CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Electronics is the combination of science and technology which makes use of the controlled motion of electrons or charged carriers through different media, and collected some useful information to design electronic devices **[1-3]**. Semiconductor technology has been continuously developed for these in form of many applications such as transistors, integrated circuits (ICs) and others electronic circuits. In the fabrication, epitaxial growth is one of several techniques used to grow an oriented single crystal on a substrate to improve the properties of many devices **[4]**. Heteroepitaxy is very interesting structure because epitaxial layers can be produced with different electrical properties of various types of substrates. In the early generation, semiconductor materials that make up these devices can be grown by various epitaxial techniques, especially vapor phase epitaxy (VPE) and liquid phase epitaxy (LPE) **[5]**. However, these growth techniques have some limitations. VPE requires high temperatures which enhance bulk diffusion, and LPE does not produce films of uniform thickness. In case of semiconductor materials, silicon is widely used in the past because this material is abundant on earth and can be produced with low cost **[6]**. For these reasons, silicon technology is very influential in electronic device industry and most of the electronic devices are based on silicon. However, silicon's indirect bandgap characteristic and the poor efficiency of producing light emission are significant drawbacks for developing optoelectronic devices from this material **[7-9]**.

In recent years, nanostructures have been attracting interest for the evolution of semiconductor technology because of their potentials for high performance devices **[10-11]**. Progression of physics and device application technology lead to the fabrication of quantum-confined nanostructures by self-assembly growth methods (bottom-up technology **[12]**) has been intensively investigated in the last decade over the electron beam lithography (top-down technology **[13]**). The top-down method starts with a large-scale object, quantum well epitaxial growth on the substrate called "heterostructure", then reduces its dimension by removing the neighboring the hetero-structure with etching procedures which can produce desired structures.

In spite of the fact that lithography technique can produce precise structure on substrate by the benefit of mask which allow for various patterns, for microscopically scale this has some limitations. In addition, it is very slow process for mass manufacturing. For optoelectronic devices this technique is not suitable for the fabrication due to the high density of surface states created during the lithography and etching steps **[14]**. The bottom-up technology can solves these disadvantages even through the formation of structures is random but nowadays several techniques have been used to improve this and it manifests an obviously advantages to investigate through the nanostructures. One of these results from many pieces of research yields a novel structure, which was first appeared in the last two decades, called **"quantum dot (QD)"**.

The quantum dot structures which is a new direction of modern research in physics and technology based on nanoscale science has been developed **[15-16]**. The idea of reducing the size becomes popular since the vision of low power consumption, fast speed operation, smaller sizes with high efficiency in many electronic devices which is attractive to microelectronic industry, so studying new things in nanotechnology has revealed the new properties of matters with the contemporary development of relevant device applications. These nanostructures are the three-dimensional quantum confinement composed of lower energy bandgap material surrounded by higher bandgap materials (localized carriers) **[17]**, which is different from bulk structure in which carriers can move to the all directions (freedom in three-dimensional). Their atom-like properties of electron confinement and energy level quantization by formation of discrete quantum energy levels determined by the same quantum mechanical laws drag into the emission of certain-energy photon when the nanostructures are stimulated **[18]**. Due to the discretized density of states of carriers inside quantum dots, these objects are expected to bring significant progress in electronic device applications. Nevertheless, studying about the behavior mentioned above remains ongoing both theoretically and experimentally **[19]** so as to find the others properties which is expected to be suitable for novel electronic devices.

One significant epitaxial technique of bottom-up approach that has a high potential for the growth process is molecular beam epitaxial (MBE) technique **[20]** which resulted in various modifications to produce the purification of semiconductor crystals. The growth process is controlled by using efficient tools of surface analysis to monitor a real-time surface structure with precise thickness in the nanometer-scale size. This heteroepitaxial growth in the ultra high vacuum condition via Stranski-Krastanow (SK) growth mode **[20]** yields a high crystalline quality quantum dots nanostructure. Furthermore, some interesting materials have been used to improve some characteristic which is limited in silicon for electronic devices. III-V compound semiconductors are remarkable from the others as efficient coherent light emission property **[21]** especially GaAs which is considerable from many researchers in term of good crystalline material that allow for optoelectronic devices due to its energy gap is suitable for the wavelengths of fiber-optic communications, in which 1.3 μm (minimum lossless) and 1.55 μm (minimum dispersion) **[22]**. Therefore, searching for suitable materials for optoelectronics devices become crucial role in the optoelectronic technology. Parallel utilizing both modern fabrication tools and high quality materials will lead to high-performance electronic devices in the future.

1.2 Self-assembled aligned quantum dots

In the optoelectronic devices, several methods can be applied to increase performance **[23-24]**. A clear example of the applications is the laser device. Technological effort in the past decades to change from bulk to quantum-well semiconductor laser (such as edge-emitting lasers) by using quantum-confined properties has been demonstrated to show low thermal dependence, low threshold current, high gain, high power emission, and operation at room temperature with wavelength around the communication spectral. The efficiency of emission is level up by next generation laser device, vertical cavity surface-emitting laser (VCSEL) **[25]** owing to it is a microlaser with many layers of dielectric mirrors made from alternating high and low refractive index so ultrathin layers of wide and narrow bandgap in form of multiple quantum-well (MQW) induce more population inversion to strongly stimulate an emitted photons for lasing at high intensity. Besides, one of the most significant advantages of microlasers is that they can be arrayed to form a matrix emitter. Such laser arrays can provide a higher optical power than single microlaser since coupling effect of each adjacent laser and this effect becomes more powerful when expanding to the matrix. The concept of arrayed laser is very interesting and many researchers try to link this idea with the quantum dot. Although the benefits of self-assembled quantum dots have been demonstrated in many optoelectronic device applications, their random sizes and distributions give some poor qualities for other electronic and optical devices since the existence of these randomly distributed quantum dots may cause non-radiative recombination center and cast itself as a blind spot for emission **[26]**. For many practical applications, quantum dots should be formed with a well-controlled, uniform size and position distribution so it is necessary to fine-tune their properties to become proper structures for useful applications. Among quantum-dot nanostructures, self-assembled aligned quantum dots have attracted a great deal of attention for revising this drawback because fascinating properties have been predicted and demonstrated **[27]**.

Ordered quantum dots are a special class of quantum-confinement structures that have attracted a lot of attention due to their potential electronic and optoelectronic device applications **[28]**. Since laterally ordered quantum dots have been investigated through several mechanisms by many research groups **[29-31]**, but this procedure has some technical limitation due to complexity of multiple processes and crystallographic defects so it exhibits an imperfect structure which degrades an optical quality. The expectation of absolute self-assembled laterally ordered quantum-dot structure is to produce more radiative photons even at room temperature and reduce the intensity loss due to trapping center. By modifying growth technique, the perfectly self-assembled laterally aligned quantum dots with high emission and narrow linewidth may be achieved in the future which leads to some novel photonic devices like quantum-dot lasers and quantum-dot photo-detectors for increasing the device performance **[32-34]**.

1.3 Effect of electric field

In the operation of electronic devices, some of them make use of applying an electric field via controlled voltages. A good example is electroabsorption modulators. Their operation is based on the phenomenon called "electro-absorption", which is the absorption of photons with energies smaller than the bandgap of the material in the presence of an electric field **[35]**. The splitting of energy level in an electric field causes shifting of atomic energy with respect to its normal state is proportional to the magnitude of the electric field. Electroabsorption modulators based on this effect can be fabricated by choosing the light wavelength corresponding with energy smaller than the bandgap. However, the effect is very weak even when large fields are applied in bulk materials (Franz-Keldysh effect **[35]**), so quantum-well structures were normally used instead. The situation is more pronounced in multiple quantum wells, and this is called the **"Quantum Confined Stark Effect (QCSE) [35]"**, resulting in high oscillator strength of interband transition between discrete electron and hole energy bound states. Consequently, strong resonances corresponding to the heavy-hole and light-hole transitions near the band edge of well material even at room temperature. These result to a strong absorption with the appearance of absorption spectrum shifting to lower energies (red shift) by requiring less electric filed (compare with bulk matter) and allowing for electron tunneling to be occurred. The interesting question is, what about an effect of electroabsorption in nanostructure? Many research groups have investigated, both theoretically and experimentally, to find significant effects of completely confined structure for comparing with the previous effect in larger-scale materials **[36-37]**. There is a great of theoretical research which uses advanced quantum mechanic approach, but for the experimental study there are very few results reported. Investigation on the influence of the electric field on self-assembled aligned quantum dots is a new idea which is challenging to seek the results in order to obtain useful data like performance of phase shifter, QCSE, state filling effect, excitation oscillator strength and others.

1.4 Objectives

The objectives of this work hammer to the point on studying optical properties self-assembled InAs aligned quantum dots under the effect of applied electric field. This work can be divided into two main parts.

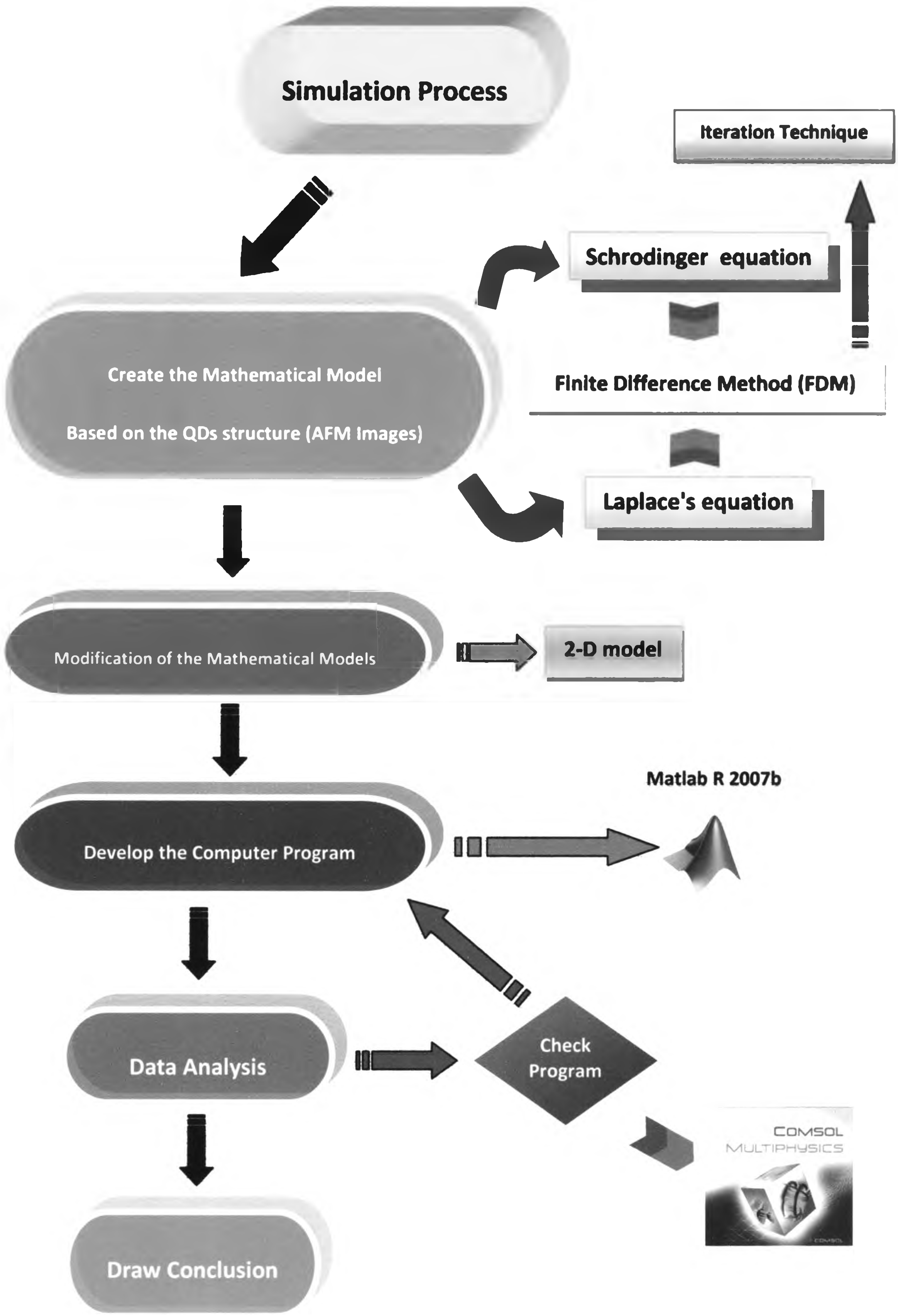
The first part is to investigate the optical polarization property of self-assembled InAs aligned quantum dots under the effect of applied electric field from the theoretical basis with a view of developing a qualitative model used to predict results on the real structural system.

The second part is to seek an appropriate structure with good optical properties which will further force MBE growth techniques to be developed and eventually lead to the fabrication of desired nanostructures.

1.5 Scope of Work

The main point of this work is to simulate the mathematical model of laterally aligned quantum dot system by solving Schrödinger equation and modifying via some important variables in order to get the most exact solution which is acceptable accuracy when compares with practically real model. Then, boundary electrical system obtained from Laplace's equation was applied to complete the model. The final goal of this work is to compare the degree of linear polarization of laterally aligned quantum dots with and without applied field. Besides, relation of linear polarization degree with the number of ordered quantum dots were expected. This research also covered a study of the ground-state energy splitting of laterally aligned QDs which was the starting point of the polarization behavior to achieve the objectives mentioned above.

1.6 RESEARCH METHODOLOGY



1.7 Significance of the Research

This research work focuses on the optical polarization property of self-assembled InAs aligned quantum dots under the influence of an applied electric field by utilizing the concept of quantum mechanics to create a mathematical model to predict some behaviors before real experiment, which is essential for navigating a practical work on theoretical path and developing them together. Moreover, the results may be useful for developing new physical concepts, which will in turn lead to an innovation of new optoelectronic devices incorporated with benefit of polarization property based on III-V semiconductor quantum dots and boost up their performance.

1.8 Overview

This thesis presents a detailed study effect of electric field on self-assembled InAs aligned quantum dots by focusing only theoretical model via computer programs. The polarization property of various electric-field magnitudes and number of aligned quantum dot structures was investigated. The purpose is to analyze the effect of electric field on aligned quantum dots for utilizing the polarization property in optoelectronic device applications. The thesis is organized as follows:

Chapter 2 reviews and illustrates the fundamental concepts of low-dimensional nanostructures. This also includes fabrication techniques for nanostructure formation. Furthermore, basic concepts of electric field effect on semiconductor material and polarization properties were presented.

Chapter 3 considers with theoretical calculations in which the finite-difference method is described and later on is used to solve the Schrödinger equation and Laplace's equation to obtain both the polarization characteristics of laterally aligned QDs and distribution of two dimensional electric field system. The theoretical characteristics of these quantum-dot systems are also mentioned.

Chapter 4 gives the results obtained from the calculation. The analysis categorized in each case is also reported and discussed deeply in detail to explain why the phenomena occurred based on the concepts of quantum mechanics.

Chapter 5 concludes and gives suggestions for the further work.

Finally, the Appendix will deal with the Matlab® program which was written and used in the theoretical part of this thesis work.