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Growth and characterization of InGaN blue LED structure on Si(1 1 1) by MOCVD

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Abstract

High-performance InGaN blue light-emitting diodes (LEDs) on Si(1 1 1) substrates were fabricated by metalorganic chemical vapor deposition. Crack-free films were obtained using Ga-rich GaN high-temperature buffer. The full-width at half-maximum (FWHM) of the (0 0 2) X-ray rocking curve and the (1 0 2) X-ray rocking curve were 343 and 520 arcsec, respectively, which indicate that the LED wafer on Si is of high crystalline quality. The operating voltage of 3.8 V, turn-on voltage about 2.5 V and series resistance of 47 Ω were obtained for the LED. The electroluminescence peaks at 460 nm with a FWHM about 28 nm at 20 mA current. In addition, the LED shows an EL intensity of 20 mcd at an injection current of 20 mA. These characteristics are comparable to those of LED on sapphire.

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1. Introduction

GaN-based devices have demonstrated superior properties particularly as light emitters for the blue and UV as well as for high-power and high-temperature transistors. Commercially available nitride devices such as light-emitting diodes (LEDs) are usually grown by metalorganic chemical vapor deposition (MOCVD) on sapphire or SiC substrates due to lack of large and inexpensive GaN substrates. Si is a very attractive substrate for GaN-based devices due to the merits of cost effectiveness in device fabrication, the availability nature and the possibility of integration of III-nitride devices with the mature Si technology. However, it is difficult to get crack-free and device-quality GaN on Si substrate due to their large mismatches of lattice and thermal expansion coefficient between the epilayer and the substrate.

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In addition, GaN can hardly nucleate on a Si substrate since the silicon substrate can be quickly passivated by the nitrogen that is decomposed from a nitrogen-source gas such as ammonia needed for the GaN deposition. In recent years, many efforts have been conducted to grow high-quality GaN films [1–5] and GaN LEDs [6–12] on Si(1 1 1) substrates. However, the quality of GaN epitaxial layers and the performances of GaN LED on Si were not comparable to those obtained on sapphire. Recently, Dadgar et al. reported the bright InGaN/GaN LED on Si(1 1 1) substrates using low-temperature AlN and Si_xN_y interlayers, the packaged LED structures grown on such interlayers have an output power of 0.42 mW at 498 nm and 20 mA [12] . To our knowledge, this is the best light power output ever reported for GaN-based LED on Si substrate. However, the LED shows high voltage and large series resistance. Zhang et al. reported the InGaN MQW blue LEDs on Si(1 1 1) using AlN/GaN multilayers with a thin AlN/AlGaN buffer layer, the LED operating voltages are 3.7 and 4.2 V for the lateral and the vertical conduction, respectively [11], and the light power output of the LED is about 35 μW.

In this paper, we report the growth of high-quality InGaN MQW LED structure on Si(1 1 1) substrates using high-temperature Ga-rich GaN buffer and low-temperature AlN buffer layer by low-pressure metalorganic chemical vapor deposition (LP-MOCVD). The performances of these fabricated LEDs will also be evaluated.

2. Experimental procedures

The MOCVD growth of InGaN MQW LEDs on Si(1 1 1) substrates was performed in a Thomas Swan close-coupled showerhead (CCS) MOCVD reactor. During the growth, trimethylaluminum (TMAl), trimethylgallium (TMGa), trimethylindium (TMIn) and ammonia (NH_3) were used as the source materials of Al, Ga, In and N, respectively. Silane (SiH_4) and biscyclopentadienyl magnesium (CP_2Mg) were used as n-type and p-type doping sources, respectively. Prior to growth, the substrates were cleaned by a H_2SO_4:H_2O_2 (3:1) solution for 10 min, then etched in 2% HF solution and rinsed in deionized water followed by N_2 blow-drying. After loading, an in situ thermal cleaning procedure was applied to the Si(1 1 1) susbstrates for 10 min at 1100 °C under H_2 ambient to remove native oxide on the substrate surfaces. After cooling down from the thermal-cleaning step, an AlN buffer layer about 10 nm was then deposited at 800 °C. After that, the temperature was raised to 1050 °C to grow a 200-nm-thick unintentionally doped GaN layer at low V/III ratio, a 0.4-μm-thick unintentionally doped GaN layer and a 2-μm-thick Si-doped n-type GaN layer at high V/III ratio. The substrate temperature was subsequently ramped down to grow the InGaN well layer at 720 °C and grow the InGaN barrier layer at 840 °C. The InGaN MQW active region consists of five periods of 3-nm-thick $In_{0.15}Ga_{0.85}N$ well layer and 9-nm-thick $In_{0.02}Ga_{0.98}N$ barrier layer. After the growth of the active region, substrate temperature was elevated to 1000 °C to grow a 200-nm-thick Mg-doped p-type GaN layer. In order to increase the indium incorporation rate, nitrogen was used as the carrier gas when we grew the InGaN MQW active regions. On the other hand, hydrogen was used as the carrier gas when we grew other parts of the samples. The as-grown LED structure samples were annealed at 730 °C for 30 min in N_2 ambient to activate the Mg-doped p-type GaN layers. The growth was monitored in situ by reflectometry measurements at laser wavelength of 635 nm.

After the annealing, the surface of the as-grown samples was partially etched by inductively coupled plasma etching (ICP) until the n-type GaN layer was exposed for n-type ohmic contact. Ni/Au contacts were subsequently evaporated onto the p-type GaN layer to serve as the p-electrode. On the other hand, Ti/Al/Ni/Au contacts were deposited onto the exposed n-type GaN layer to serve as the n-type electrode. Fig. 1 shows a schematic drawing of the sample structure.

The samples were characterized by double crystal X-ray diffraction (DCXRD) and differential interference contrast microscopy. The performances of these fabricated LEDs were also demonstrated.