CHAPTER I

INTRODUCTION

1.1 Motivation

During the past few decades, electronic devices and circuits, the indispensable components of the process of calculation and data storage, have been developed very rapidly, especially since the invention of the transistor in 1947. It was the major step in the history of computing revolution. The transistors revolutionised computing and smaller and more efficient electronics emerge on a regular basis. Attempts to scale down the transistor in order to improve its capabilities in response to the needs for higher computing efficiency, higher speed and longer life-time leads to the doubling of the number of transistors per chip every 18 months, first observed by Moore and become known as the Moore's law [1]. However, transistor miniaturisation is facing significant technological limitations, such as the short channel effects, the high power dissipation associated with quantum tunnelling through the gate oxide and the depletion regions, and the difficulties in doping shallow junctions and uniform channels [2]. Consequently, a new computing architecture based on quantum dots has emerged [3, 4, 5, 6, 7].

By the end of 1980s the properties of quantum wells and superlattices were rather well understood and the researchers have looked further to the lower-dimensional nanostuctures including quantum wire and quantum dot. Quantum dots (QDs) are the structures which can confine carriers in three dimensions [8]. They are categorised roughly into two groups; top-down and bottom-up (or self-assembled) QDs, according to growth technologies. The advantages of QDs allow them to be used as a basic structure in many device applications,especially, quantum computing.

Quantum computing is a future technology for designing computers based on quantum mechanics, the science of atomic structure and function. It uses the "qubit," or quantum bit, which can hold an infinite number of values. Quantum computers would allow a bit to store a value of 0 and 1 simultaneously. Unlike a classical computer that operates on a 3 bit register, which the bits in the register are in a definite state, such as 101, at any given time, quantum computer use the qubits which can be in a superposition of all the classically allowed states. It is believed that such a device can handle multiple operations simultaneously and can factor large numbers 10,000 times faster than today's computers. One approach for quantum computing is based on Coulomb repulsion of like charges, named "quantum cellular automata (QCA)". The unit cell of a QCA consists of four QDs positioned at the corners of a rectangle [9, 10, 11]. Another approach is based on a quantum mechanical property, a spin, of electrons in semiconductors [12]. The two approaches are candidates to overcome the current problems of transistor miniaturisation. Although, It is possible to form the physical architecture of basic cell using top-down technology such as shadow-mask patterning, lithography and etching to form homogeneous QDs, QDs grown by these techniques have many defects.

Currently, we have focused on self-assembled QDs, which are defect-free nano-structures and are expected to be the new working horse of nanoelectronic devices. InAs QDMs are grown by solid-source MBE technique via Stranski-Krastanow (SK) growth mode. It requires only the sequencing of thin-capping and regrowth processes. This bottom-up technique provides many benefits and is more practical and suitable for industrial fabrication. Thin capping of GaAs on as-grown InAs QDs at low temperatures leads to nano-hole templates [13, 14]. Subsequent regrowths of InAs result in nano-propeller QDs. We observed that the length of the propeller blades is controlled by the capping temperature and the capping thickness. When the regrowth of InAs is carried out at an appropriate thickness, QDMs are formed. By controlling the number of dots per ensemble, QDM with a suitable number of QDs per unit cell can be obtained and can be used as a basic building block for quantum computation.

In this work, we are going to describe how the shape, size and depth of nanoholes as well as the length of nano-propeller's blades are related to the QDMs' patterns in terms of dot number and dot uniformity. The surface morphology are presented by atomic force microscopy (AFM). The analytical optical properties are also confirmed by the photoluminescence (PL) spectra of respective samples at 77K showing their PL peaks and respective PL full width at half maxima (FWHM).

The review on quantum nanostructures is presented in chapter 2. The basic concept of low-dimensional nanostructures are reviewed. The strain effects on energy gap of semiconductors are also included. The fabrication techniques for quantum dots both top-down and bottom-up approaches are introduced. Moreover, the two approaches of quantum computing are presented at the end of this chapter. Chapter 3 shows the experimental details, including the details of molecular beam epitaxy (MBE), an in-situ reflection high energy electron diffraction(RHEED), an ex-situ atomic force microscopy (AFM) and photoluminescence (PL) spectroscopy. In addition, the material consideration and sample preparation are described in this chapter. The experiments focused on the effect of capping layer thicknesses are presented in chapter 4. This chapter contain the main idea of this thesis. Finally, the summary of this work is presented in chapter 5. The profiles of all samples are illustrated in appendix.

1.2 Objective

Nowadays, the mechanism and properties of III-V compound QD formation has been studied all through. However, the study of the mechanism and properties of self-assembled quantum dot molecules due to the anisotropic strain field has not been described clearly. So, we make an attempt to figure out the key parameters that effect on the number of QDs per QDM. In previous work, we can conclude that the different temperature of thin-capping and regrowth process result in different number of QDs per QDM [14].

In this thesis, we focus on the effect of capping layer thickness. We propose that appropriate quantum dot number per quantum dot molecule can be controlled by capping layer thickness. This lateral quantum dot molecule is believed to act as a fundamental cell for quantum computing in the not too distant future.