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Band gap widening of MBE grown InN layers by impurity incorporation

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Abstract

Band gap widening due to impurity contamination such as oxygen (O) incorporation into InN layers has been observed by growth without PBN sealing in the RF-plasma reactor. Furthermore, V/III ratio dependence of the absorption edge of InN layers grown under O-contaminated background has shown a strong correlation with that of the residual carrier concentration. A clearly red-shift of the absorption edge has been also observed for InN layers grown under the simultaneous irradiation of Ga beam. These results strongly indicate that O may be one of the strong candidates of impurity identified as an origin of band gap widening of InN.

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1. Introduction

Recently, it has been reported by many groups that band gap energy (E_g) of InN is about 0.7 eV [1–4], although it was believed that the E_g was about 2.0 eV for a long time. We have already reported that InN layers with absorption edge of continuously up to 0.7–2.0 eV have been obtained by the conventional MOVPE, ArF-beam-assisted MOVPE (LA-MOVPE), and radio-frequency plasma-assisted molecular beam epitaxy (RF-MBE) with a quartz tube reactor [1]. If InN is a true narrow band gap semiconductor, it is expected that InN becomes an important material for various device applications such as high-efficiency tandem solar cells and long wavelength laser diodes. However, crystal quality of InN is not good enough for the device applications at present, because of highly residual electron concentrations of 10^{18}–$10^{20}\,cm^{-3}$. Although the origin of both highly residual carrier concentrations and band gap widening has not yet been understood so well, one of the strong candidates seems to be some

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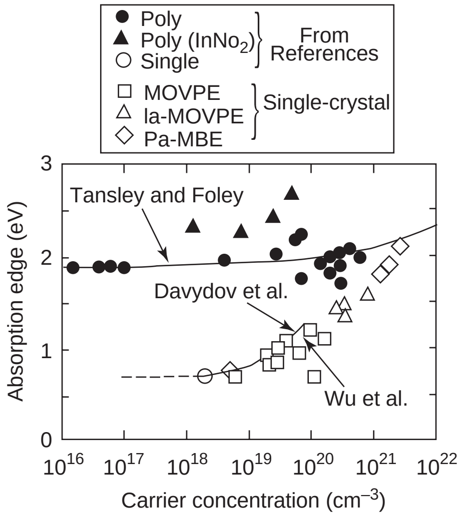

Fig. 1. Absorption edge values for InN films grown by different methods as a function of the carrier concentration.

impurities and defects such as O atoms or N vacancy by both theoretical and experimental data analysis using the Burstein–Moss model proposed by Davydov et al. [1], as shown in Fig. 1. However, any systematic investigation on the band gap widening due to impurity contamination has not been performed yet. In this paper, we have investigated the band gap widening due to impurity contamination such as O incorporation into InN layers grown by RF-MBE.

2. Experimental procedures

InN layers were grown on α-Al_2O_3 (0 0 0 1) substrates at 550 °C by RF-MBE. In and Ga high-purity metals were used as solid sources and a RF-plasma cell was used as N source. The RF-power and the N_2 flow rate of RF-plasma cell are 150 W and 0.6 sccm, respectively. O amounts into InN layers was controlled mainly by a PBN tube inserted into the quartz tube of RF-plasma reactor. In beam flux was changed in the range of 4.0–8.0×10^{-6} Pa in order to investigate V/III dependence of impurity contamination during growth. An extremely low Ga beam flux was supplied simultaneously to remove O-related adducts under O-contaminated background.

Optical absorption spectra were measured at room temperature by the Perkin Elmer Lambda 19, double monochromatic spectrometer. Carrier concentrations were estimated by Hall measurements and crystal quality was evaluated by θ–2θ X-ray diffraction (XRD) method with symmetrical Bragg geometry. O concentration of InN layers was estimated by Rutherford backscattering spectroscopy (RBS).

3. Results and discussions

Fig. 2 shows absorption spectra of InN layers grown by RF-MBE (a) with and (b) without insertion of a PBN tube into the present quartz RF-plasma reactor. A clear red-shift of the absorption edge about 0.3 eV was observed in the case of the growth with insertion of the PBN tube. Furthermore, the decrease in residual carrier concentration of InN layers was also observed simultaneously with the red-shift of the absorption edge. Contamination of O and carbon(C) from an electron cyclotron resonance (ECR) cell caused by decomposition of hydrocarbons due to excited ions was reported by Hasegawa et al. [5]. It is said that the production amounts of ions excited by

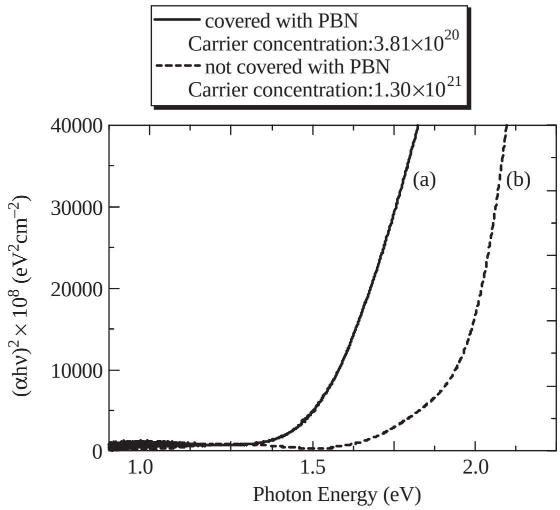

Fig. 2. Absorption spectra of InN layers grown by RF-MBE (a) with insertion of a PBN tube into RF-plasma reactor and (b) without it.