Superlattices and Microstructures 64 (2013) 88–97

Contents lists available at ScienceDirect

Superlattices and Microstructures

journal homepage: www.elsevier.com/locate/superlattices

Growth of GaN films on silicon (1 1 1) by thermal vapor deposition method: Optical functions and MSM UV photodetector applications

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ARTICLE INFO

Article history:
Received 15 July 2013
Received in revised form 24 August 2013
Accepted 26 August 2013
Available online 14 September 2013

Keywords:
Gallium nitride (GaN)
Vapor growth
NH_3 solution
Texture morphology
Detector
Schottky diodes

ABSTRACT

In this study, gallium nitride (GaN) films were grown on n-Si (1 1 1) substrate by thermal vapor deposition method in quartz tube furnace for different growth duration. Gallium metal mixed with GaN powder and aqueous ammonia (NH_3) solutions were used as sources of Ga and N. Structural, elemental, and optical characterizations were carried out using various techniques in order to investigate the properties of the films. Scanning electron microscopy images showed that the films surface have self-textured morphology, which was introduced during the growth process. Moreover, further deposition resulted in the formation of heterogeneous film. X-ray diffraction (XRD) measurements reveal in all samples a typical diffraction pattern of hexagonal GaN wurtzite structure. Raman spectra demonstrated redshifts in E_2-high with increasing deposition time due to tensile stress inside the GaN films, confirmed by XRD. The photoluminescence spectra of the films demonstrated strong near band edge emission at about 363 nm. The fabricated GaN films based metal–semiconductor-metal (MSM) UV photodetector shows a contrast ratio of ~240–40 at +5 V and responsivity in the range of 0.28–0.01 A/W for the UV photodetectors. This study shows the possibility of synthesizing GaN films on Si wafers at low-cost and has potential applications in UV photodetection.

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http://dx.doi.org/10.1016/j.spmi.2013.08.024

1. Introduction

Gallium nitride (GaN) is an important semiconductor with a wide direct-band gap for photonic and high-power devices [1]. The characteristics and properties of GaN based wide band materials have been found suitable and reliable and hence under increasing investigation due to their potential for optoelectronic, high temperature and high power applications [1,2]. Unique features like large band gap energy of (3.4 eV), allow for the application GaN in UV sensing [3–5].

GaN-based layers are often epitaxially grown on sapphire or silicon carbide substrates [5–8]. Silicon (Si) has attracted considerable attention as a substrate material for GaN growth because of its high quality, low cost, accessibility and wide availability in large diameter [9]. These advantages have made GaN growth on Si highly desirable in the Si-based electronic industry, as well as a promising route for large-scale, low-cost mass production of GaN-based electronic devices [3,10,11]. In addition, the integration of well-established Si electronics with GaN-based photonic devices (optoelectronic integrated circuits, (OEICs)) has also proved lucrative in the manufacturing industry [9]. Also, there have been rare reports on the growth of GaN on Si (1 1 1) and Si (1 0 0) substrates [3,10,12–16]. Nonetheless, the growth of GaN films on clean Si substrates might allow the use of current Si technology for the fabrication of GaN based devices and the integration of Si with GaN based optoelectronics, which can largely reduce the cost.

Numerous techniques [4,12,17–21] have been employed to produce high-quality GaN films. Among the widely studied techniques for GaN film growth, the thermal evaporation technique via vapor phase transport has shown the most potential because of its comparatively uncomplicated experimental procedure, its inexpensive method, and high growth yield. However, GaN materials are normally grown via the vapor phase reaction between GaCl or Ga and ammonia (NH_3) gas, while H_2 and N_2 are used as carrier gas [20,22–25]. Most of these methods, realized in an atmosphere of dry NH_3 gas, which it is expensive and unsafe. A simple low-cost method for the synthesis of GaN films on n-Si (1 1 1) substrate using aqueous NH_3 solution as the nitrogen source is reported here. In this work, the growth mechanism of GaN films is studied through the direct reaction of Ga metal with NH_3 using a furnace tube with varying deposition times. The effects of deposition time on the surface morphology, structural, optical and ultra violet detection properties of the grown films are also studied.

2. Experimental procedure

GaN films were synthesized via direct reaction between Ga and NH_3 in three zone horizontal tube furnace (HTF) on Si substrates [20]. About 0.1 mg (99.99) of Ga metal mixed with 0.2 mg GaN powder that was placed in front of the alumina boat. The boat was then loaded at the center of a HTF. 100 mL of NH_3 solution with a weight concentration of 25% (w/w) and a density of 0.907 g/cm^3 was used as the nitrogen source. The N_2 (5 N) carrier gas was used to dilute the NH_3 and carry gaseous NH_3 from the solution to the HTF. Silicon (1 1 1) substrates were cleaned before loading to the center of a HTF. The distance between material source and substrate was adjusted to 10 cm. Before operating the HTF, it was heavily flushed with high purity N_2 gas and its flow rate was set at 3 liter per minute (L/min). Subsequently, the furnace was heated up to a maximum temperature of 1050 °C which was maintained for different durations (30, 45 and 60 min). When the temperature was about 1050 °C, NH_3 was introduced into the HTF with N_2 gas, at a flow rate of 2 L/min flowing through a flask containing NH_3 solution at room temperature (*RT*) [20]. After the reaction, the NH_3 source was turned-off, while furnace was cooled to ambient temperature under N_2 flow at the rate of 3 L/min. The morphology characterization and simple composition analysis of the samples were carried out using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) attached to the SEM and high-spatial resolution X-ray diffraction (XRD) using Cu Kα1 radiation (λ = 1.5406 Å) source. The optical properties of the samples were recorded by Raman spectroscopy using Jobin Yvon (HR 800 UV) system with an argon ion laser (λ = 514.5 nm) as an excitation source. Photoluminescence (PL) was measured at *RT* using a He–Cd laser (λ = 325 nm) as the excitation source. The spectral responsivity was measured using a Hitachi U-2000 UV–VIS double-beam spectrophotometer with 45.6 μW