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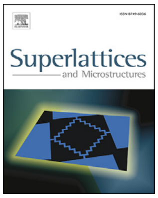

AlGaN-based ultraviolet light-emitting diodes on sputter-deposited AlN templates with epitaxial AlN/AlGaN superlattices

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ABSTRACT

We demonstrate AlGaN-based ultraviolet light-emitting diodes (UV-LEDs) grown by metalorganic chemical vapor deposition (MOCVD) on sputter-deposited AlN templates upon sapphire substrates. An AlN/AlGaN superlattices structure is inserted as a dislocation filter between the LED structure and the AlN template. The full width at half maximum values for (0002) and $(10\bar{1}2)$ X-ray rocking curves of the n-type $Al_{0.56}Ga_{0.44}N$ layer are 513 and 1205 arcsec, respectively, with the surface roughness of 0.52 nm. The electron concentration and mobility measured by Hall measurement are $9.3 \times 10^{17} cm^{-3}$ and 54 $cm^2/V \cdot s$ at room temperature, respectively. The light output power of a 282-nm LED reaches 0.28 mW at 20 mA with an external quantum efficiency of 0.32%. And the values of leakage current and forward voltage of the LEDs are ~3 nA at −10 V and 6.9 V at 20 mA, respectively, showing good electrical performance. It is expected that the cost of the UV-LED can be reduced by using sputter-deposited AlN template.

1. Introduction

AlGaN-based ultraviolet light-emitting diodes (UV-LEDs) are attracting more and more attention for applications such as sterilization, water/air purification, zero-emission automobiles, medicine and biochemistry, white light illumination, and fluorescence identification of biological/chemical agents [1,2]. Despite the significant progress of UV-LEDs over the decades, attaining low-cost devices still remains challenging, especially in the application of low-power personal consumer devices. One of the hurdles is that the most reported UV-LEDs are grown by expensive metalorganic chemical vapor deposition (MOCVD) techniques for a long time. The growth of the AlN template that is widely adopted to alleviate the lattice coefficient mismatches between the commonly-used sapphire substrate and the high-Al-content AlGaN functional material further increases the growth time in the MOCVD system [1–3]. Compared to MOCVD, magnetron sputtering represents an attractive low-cost growth technique, which has great potential for preparing highly uniform and large-scale AlN films for commercial use. The source materials and equipment of magnetron sputtering are simple and cost-efficient. In addition, magnetron

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sputtering allows deposition at low temperatures and in both rigid and flexible substrates [4,5]. Highly (0002)-textured and atomically smooth sputter-deposited AlN films with thickness ranging from a few nanometers to several microns have been obtained on sapphire substrates at temperatures below 600 °C [4–7]. Furthermore, bulk acoustic wave devices based on sputtered AlN thin films are currently commercially available [8,9]. Recently, sputter-deposited AlN has been applied as a thin nucleation layer to reduce the threading dislocation density in MOCVD-grown AlN [10]. However, there is few study on the AlGaN-based ultraviolet optoelectronic devices directly grown on the sputter-deposited AlN template. If the sputter-deposited AlN can replace the MOCVD-grown AlN as the template for the UV-LED, it is possible to significantly reduce the epitaxial layer growth time in MOCVD and thus decrease the device cost.

In this paper, we demonstrate 282-nm AlGaN-based UV-LEDs on sputter-deposited AlN templates upon sapphire substrates, without AlN templates growth by MOCVD at high temperature. By the use of AlN/AlGaN superlattices (SLs) as dislocation filters as reported previously [11,12], n-type $Al_{0.56}Ga_{0.44}N$ films are obtained on 200- and 800-nm the AlN templates. The minimum full width at half maximum (FWHM) values for (0002) and $(10\bar{1}2)$ X-ray rocking curves (XRCs) of the n-$Al_{0.56}Ga_{0.44}N$ film on a 200-nm AlN template are 513 and 1205 arcsec, respectively, with the surface roughness of 0.52 nm. The best room temperature electron concentration and mobility are $9.3 \times 10^{17} cm^{-3}$ and $54\ cm^2/V\cdot s$, respectively. The light-output power (LOP) of the LED reaches 0.28 mW at 20 mA with external quantum efficiency (EQE) of 0.32%. And the values of leakage current and forward voltage of the LED on the 200-nm AlN template are ~3 nA at −10 V and 6.9 V at 20 mA, respectively. As mentioned above, the sputter-deposited AlN has the potential to be employed as an optional template for AlGaN-based UV-LEDs with advantages of low cost.

2. Experiment

In order to realize UV-LEDs, it is important to develop an applicable AlGaN epitaxial layer. 200- and 800-nm AlN films were deposited on 2-inch *c*-plane sapphire substrates by reactive radio frequency magnetron sputtering. Magnetron operated at a power of 3000 W and frequency of 100 kHz. The temperature of substrates was 600 °C for all grown films. Oxygen plasma, nitrogen plasma, and aluminum target were used as the precursors. All the sputter-deposited layers consist of 10-nm thick AlON layer and subsequent AlN layer and the composition of oxygen, aluminum, and nitrogen atoms in the AlON layer is gradually changed from Al_2O_3 to AlN. The growth rate of sputter-deposited AlN films is 45 nm/min. Before the epitaxial growth, the AlN films were characterized X-ray diffraction (XRD) and atomic force microscopy (AFM) to exam the crystal quality and surface morphology. A homemade low-pressure (LP-MOCVD) system was used to process the epitaxial growth. Trimethylgallium, trimethylaluminum, and ammonia were used as gallium, aluminum and nitrogen precursors, respectively. Hydrogen was the carrier gas and silane was the n-dopant. First, 20-period $AlN/Al_{0.65}Ga_{0.35}N$ SLs with the period thickness of 15/30 nm were grown on the two AlN templates at 1130 °C by MOCVD in the same run. Then a silicon-doped 1.5-μm n-type $Al_{0.56}Ga_{0.44}N$ layer was grown on the AlN/AlGaN SLs at 1005 °C. XRD and AFM were used to evaluate the crystal quality and the surface morphology of the n-AlGaN samples, respectively. Hall measurement was used to examine the electrical properties of the n-$Al_{0.56}Ga_{0.44}N$ layers. For the Hall measurement, the ohmic contact was formed by Ti/Al/Ti/Au evaporation and subsequent annealing in nitrogen. After the property evaluations of the n-AlGaN films, the UV-LED structures were grown in the LP-MOCVD system.

Fig. 1 shows the schematic diagram of UV-LEDs on the 200- and 800-nm sputter-deposited AlN templates. The n-type AlGaN layers were grown by the same method mentioned above on the 200- and 800-nm AlN templates. Five pairs of $Al_{0.5}Ga_{0.5}N/Al_{0.4}Ga_{0.6}N$ MQWs were grown as the active region, followed by a 50-nm Mg-doped p-$Al_{0.65}Ga_{0.35}N$ electron-

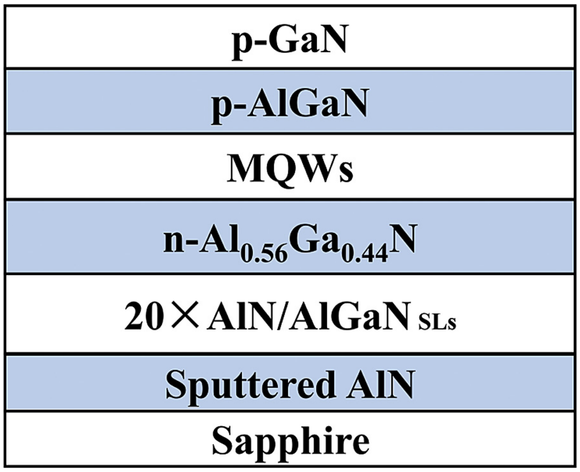

Fig. 1. Schematic diagram of UV-LEDs on the 200- and 800-nm AlN templates.

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