CHAPTER I

INTRODUCTION

1.1 Overviews of GaAsN Alloy

Nitrogen-containing III-V alloys, such as $GaAs_{1-x}N_x$ and $In_yGa_{1-y}As_{1-x}N_x$, have been studied intensively in recent years due to the large bandgap bowing caused by the incorporation of a small amount of nitrogen (N) [1-5]. This is unlike the conventional ternary III-V semiconductor alloys, such as $Al_yGa_{1-y}As$, $In_yGa_{1-y}As$, $In_yGa_{1-y}P$, etc., where the bandgap energy of these alloys can be approximated as a linearly weighted average of the bandgap energy of the parental binary compounds [6, 7]. The low-bandgap $GaAs_{1-x}N_x$ and $In_yGa_{1-y}As_{1-x}N_x$-based quantum well (QW) structures are expected as useful for optoelectronic devices such as laser diodes (LDs) emitting at 1.3 and 1.55 μm for optical communication systems [8, 9]. Both $GaAs_{1-x}N_x$ and $In_yGa_{1-y}As_{1-x}N_x$ alloy materials theoretically allow a large extension of emission wavelength [5, 7] and enlargement of conduction band offset (ΔE_C) of the QW structures, which leads to excellent laser operation at high temperature. This allows a strong reduction of an electron overflow from the quantum wells to the barrier layers, which could potentially lead to significant improvement in temperature characteristics of conventional long-wavelength LDs for optical fiber communication systems. The thermal stability of the lasers is also improved due to better electron confinement in the quantum well of the active region.

The $GaAs_{1-x}N_x$ alloy films with N concentrations (x) up to $x \sim 0.050$ - 0.080 were grown on the GaAs (001) substrates by metalorganic vapor phase epitaxy (MOVPE) [10, 11]. However, optical quality of GaAsN alloy layers has been found to degrade with higher N incorporation. This may come from the formation of highly inhomogeneous material with inclusions of cubic GaN (c-GaN), GaAsN and GaAs phases [12]. This is due to an extremely large miscibility gap between c-GaN and GaAs caused by the large differences in lattice constant. Generally, post-growth thermal annealing is carried out to improve the luminescence properties, but leads to a blue-shift of the photoluminescence (PL) peak energy [11, 13]. However, there are few researches reporting this effect on the high N-containing GaAsN films [10, 14]. In addition, the improvement of optical quality by the GaAsN/GaAs QW structure is also concerned.

Previously, the results on the MOVPE growth of the high N-content $GaAs_{1-x}N_x$ films with N content range of $x = 0 - 0.051$ using trimethylgallium (TMGa), 1, 1-dimethylhydrazine (DMHy), and tertiarybutylarsine (TBAs) as the source materials for Ga, N and As, respectively, were reported [14]. In this work, we have investigated the influence of post-growth thermal annealing and QW structures on structural and optical properties of the high N-containing $GaAs_{0.949}N_{0.051}$ thick film and its QWs.

Recently, the optical investigation has been mainly focused on the dependence of the alloy bandgap on the N concentration. However, the recombination mechanism of these alloys is involved in the alloy composition fluctuation [15, 16], due to deterioration of the crystal quality with higher N incorporation. In addition, it has remaining unsolved issues regarding the electronic properties of the GaAsN alloy and the GaAsN/GaAs QWs structure involving the structural origin of carrier localization and type of band alignment for the GaAsN/GaAs QWs system, respectively.

1.2 Objectives

Objectives of this work are to establish a basic understanding of structural and optical properties of high N-containing $GaAs_{1-x}N_x$ alloy film and its QWs ($x \sim 0.050$), which are very important for developing long-wavelength semiconductor LDs, and further, to enhance the knowledge of the fundamental physics of the N-containing III-V alloy system. The following topics are mainly focused:

i) optical and structural investigation of the high N-containing $GaAs_{0.949}N_{0.051}$ alloy film and its QWs;

ii) effects of N incorporation on the physical mechanisms of photoluminescence and recombination process in the high N-containing $GaAs_{0.949}N_{0.051}$ alloy film and its QWs;

iii) correlation between the compositions fluctuations and the localization in the $GaAs_{1-x}N_x$ alloy films with different N concentrations as well as QWs;

iv) effects of post-growth thermal annealing on the composition distribution in the high N-containing $GaAs_{0.949}N_{0.051}$ alloy film and its QWs in connecting with their optical properties;

v) band alignment type of the GaAsN/GaAs QW system.

In order to study these interesting subjects, the structural and optical properties of high N-containing $GaAs_{0.949}N_{0.051}$ alloy film and its QWs were investigated using high-resolution X-ray diffraction (HRXRD), transmission electron microscopy (TEM), Raman scattering and PL.

1.3 Organization of the Thesis

The major part of the thesis is describing of the structural and optical properties of the MOVPE grown high N-containing GaAsN alloy films and GaAsN/GaAs QWs structures, with an emphasis on the effects of post-growth thermal annealing of the films and the QWs with higher N incorporation ($x \sim 0.050$). The thesis is organized as follows.

In the beginning, in Chapter II, the current knowledge of the characteristic properties of III-V-Nitride ternary alloys is reviewed.

In Chapter III, the growth information of GaAsN thin films (bulk layer) and GaAsN/GaAs MQWs is described. In addition, the basic understanding of HRXRD and PL measurements are described.

In Chapter IV, optical and structural properties of the high N-containing $GaAs_{0.949}N_{0.051}$ alloy films investigated by PL, HRXRD, Raman scattering and optical microscopy were discussed on the basis of the extended experimental methods and the simple models. The effects of post-growth thermal annealing on the optical and structural properties were also described.

In Chapter V, optical and structural properties of as-grown and annealed GaAsN/GaAs MQWs investigated by PL, HRXRD and TEM were discussed. Also, the effects of post-growth thermal annealing on the optical and structural properties were discussed. Furthermore, the fundamental band alignment type of the GaAsN/GaAs QWs structure is considered.

Finally, Chapter VI gives the conclusions of the thesis.