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Pulse source injection molecular beam epitaxy and characterization of nano-scale thin GaN layers on Si substrates

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Abstract

We report the successful growth of thin GaN layers on (111) orientated Si substrates utilizing a newly developed pulse source injection molecular beam epitaxial (PSIMBE) technique. RHEED patterns showed that two-dimensional layer-by-layer growth started at a very early stage during deposition (within 20 nm). AFM studies showed that an almost atomically smooth surface was obtained with an area RMS roughness of less than 0.2 nm. The crystal structure and quality were determined from high resolution 2-Theta-Omega scan and exhibited only three strong and sharp lines at 28.56°, 34.70° and 73.05° due to the Si substrate and the single crystalline wurtzite (w-) GaN (0002) and (0004), respectively. Raman scattering study showed the characteristic w-GaN E_2 band at 565 wave-numbers and the longitudinal optical (LO) phonon-plasma coupling mode at 731 cm^{-1}. These data indicate the success of MBE growth of single crystalline w-GaN thin layers on the order of less than 100-nm thick on Si substrates without using a complicated buffer structure.

Keywords: GaN; Si; PSIMBE; Optical reflectance; X-ray diffraction; Raman scattering; Photoluminescence; Reflection high-energy electron diffraction; Atomic force microscopy

1. Introduction

GaN-based materials and structures have attracted much interest in recent years for applications such as UV–blue-green light emitting diodes (LEDs), laser diodes (LDs) and other optoelectronic and electronic devices [1,2]. Despite recent breakthroughs in GaN device quality, developing a successful technique to grow high quality GaN on silicon for low cost production remains a great challenge. The favorable physical properties, high quality, and low cost of silicon make it a very attractive substrate for GaN-based devices especially for large-scale production. The crystal perfection of silicon is much higher than SiC and can be obtained with extremely smooth surfaces that satisfy the demanding morphology requirements for subsequent two-dimensional expitaxial growth needed for device applications. Additionally, the use of Si promises the development of a new generation of 21st century devices through the integration of Si- and III-N based materials and technologies on one substrate.

To date, however, the quality of GaN grown on silicon is inferior to that grown on silicon carbide mainly due to the large lattice mismatch and big thermal expansion coefficient difference between these two materials [3]. Buffer layers with composite structures between GaN and Si have been employed to improve the quality of the GaN films, but with limited success [4–10]. A unique molecular beam epitaxial (MBE) process using pulsed source injection was developed at the Georgia Tech Research Institute to grow a thin GaN buffer layer for subsequent GaN layer growth. This pulse source injection molecular beam epitaxial (PSIMBE) technique provided sufficient relaxation time for the growth species on the growth surface to relax and grow two-dimensionally, thereby effectively overcoming the common problem of 3D nucleation of GaN at the early growth stage when a foreign substrate, such as Si, was used [11–14].

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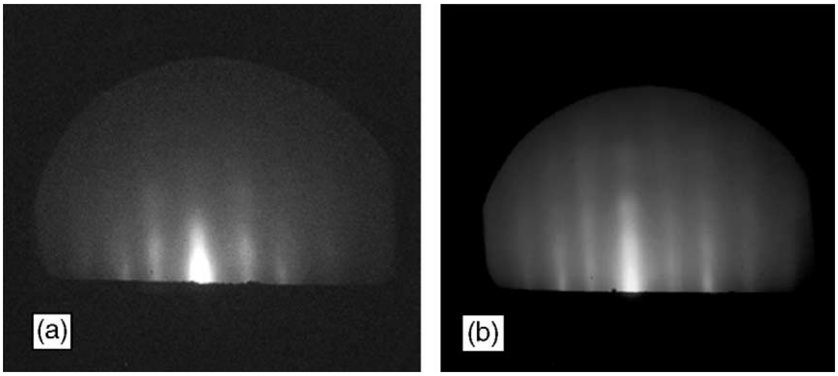

Fig. 1. RHEED pattern of AlN (a) and GaN/Si(111) (b) grown by PSIMBE.

In this study, we report the successful growth of thin GaN layers on (111) orientated Si substrates utilizing the PSIMBE process. These thin GaN layers can be used as an extremely smooth buffer layer for subsequent GaN-based device structure growth. The thin GaN layers were characterized by a variety of techniques such as reflection high-energy electron diffraction (RHEED), high resolution X-ray diffraction (HRXRD), optical reflectance (OR), atomic force microscopy (AFM), room temperature photoluminescence (PL) and Raman scattering (RS).

2. Experiment

A MBE system, equipped with an EPI UNI-Bulb RF Source and an EPI SUMO thermal effusion cell, was used for this research. The system was pumped by a Leybold magnetic bearing turbo pump and a cryopump. The nitrogen gas flow was controlled by a MKS 1479A gas flow controller and Ga was thermally evaporated from the SUMO cell. An EPI hot tip effusion cell was used to evaporate Al to grow an AlN buffer layer on silicon prior to GaN growth. The UNI-Bulb plasma source was operated at 350 W with a nitrogen flow rate of 0.6 sccm for this study. The background pressure of the chamber during the deposition was 6.0×10^{-6} Torr.

During the growth, silicon (111) substrates were first etched with buffered HF (6:1) solution for 2 min prior to loading into the system. The substrates were baked in the chamber at 80 °C for 24 h before growth. The Al layer was first deposited on the silicon with a flux of 4×10^{-8} Torr for 1 min and then the nitrogen plasma was introduced to form an AlN buffer layer for GaN growth. Growth temperatures for AlN were between 650 °C and 800 °C and the typical AlN buffer layer thickness was less than 10 nm. Ga and N plasmas were alternatively injected onto the surface for GaN growth. The duration of injection of each source was varied from 1 min to 3 min. With this method, two-dimensional growth of GaN was achieved at a very early stage of growth as indicated by in-situ RHEED study. The growth temperatures were varied from 550 °C to 700 °C.

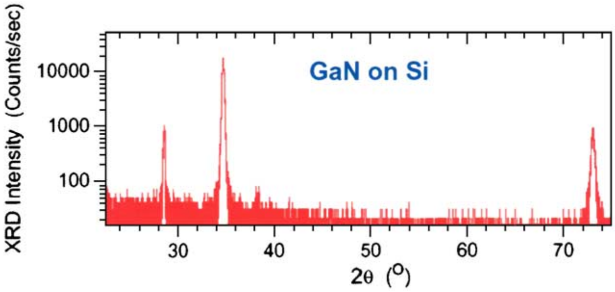

Fig. 2. High resolution XRD characterization of GaN/Si (111) grown with pulsed source injection MBE.

A Filmetrics F20 thin film measurement system was used to determine film thickness. The typical GaN layer thickness for this study was less than 300 nm. An AFM made by Park Scientific Instrument (Autoprobe CP), operated in the contact mode, was used to study the as-grown GaN layer surface morphologies. RS measurements were performed using a triple monochromator T64000

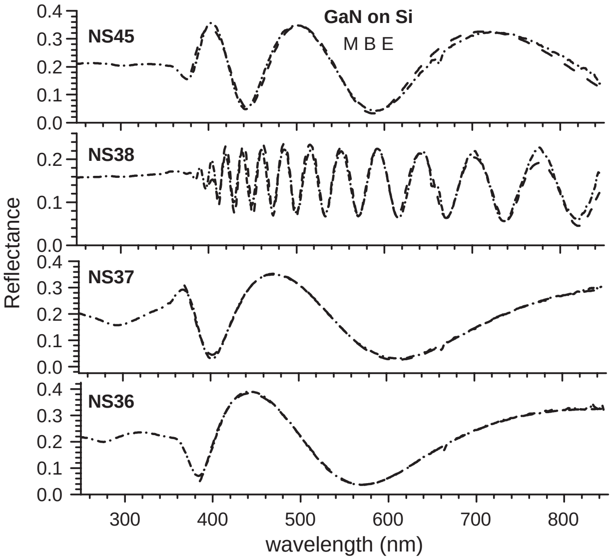

Fig. 3. The optical reflectance spectra for four MBE GaN/Si, measured in 250–850 nm with simulation done in 400–850 nm.