Chapter1

Overview

1.1 Introduction

GaN-based materials have been attracting a great deal of attention in the early 1990s due to the large direct band gap and the promising potential for the optoelectronic devices, including light emitting diodes (LEDs) and laser diodes (LDs) [1-7]. In 1993 the first prototype high brightness (> 100 times greater than previous alternatives, about 1 candela) GaN-based blue LEDs were developed by Nakamura's group, also they developed the first GaN-based violet LD with an emission wavelength of around 400nm in 1996[5]. From that time, research groups in the laboratories and companies have spent more time on the development of GaN-based devices and many commercial products with various applications were produced. Today, blue LEDs are widely used in many applications such as illumination, exterior automotive lighting, full color display, traffic signals, back light of liquid crystal display and etc. The blue LD can serve as the light source of high density data storage (about 25GB/disk, 5 times larger than now) in high definition digital versatile disk (HD-DVD) which is the main stream of next generation data storage. The big market of HD-DVD has shown up the importance of blue LDs. Besides, the blue and violet LDs may have many other possible markets, such as high brightness projector, high speed printer, medical field and others. However, commercial blue LDs are edge emitting lasers (EELs), not vertical cavity surface emitting lasers (VCSELs). The VCSEL possesses many advantageous properties over the EEL, including circular beam shape, light emission in vertical direction, low cost and formation of two-dimension arrays. In particular, the use of two-dimensional arrays of the blue VCSEL could reduce the read-out time in high density optical storage and increase the scan speed in high-resolution laser printing technique. Recently, many efforts were devoted to the fabrication of GaN-based VCSEL, and some optically pumped laser operation results were achieved and reported [8-14]. Although electrically injected GaN-based VCSEL has not to date been achieved, some VCSEL-like GaN-based microcavity light emitting diodes (MCLEDs) [15-22], the basis of electrically injected GaN-based VCSEL, have also been reported. In brief, the GaN-based MCLED is an electronic surface emitting device with VCSEL structure but unable to achieve the stimulated emission yet. However, it is believed that the obtainment of high quality materials, performed by the improvement of the epitaxially grown technique of

VCSEL structure, would realize the electrically injected GaN-based VCSEL.

1.2 GaN-based Surface Emitting Devices

The fabrication of GaN-based surface emitting devices, including GaN-based VCSEL and MCLED, requires a pair of high-reflectivity mirrors, usually in the form of DBRs, for forming a high quality vertical cavity. The favorite design of GaN-based surface emitting device is the hybrid structure employed the in-situ epitaxially grown nitride-based DBR, and the dielectric DBR. Compared to the structure with all epitaxially grown DBRs or all dielectric DBRs, the hybrid one is more easy and convenient. In addition, most reported GaN-based surface emitting devices employed more than 40 pairs $Al_xGa_{1-x}N$/GaN DBR to form the high reflectivity mirror [8][11][19]. However, the high refractive index contrast between AlN/GaN indicates that about 20~25 pairs AlN/GaN DBR could achieve high reflectivity and also suggests that using AlN/GaN DBRs as the reflecting mirror of GaN-based surface emitting device could be the better choice. But, the AlN/GaN combination has relatively large lattice mismatch (~2.4%) that tends to cause cracks in the epitaxial film during the growth of the AlN/GaN DBR structure and could result in the reduction of reflectivity and increase in scattering loss. Therefore, GaN-based VCSELs and MCLEDs employed AlN/GaN DBRs were not reported until now. Recently, we have achieved high-reflectivity AlN/GaN DBR structure with relatively smooth surface morphology and could be used in the GaN-based surface emitting device [23][24].

1.3 Objective of the Thesis

In this thesis, we report the fabrication of GaN-based VCSEL using the AlN/GaN DBRs as the bottom mirror and a Ta_2O_5/SiO_2 dielectric multiple layer structure as the top DBR mirror, and demonstration of the laser operation under optical pumping at room temperature. We also present the characteristics of optically pumped GaN-based VCSEL such as excitation energy - emission intensity curve (L-I), near field pattern (NFP), far field pattern (FFP), threshold carrier density (N_{th}), threshold gain(g_{th}), degree of polarization (DOP), temperature dependent threshold and characteristic temperature (T_0). Through these complete discussions, the performance of the VCSEL could be well realized. We also show the fabrication of GaN-based MCLED with hybrid structure, composed of high reflectivity, crack-free, wide stopband width in-situ grown AlN/GaN bottom DBRs and ex-situ deposited SiO_2/TiO_2 top DBRs, could be used as basis for the electrical drive GaN-based VCSEL. The process flowchart and the electrical and optical characteristics of GaN-based MCLED are also presented.

1.4 Outline of the Thesis

This thesis is organized in the following manner. In chapter 2, the formation, operation mechanism and applications of VCSEL and Fabry-Perot resonant are briefly introduced. In chapter 3, the design and fabrication of GaN-based VCSEL, set up of optical pumping experiment, and pumping results are presented. In chapter 4, we describe the fabrication and characteristics of GaN-based MCLED. Finally, chapter 5 is the conclusion and future work.