Epitaxial Growth of High Quality AlN and AlGaN Layers for Deep Ultraviolet Light-Emitting Diodes

by

Won Seok Lee

A Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the degree of

MASTER OF SCIENCE

Major Subject: MATERIALS ENGINEERING

Approved:

____

E. Fred Schubert, Thesis Adviser

____

Richard W. Siegel, Thesis Adviser

____

Jong Kyu Kim, Thesis Adviser

Rensselaer Polytechnic Institute
Troy, New York

August, 2007

ABSTRACT

In this Master Thesis, we optimize the growth process for high quality AlN and AlGaN epitaxial layers used for deep ultraviolet (UV) light-emitting diodes (LEDs). Structural, optical, and electrical properties of AlN and AlGaN epitaxial layers grown by metal organic vapor-phase epitaxy (MOVPE) on sapphire substrates are analyzed using various measurement techniques. After optimization of the growth conditions for AlN layer, a significant reduction of the x-ray diffraction (XRD) (102) full-width-at-half-maximum (FWHM) from double peaks to a single peak of 1950 arcsec is obtained, indicating a low edge dislocation density. In addition, Si-doped AlGaN layer, grown on low-dislocation-density AlN template, are demonstrated to have outstanding optical and electrical properties. Therefore, we believe that a low dislocation density is one of the most important factors in obtaining good optical and electrical properties of Si-doped AlGaN and a fundamental requirement for highly efficient UV LEDs.

Chapter 1 introduces (1) operating principles of LEDs; (2) properties of group III-nitride semiconductors; and (3) applications of group III-nitride semiconductors. A p-n junction LED is a semiconductor device that emits narrow-spectrum light when electrically biased in the forward direction. As compared with the incandescent light bulbs, LEDs have many advantages such as energy-saving potential, tunability of the wavelength, low production costs, smaller size, and longer lifetime. Group III-nitride semiconductors have been recognized as one of the most promising materials for realizing highly efficient LEDs.

Chapters 2, 3, and 4 discuss the operation principle, hardware and growth mechanisms, and an example of a real recipe a horizontal flow MOVPE reactor based on the Aixtron 200/4 RF-S system. MOVPE is currently the most widely used epitaxial growth technology. Actually, the vast majority of optoelectronic commercial device structures are fabricated using MOVPE.

Chapter 5 discusses challenges and key inventions that overcome these challenges in the history of group III-nitride semiconductors-based UV LEDs. Extending existing UV LED technology to shorter UV wavelengths involves overcoming a number of materials challenges such as the internal absorption of the generated light, high dislocation density, and high resistance in n-type and p-type AlGaN.

Chapter 6 is the main part of this thesis. This chapter discusses the MOVPE growth of AlN and AlGaN and the measurement data obtained. In order to develop a UV LED structure, it is definitely necessary to achieve high quality AlN and AlGaN epitaxial layers. A systematic optimization process to achieve high quality AlN layers is described. After optimization of the growth conditions for AlN, a significant reduction of the XRD (102) FWHM from two split peaks to a single peak with 1950 arcsec is obtained, indicating a low edge dislocation density. Next, the effect of the structural properties of AlN layers on the optical, electrical, and structural properties of n-type AlGaN epitaxial layers grown on top of the AlN templates, is systematically studied. Depending on the growth conditions for the 400 nm thick AlN template layers, different XRD (002) and (102) FWHMs and thus dislocation densities are obtained. Si-doped AlGaN layers with an Al mole fraction of 30% are grown on AlN template layers that have different dislocation densities.

In photoluminescence measurements, the Si-doped AlGaN layer grown on the high-edge-dislocation-density AlN templates shows band-edge-related luminescence at a wavelength of 300 nm and deep-level-related luminescence at a wavelength of 460 nm. However, no such deep-level related luminescence is observed in the Si-doped AlGaN grown on the low-edge-dislocation-density AlN template, indicating that the origin of the deep-level related luminescence at 460 nm is likely related to the dislocation density.

The sheet resistance of the Si-doped AlGaN layer grown on the different AlN templates decreases from 4570 Ω/□ (grown on the high-dislocation-density AlN template; thickness of AlGaN is 1.1 μm) to 520 Ω/□ (grown on the low-dislocation-density AlN template; thickness of AlGaN is 0.7 μm), which indicates that the dislocation density is one of the most important factors in obtaining good electrical properties of Si-doped AlGaN.

Chapters 7 and 8 discuss conclusions drawn from our experimental results and proposed future work to improve the material quality and performance of UV LED devices.