Materials Science in Semiconductor Processing 29 (2015) 357–361

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

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

Green light emitting diode grown on thick strain-reduced GaN template

Jiankun Yang, Tongbo Wei *, Qiang Hu, Ziqiang Huo, Baojuan Sun, Ruifei Duan, Junxi Wang

Semiconductor Lighting Research and Development Center, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China

ARTICLE INFO

Available online 17 July 2014

Keywords:
Green light-emitting diode
MOVPE
GaN

ABSTRACT

We report a green light-emitting diode (LED) grown on thick strain-reduced GaN template. As the injection current changes from 20 mA to 120 mA, blue-shift of EL peak wavelength reduces from 9.3 nm for the LED on sapphire substrate to 6.8 nm for the LED grown on thick strain-reduced GaN template. Furthermore, the light output power and external quantum efficiency of the LED on thick strain-reduced GaN template are respectively 1.48 mW and 2.5% at the forward current of 20 mA, which is twice as much as the LED on sapphire substrate. In contrast, the reverse current is 2 μA lower than that of the LED on the sapphire at −8 V.

1. Introduction

Current commercially available GaN-based light-emitting diode (LED), typically grown on foreign substrates such as sapphire, SiC and Si, suffers from high density of threading dislocations (TDs) due to large lattice and thermal mismatches between GaN epilayer and substrate. As a result, the TDs act as a non-radiative recombination center inside GaN film and hence limit the light output efficiency of optoelectronic devices [1–2]. Especially, for green LED, on the one hand, indium tends to cluster around the existing extended defects such as TDs, promoting the formation of V-defects, on the other hand, and the devices suffer from a significant drop in quantum efficiency at high injection level, which has been confirmed that TDs play an important role [3–6]. Therefore, it is believed that, if high quality GaN substrates are available, the performance of devices would be drastically improved. Up to now, high-quality free-standing GaN has been used as substrates for homoepitaxial growth [7–8]. Meanwhile, this method is of cost-efficiency for the mass production because the LED structure typically begins with the n-GaN layer [9]. However, small size and high cost limit the application of bulk GaN substrates, although huge progress has been made in recent decade [10].

Another effective approach is to grow LED on thick GaN template. These templates are grown by hydride vapor phase epitaxy (HVPE) with less 10^7 cm^{-2} of threading defects, which is available at present. In this paper, we report that a green LED is fabricated on thick strain-reduced GaN template, and demonstrate the improved property compared with LED grown on sapphire substrate.

2. Experimental

First, nano-patterned GaN template is fabricated by inductively coupled plasma (ICP) dry etching, using self-assembled CsCl nanospheres as the mask. The detailed process is reported in Ref. [11]. Then, about 30-μm GaN layer was grown on nano-patterned GaN template by

* Corresponding author. Tel.: +86 10 82305247; fax: +86 10 82305304.
E-mail address: tbwei@semi.ac.cn (T. Wei).

http://dx.doi.org/10.1016/j.mssp.2014.06.057
1369-8001/

HVPE, which was intentionally undoped but possessed n-type conductivity. Finally, green LED structure was grown by MOVPE in a $3\times2''$ reactor. For comparison, 3-μm GaN template grown on sapphire substrate was simultaneously loaded into the reaction chamber for LED growth.

The schematic view of LED structure is illustrated in Fig. 1. The structure consists of 3 μm Si-doped n-type GaN layer, two pairs of InGaN/GaN as pre-strained layer, an active region consisting of a five period multiple quantum wells stack with 12 nm undoped GaN barriers and 3 nm InGaN quantum wells (QWs) ending with an undoped 16 nm thick GaN barrier, 10 nm electron block layer (EBL), and a 150 nm p-type GaN:Mg layer. The LED chip with $305\times330\ \mu m^2$ mesa sizes was formed by conventional photolithography followed by chlorine-based ICP etching techniques. An indium tin oxide (ITO) layer was deposited by electron beam deposition as transparent p contact. Ti/Al/Au based n contact and p pad were deposited on the n-GaN layer and the ITO transparent p contact, respectively. The electroluminescent (EL) spectra were studied with an Everfin-PMS50 optical spectrum analyzer. All measurements of LED were carried out on bare-chips under DC conditions at room temperature.

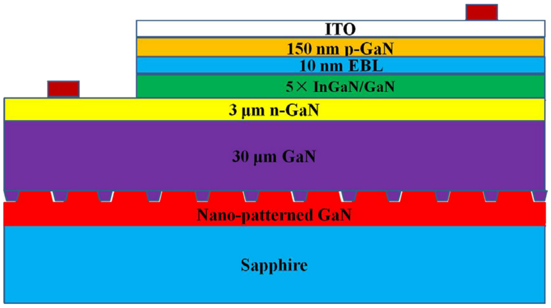

Fig. 1. A schematic view of green LED structure.

3. Results and discussion

The surface morphology was characterized by atomic force microscopy (AFM), using a Nanoscope III atomic force microscope. Fig. 2(a) and (b) presents AFM images of the nano-patterned GaN template and 30-μm GaN template with the scan area of $5\times5\ \mu m^2$, respectively. These nano-patterns are of truncated cone shape with the average diameter of 650 nm for upper surface. For 30-μm GaN template, step-flow morphology can be clearly observed, and the root-mean-square roughness is measured to be 1.2 nm.

The crystalline quality of as-grown GaN template was studied by high resolution X-ray diffraction (HRXRD), using Cu Kα_1 radiation. Fig. 2(c) shows on-axis X-ray rocking curves (XRCs) for both templates. For 3-μm GaN grown by MOVPE, the full width at half-maximum (FWHM) is 298 arcsec. In contrast, the FWHM reduces to 143 arcsec for 30-μm GaN grown by HVPE. In addition, the etch-pit density reduces from $1.1\times10^8\ cm^{-2}$ for 3-μm GaN grown by MOVPE to $5.6\times10^7\ cm^{-2}$ for 30-μm GaN grown by HVPE [11]. It has been shown that the FWHM of on-axis XRCs is related with screw and mixed dislocations for (0002) GaN layer [12]. So, the results show the reduced defect density for thick GaN template.

The stress is analyzed by Raman spectroscopy, which is reported by us in Ref. [11]. The E_2 (High) phonon peak shifts from $569.4\ cm^{-1}$ for 3-μm GaN grown by MOVPE to $568.9\ cm^{-1}$ for 30-μm GaN grown by HVPE, which indicates that a net red-shift of about $0.5\ cm^{-1}$ takes place. Thus, a compressive stress relaxation of 0.12 GPa is assessed by using the proportionality factor of $4.2\ cm^{-1}\ GPa^{-1}$ for GaN, which indicates that the strain reduces in thick GaN template. It is should be noted that the reduced defect density and strain is ascribed to nano-epitaxial lateral overgrowth (NELOG), using nano-patterned GaN template [11].

Fig. 3(a) shows the current–voltage (I–V) characteristics of both LEDs. The V_f is 3.0 V at 20 mA, which indicates that

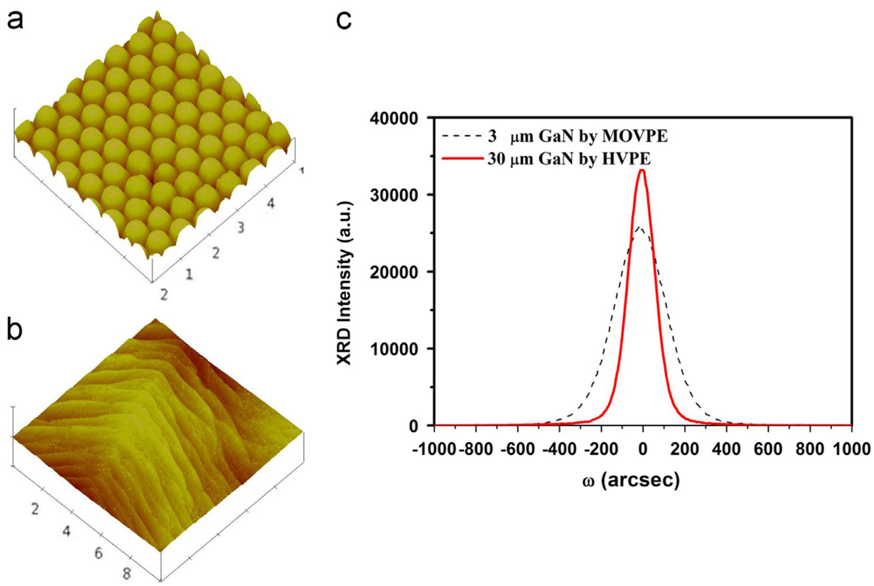

Fig. 2. AFM images of (a) the nano-patterned GaN template and (b) 30-μm GaN template. (c) on-axis X-ray rocking curves for both templates.