffraction measurements on these samples [7]. Another striking feature in the Raman spectra of InN films with high carrier concentrations is the observation of the higher order peaks with considerable intensity. A possible reasons for this could be the resonance enhancement due to the closeness of the energy bandgap (~1.5 – 1.9 eV) in these samples to the excitation energy (2.41 eV).

The behaviour of LO-phonon mode in these degenerate InN films is especially interesting. In principle, the coupling between the unscreened LO-phonon and the plasmon modes should create two coupled modes (plasmon LO-phonon + and −, abbreviated as PLP+ and PLP−) with energies very different from the fundamental modes [8]. Instead phonons near frequencies corresponding to fundamental LO-phonons are observed, without the presence of PLP+ and PLP− modes. For example, the expected PLP+ and PLP− modes for $n_e = 7 \times 10^{17}$ cm^{-3} (1.1×10^{19} cm^{-3}) sample are expected at 642 cm^{-1} (1212 cm^{-1}) and 251 cm^{-1} (424 cm^{-1}). For highly degenerate samples PLP+ modes are expected ~4300 cm^{-1} (beyond the instrument limit) and PLP− modes ~448 cm^{-1} {A_1(TO)}. Furthermore, the mode near A_1(LO) frequency shifts up from 582 cm^{-1} to 587 cm^{-1} when n_e changes from 7×10^{17} cm^{-3} to 1.1×10^{19} cm^{-3} and approaches 590 cm^{-1} in highly degenerate InN samples.

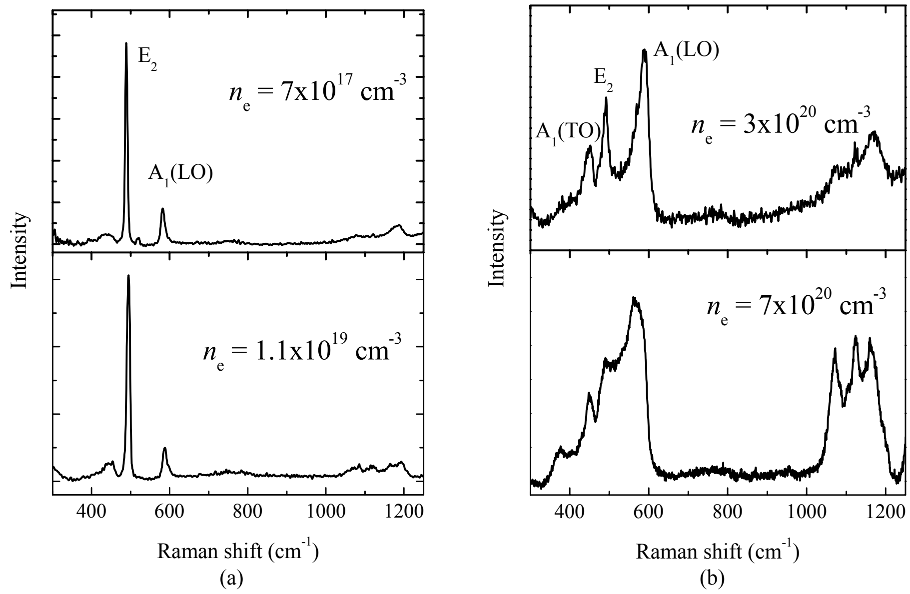

Fig. 1. Raman spectra of (a) low degenerate and (b) highly degenerate InN films. The carrier concentration (n_e) in the films are shown.

Our theoretical calculations [9] show that the phonon mode appearing near A_1(LO) is a high wave-vector mode in degenerate InN films. When the higher energy PLP+ mode gets Landau damped, the coupling of the lower energy PLP− mode with the electron-hole pair excitations, leads to the emergence of a mode very close to the A_1(LO) mode. Larger the value of n_e, the mode seems to appear at higher wave vector and hence approaches the unscreened A_1(LO) frequency, in agreement with our experimental observations.

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