CHAPTER V

CONCLUSIONS

This work presents a fundamental study and the fabrication process to realize the novel nanostructures by droplet epitaxy technique using solid-source MBE such as InP QRs and InP ring-shaped QDMs in the $In_{0.5}Ga_{0.5}P$ matrices grown on GaAs (001) substrates.

First, a brief overview on the properties of low-dimensional nanostructures, especially QDs, was given. Details of self-assembled growth by the Stranski-Krastanow mode and droplet epitaxy techniques were given. From material considerations, the InP QDs in the $In_{0.5}Ga_{0.5}P$ matrices on GaAs (001) substrate are chosen to form the ring-shaped QDMs for quantum information processing application. The instruments and their utilizations in this work were explained.

In situ RHEED observations were used to calibrate the substrate temperature and all growth rates and to investigate the InP ring-shaped QDMs formation. The composition and growth rate of $In_{0.5}Ga_{0.5}P$ were adjusted according to SEM, HRXRD and PL measurements. The structural and optical properties of QDM samples were characterized by *ex situ* AFM and PL. The PL power and temperature dependences and cross-sectional TEM images of optimized InP ring-shaped QDMs were also investigated.

The growth parameters of self-assembled InP ring-shaped QDMs deposited by droplet epitaxy technique were investigated to improve the QD size homogeneity QDM uniformity and number of QDs per QDM control. The growth was divided into 2 stages: In droplet deposition and crystallization under the P_2 pressure. The deposition temperature, crystallization temperature, In growth rate and In thickness were systematically varied to provide and understand the QD formation mechanism and a way to adjust the QD and QDM properties. Large, low density and small, high density QDs and QDMs were realized by changing these growth factors. The effects of each growth parameter can be summarized into 4 categories:

1. The deposition at high substrate temperature gives larger QDs and ring-shaped QDMs sizes with low densities. The PL peaks, PL intensities and FWHMs are gradually redshifted, lowered and narrowed with higher deposition

temperature toward 250 °C. The best QD size uniformity and the highest number of QDMs which consist of eight QDs per QDM could be achieved at the deposition temperature of 250 °C.

2. The effect of crystallization temperature is quit similar to that of deposition temperature. However, the effect of deposition temperature is remarkably stronger than the other because the QD and ring-shaped QDM sizes are mainly determined during the deposition and slightly transform by the crystallization process. The crystallization temperature which is slightly lower than deposition temperature is preferred for a good QD quality. The best experimental result could be achieved at crystallization temperature of 200 °C with deposition temperature of 250 °C.
3. The effect of In deposition rate is inverse with the experiment of temperature modification. The smaller sizes QDs and ring-shaped QDMs with high density, the blueshifted PL peaks, the enlarge PL intensities and widened FWHMs are achieved with higher In deposition rate. The best In deposition rate condition which give the best output is 1.6 ML/s, limited by the capacity of MBE system inthis work, with deposition and crystallization temperatures of 250 °C and 200 °C, respectively.
4. The critical In thickness and In amount of coherent QD formation by droplet epitaxy technique in this work could be estimated between 1.6 ML-3.2 ML and 3.2 ML, respectively. The best fixed growth condition in order to form the best QD quality and the highest number of QDMs (46%) which consist of eight QDs per QDM is created from the deposition and crystallization temperatures of 250 °C and 200 °C with In deposition rate of 1.6 ML/s and 3.2-ML In coverage. The PL peaks and FWHMs of these InP ring-shaped QDMs are 1.68 eV and 43 meV at 20 K and 1.61 eV and 60 meV at room temperature.

In view points of physical and optical properties of InP ring-shaped QDMs, the growth parameters have already been investigated and optimized. However, for some applications including quantum information processing (extended quantum cellular automata), the uniformity of ring-shaped QDMs, directional arrangement of QDs in ring-shaped QDMs and QD spacing in a QDM are critical parameters which the further investigation is mandatory. One of promising improvement method is to consider the growth parameters concurrently. This is because the growth parameters are not independently affects the QD and ring-shaped QDMs formation which is mainly determined by the volume of initial droplet. The other growth parameters, for example, P_2 BEP, crystallization time, should also been taken into consideration.