CHAPTER I

INTRODUCTION

1.1 Motivation

The techniques of self-assembled fabrication for nanostructures are highly attractive for basic physics and device applications. Useful for opto-electronics, the atom-like properties of quantum nanostructures such as carrier confinement and energy level quantization can lead to the emission of photon with a specific wavelength. For decades, various fabrication techniques for quantum nanostructures have been developed. In particular, the Stranski-Krastanov (SK) growth mode, one of the most widely used methods for fabrication, is driven by the strain from lattice mismatch between the substrate and the overlayer [1]. However, the non-uniform strain distribution in the lattice-mismatched system can affect the energy band structures, undesirable for studies of the physics of semiconductor nanostructures. Another growth technique that has been applied to form nanostructures without strain is droplet epitaxy technique [2-4]. This technique is simple and flexible. The droplet epitaxy process is simply based on the formation of the group III element droplets by depositing group III atoms on a crystalline surface, followed by a reaction with a group V element for crystallization into III-V compound nanostructures. The lattice-matched system in droplet formation can eliminate the strain energy and its effects on the energy-band structures. Moreover, it does not require additional complicated processing and has potential to develop the quantum nanostructures. Not only quantum dots (QDs) but also the complex nanostructures such as nanoholes [5,6], quantum rings (QRs) [2], and quantum dot molecules (QDMs) [7] have been demonstrated by this technique.

Among them, QRs, or ring-shaped nanostructures, are a special class of quantum-confinement structures. Just like QDs, QRs also have quantized energy levels due to their carrier confinement, which makes them potentially applicable in opto-electronics [8-10]. However, the QRs have attracted a lot of attention due to the additional features such as the Aharonov-Bohm effect [11,12]. One predicted feature of quantum rings is the magnetic properties which are related to the possibility of inducing persistent currents [12]. The QRs have been demonstrated through several approaches including thin GaAs layer capping of InAs QDs [13-18], post-growth annealing process [1,19], SK growth [20,21], and droplet epitaxy [2,22-27]. Most of the QRs have been demonstrated by forming a thin layer of GaAs on SK-grown InAs QDs (*Lorke et al. (2001); Granados et al. (2003); Kiravittaya et al. (2003); Schmidt et al. (2002); Songmuang et al. (2003); Garc et al. (1997)*). The formation mechanism is driven by the reduction of the surface free energy around InAs QDs due to the deposition of a thin GaAs layer. After the short annealing, a remarkable morphological change results in QR formation.

While many of the approaches utilize the conversion of QDs to QRs, the droplet epitaxy technique can form QRs directly. In past years, there are experimental results reported in literatures about QRs grown by droplet epitaxy [2,5,6,22-24,26,28]. Most are the fabrication of GaAs QRs in GaAs/(Al)GaAs material systems. *Mano et al. (2005) and Lee et al. (2006)* have proposed the evolution of lattice-matched GaAs/$Al_{0.3}Ga_{0.7}As$ QRs grown by droplet epitaxy. The growth simply starts with the formation of Ga droplets on $Al_{0.3}Ga_{0.7}As$ surface and then follows by crystallization in As_4. During the crystallization, Ga droplets interact with As atoms and change to GaAs QRs. The high structural and optical qualities of the QRs are confirmed. Furthermore, *Alonso-Gonzalez et al. (2007)* demonstrated the formation of InAs QDs in a low-density template of GaAs/GaAs QRs fabricated by droplet epitaxy. By capping the template with 1.4 ML conventional InAs, InAs QDs are restrictively formed only inside the template QRs. With use of this low-density strain-free template, the low-density InAs QDs ($\sim 10^8$ cm^{-2}) can be realized. By the way, In(Ga)As/GaAs is another interesting systems due to exhibited quantum confinement. Recently, there are several literatures about InAs/GaAs QRs grown by droplet epitaxy. *Noda et al. (2008) and Lee et al. (2008)* have reported the fabrication of InAs QRs on GaAs (100) by droplet epitaxy. Diameter and Density of the resulted QRs are ~ 200-400 nm and ~ 10^6 cm^{-2}, respectively. Very low density and relatively large size of such QRs still be a limitation of InAs/GaAs QR formation and undesirable for optical application. This is resulted from a too long 2-dimentional surface migration length of In atoms and high segregation effect of newly supplied adatoms. A solution to overcome the problems is the growth at low temperature with an optimum crystallization [29]. Another solution is to limit the migration length of In atoms on GaAs. Ga is also supplied together with the deposition of In. Predictedly, the structural properties of crystallized InGaAs QRs are different from pure-InAs QRs. Moreover, it's clear that the QRs are originated from the respective droplets, so changing of droplet forming condition subjects to vary the properties of the crystallized QRs. Hence, a clear demonstration of the formation of InGaAs QRs by droplet epitaxy is desirable.

In this dissertation, the formation of low-density InGaAs ring-like nanostructures (QRs) on GaAs (100) by droplet epitaxy technique using MBE was demonstrated. The evolution of morphology and the formation mechanism have been investigated. The droplet-forming conditions have been varied by changing the growth parameters including substrate temperature during depositing InGa (T_s), $In_{0.5}Ga_{0.5}$ amount, and Indium-mole-fraction. The surface morphology of the QRs was analyzed by using an atomic force microscope (AFM). The effects of the growth parameters on the InGaAs ring-like nanostructures grown by droplet epitaxy were also investigated. For photoluminescence (PL) measurement, the InGaAs QRs were repeatedly grown under several selected droplet-forming conditions with an additional 100-nm GaAs capping layer. PL measurement was performed to characterize the optical properties of the InGaAs QRs.

1.2 Objectives

This dissertation objective is to demonstrate the fabrication of InGaAs ring-like nanostructures, so called quantum rings (QRs), on GaAs by droplet epitaxy technique using molecular beam epitaxy. The growth parameters including 1) substrate temperature during the deposition (T_s), 2) deposited $In_{0.5}Ga_{0.5}$ amount, and 3) Indium-mole-fraction (x) of In_xGa_{1-x} have been varied. The effects of growth parameters on the morphological properties of the InGaAs QRs (QR size and density) have been analyzed through the surface morphology of the InGaAs QRs grown with different growth conditions. Also, the optical properties of the InGaAs QRs have been investigated from PL spectra of the 100-nm-GaAs capped samples at 20-100 K.

1.3 Overview

This dissertation presents a detailed study of the fabrication of InGaAs ring-like nanostructures by droplet epitaxy technique using molecular beam epitaxy (MBE). The purpose is to analyze the effects of droplet forming parameters on the structural and optical properties of the nanostructures.

The thesis is organized as follows: The basic concepts are reviewed in chapter 2. This also includes fabrication techniques for nanostructure formation. Chapter 3 gives the experimental details. Moreover, the information of the equipments used in this work is briefly introduced. In chapter 4, the experimental results from the fabrication of InGaAs QRs are presented. Also, the evolution of surface morphology by RHEED observation and predicted QR-formation mechanism are represented. The effects of substrate temperature during $In_{0.5}Ga_{0.5}$ deposition, $In_{0.5}Ga_{0.5}$ amount deposited, and Indium-mole-fraction of droplets on the morphological and optical properties of InGaAs QRs are studied in this chapter. The studies are based on atomic force microscopy (AFM) and photoluminescence (PL) results. Finally, chapter 5 concludes this work.