Magnetic Field Modulated Photoreflectance Study of the Electron Effective Mass in Dilute Nitride Semiconductors

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Abstract. Magnetic field modulated photoreflectance measurements are performed on the dilute nitride semiconductor Ga(AsN) in quantizing magnetic fields. From the measured cyclotron energies, the conduction band effective mass and its dependence on the nitrogen content are determined. The effective mass is found to become significantly heavier in samples with high nitrogen composition ($> 0.1\,\%$).

Keywords: Modulation spectroscopy, dilute nitride semiconductor, Landau level
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INTRODUCTION

The effect of resonant nitrogen impurities on the conduction band structure and Landau levels (LLs) of dilute nitride semiconductors [1] is a topic of fundamental and technological interest [2–5]. However, it is generally difficult to probe the LLs, particularly at high nitrogen composition, because the disorder-induced level broadening of the LLs limits the experimental resolution. Here we report new magnetic field modulated photoreflectance (MMPR) measurements in $GaAs_{1-x}N_x$ to probe the Landau level spectra and to determine the conduction band effective mass and its dependence on the nitrogen content, x.

Modulation spectroscopy is a powerful experimental technique to investigate optically the energy band structure of semiconductors [6, 7]. Photoreflectance (PR) spectroscopy [8] is a non-contact modulation method, which measures the third derivative of the dielectric function [9] and determines the critical points of the band structure. We combine PR spectroscopy with the magnetic field modulation [10] through a double lock-in detection to enhance higher quantum number transitions.

EXPERIMENTS

The samples used in the present study consist of $GaAs_{1-x}N_x$ epilayers with $0\,\% \leq x \leq 1.5\,\%$, grown by molecular beam epitaxy (MBE) on a n^+-type GaAs substrate. The undoped $GaAs_{1-x}N_x$ layers have thickness of 1500 nm and are grown on a 25 nm-thick AlAs layer and a 100nm-thick GaAs buffer layer.

Figure 1 shows the transition energies obtained from conventional PR experiments at $T = 150\,$K and $B = 0\,$T. We observed for all samples the fundamental band gap transition, whose transition energy (E_-) decreases with increasing x. For samples with $x \gtrsim 0.7\,\%$, we observed an additonal transition, related to a nitrogen-related resonant level, whose transition energy (E_+) increases with increasing x. These observations are consistent with previous electroreflectance (ER) experiments [11]. The transition energies can be well fitted by a two-level band anticrossing (BAC) model (see solid lines in Fig. 1) [3, 12].

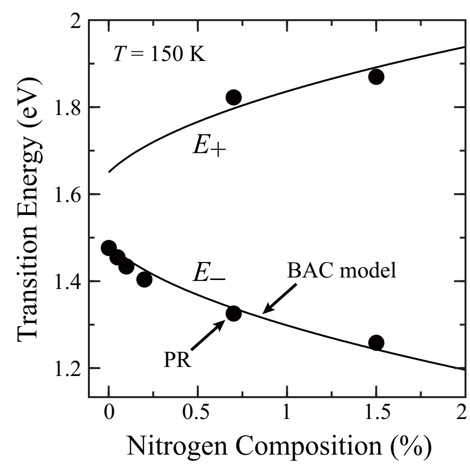

FIGURE 1. Transition energies measured by PR technique at $T = 150\,$K and $B = 0\,$T (solid circles). Solid lines correspond to the calculated energies using the BAC model.

The PR spectrum at $B = 7\,$T is shown by the dashed line in Fig. 2 for $GaAs_{1-x}N_x$ ($x = 0.1\,\%$). The magnetic field was applied normal to the sample surface. We see that signals associated with upper LLs are rather weak. In order to enhance the upper LLs, we have used a double modulation technique (electric field and magnetic field

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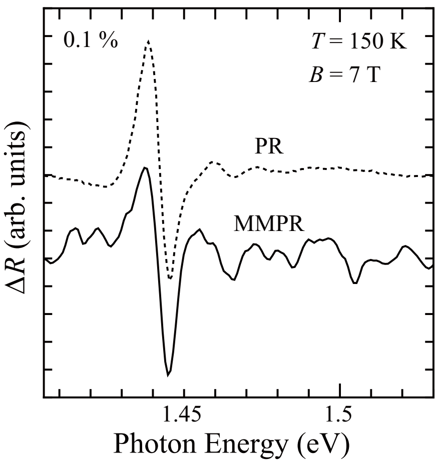

FIGURE 2. Magnetic field modulated photoreflectance (MMPR) spectrum (solid line) and photoreflectance (PR) spectrum (dashed line) for $GaAs_{1-x}N_x$ ($x = 0.1\,\%$) at $T = 150\,K$ and $B = 7\,T$.

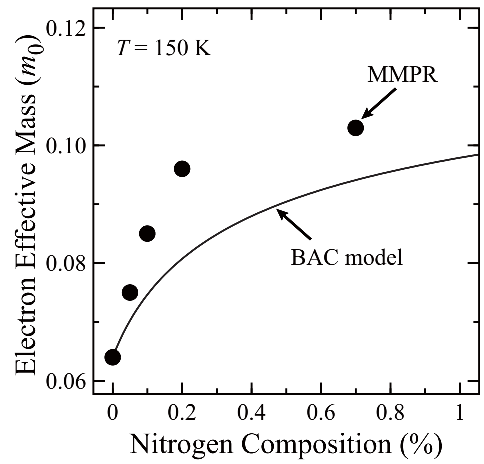

FIGURE 3. Dependence of the electron effective mass on the nitrogen content obtained from the MMPR experiments (solid circles) and from the band anti-crossing model (solid lines).

modulation), also called MMPR spectroscopy. The solid line in Fig. 2 shows the MMPR spectrum at $B = 7\,T$. We find that the higher LLs are clearly resolved in the MMPR spectra. By fitting the experimental spectra to the theoretical curves, we decomposed the MMPR signal into individual Landau level contributions. We identified up to 7 excited LLs in the MMPR spectrum.

RESULTS AND DISCUSSION

From the decomposed signals, we obtained the cyclotron energy $\hbar\omega_c$ $(= eB/\mu(x))$ and the reduced effective mass $\mu(x)$ $(= \{m_e^*(x)^{-1} + m_h^*(x)^{-1}\}^{-1})$, where $m_e^*(x)$ $(m_h^*(x))$ is the electron (hole) effective mass. We then converted $\mu(x)$ to $m_e^*(x)$ assuming that $m_e^*(0)$ is equal to the bulk GaAs electron effective mass $(= 0.064\,m_0$ at $150\,K)$ and $m_h^*(x)$ is independent of x $(= 0.53\,m_0)$. The results are plotted in Fig. 3, where we find that $m_e^*(x)$ tends to increase with the nitrogen content and becomes significantly heavier than the BAC values in samples with high nitrogen composition. This may be due to the effect of additional resonances associated with N-N pairs [3].

SUMMARY

We performed MMPR measurements in $GaAs_{1-x}N_x$ and determined the conduction band effective mass and its dependence on the nitrogen content. We find that the effective mass tends to increase with the nitrogen content and becomes significantly heavier in samples with high nitrogen composition.

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