CHAPTER 1

Introduction

1.1 Overview

The dissertation of so called low-dimensional structures is currently attracting worldwide interest among scientists and engineers. It has the potential for revolutionizing the ways in which materials and products are created and the range and nature of functionalities that can be accessed. The term ‘low dimensional’ is applied in the context that one or more dimensions have been restricted to lengths in the order of the mean free path of charge carriers or excitons in the material. A worldwide study of research and development status and trends in nanoparticles, nanostructured materials, and nanodevices (or more concisely, nanostructure science and technology) was carried out during the period of 1996-98. The most familiar of such structures is the semiconductor quantum well which may comprise, for example, a 5 nm layer of InGaN sandwiched between layers of GaN. The wider band gap of the latter provides a confining potential well for electrons and holes in the InGaN and this gives rise to many new electronic and optical properties. It is worth to mention, since the discovery /invention by Esaki and Tsu in the 1970s semiconductor quantum wells and superlattices have evolved from scientific curiosities to a means of probing the fundamentals of quantum mechanics, and more recently into wealth-creating semiconductor devices.

III-nitrides GaN, InN, and AlN with related alloys played an important role in semiconductor devices [1-3], especially in optoelectronics, in recent decades. Since wurtzite polytypes of III-nitrides form a continuous alloy system whose direct bandgap ranging from 0.7 eV for InN [4], to 3.4 eV for GaN, and to 6.2 eV for AlN [5], the optical devices using III-nitrides could be activated at wavelengths ranging from red, green, blue, to ultraviolet. This phenomenon is quite different from other III-V materials systems, such as As-based and P-based one. In addition, the III-nitrides are superior materials for high-temperature and high-power applications [6-8]. GaN/InGaN heterostructures with low values of x have been reported by several groups as a part of single quantum wells (Amano *et al.*, 1994; Koike *et al.*, 1996; Nakamura, Senoh, and Mukai, 1993; Nakamura *et al.*, 1995), multiple quantum wells, and heterostructures for stimulated emission by optical pumping.

In 1972, the first blue light-emitting-diode (LED) using III-nitrides materials were fabricated by J. I. Pankove *et al.* [9] with a metal-i-n structure. Since then, related researchs went on continually. However, due to poorly conducting p-type GaN, the device performance and the research pace was limited. Until late 1980s, I. Aksaski and H. Amano *et al.* [10,11] developed the low-temperature GaN buffer layer and low-energy electron beam interaction (LEEBI) techniques to obtain conductive p-type GaN. The first GaN blue LED constructed of a real p-n junction, which greatly improved the device performance. Then, S. Nakamura *et al.* [12] achieved conductive p-type GaN by using high temperature thermal annealing in nitrogen ambient. Until now, nitride-based blue and green LED illuminating with high brightness are now commercially available. Most microdisplays, like cell phone screens, are made of liquid crystal or LCDs, which require an external light source.

Reducing the dimension of semiconductor structures not only saves space and increases the capacity of a single chip, but also brings the benefits of quantum effects. Confining the electrons in such a low-dimensional structure will quantize the allowed energies of the electrons. It has been proven that these quantization effects in a semiconductor structure can make an electronic device more efficient and allow it to be operated at lower voltages and/or higher speeds. For example, some devices utilizing quantum wells, in which electrons are confined to a plane, are already at work in our daily life. We have already enjoyed the benefits of the so-called quantum-well laser, which have been used to read the information on a compact disk. The next level of confinement is to restrict the motion of electrons to a line, or a so-called quantum wire. If the electrons are further confined three-dimensionally, i.e., trapping the electrons in a small volume, it will form a system called quantum dot.

In fact, the quantum dots are tiny semiconductor structures (of the order of nanometers or tens of nanometers in diameter) surrounded by a material of wider bandgap. Electrons and holes are confined within these structures in all three spatial dimensions, and into a few numbers of confined energy levels, depending on their size. The density of states for these confined states is discrete or so-called δ-function-like, resembling the discrete energy levels in atoms. This feature exhibited provides many advantages for electronic devices. Researchers believe that a quantum dot can be built as a single electron transistor (SET), which may possesses higher efficiency, reduced power requirements, and increased speeds of operation, in addition to its extremely compact dimension. Moreover, quantum dots are expected to have great advantages in optoelectronics, because they present very efficiently to particular wavelengths of light. In bulk structures, light can be absorbed anywhere and emitted in any direction. On the other hand, the optical transitions within a quantum dot, combined with spatially localization effects, means that they may be effectively controlled.

1.2 Outline of this dissertation

These days, the development of new semiconductor devices seems to be limited only by the imagination of the designer. This dissertation provides a micro-to-nano size structure of III-nitride materials. It covers their fabrication, electronic, optical, and transport properties, their role in exploring new physical phenomena, and their application in devices. This dissertation is classified into four subjects. The first subject is concerned with GaN- based micro-hole array LED, including the process, electric and light output performance of the micro-scale GaN-based LED. In the following, the optical properties of the InGaN quantum dots grown on SiN nanoholes are studied in this chapter. Thermal annealing effects on its optical properties are also investigated in the chapter 3. In chapter 4, one-dimensional structure of InGaN/GaN multi-quantum-well (MQW) nanorods fabricated by induced coupled plasma etching from bulk MQW samples are present, including fabrication technique and optical properties. Then, a new growth method to improve emission output of InGaN/GaN MQW LED by using delta-trimethylindium-flow process is proposed and demonstrated experimentally. Finally, a conclusion and a brief description in the future works are presented.

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