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The preparation of different pairs near-ultraviolet AlGaN/GaN DBRs with AlN interlayer

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ABSTRACT

In this paper, near-ultraviolet AlGaN/GaN distributed Bragg reflectors (DBRs) were prepared on GaN/sapphire templates by metal organic chemical vapor deposition. A single low-temperature AlN interlayer was adopted to prevent the formation of cracks in DBRs. Moreover, different pairs of DBRs with AlN interlayer were grown to investigate the stress distribution through the epilayer, the surface morphology evolution and the variation of reflectivity spectra. The in-situ stress monitoring shows a compressive-to-tensile stress transition with the increase of DBRs pairs. The optical microscope and atomic force microscope images show that the AlN interlayer induces the appearance of trenches on the surface of DBRs and the trenches gradually coalesce when DBRs grow. Meanwhile, the experimental reflectivity spectra get closer to the simulated results. Finally, we obtain a smooth-surface 25-pair $Al_{.32}Ga_{.68}N$/GaN DBRs with a reflectance of 94% at 390 nm and a 16 nm stopband bandwidth. The preparation of high-quality DBRs lays the foundation for the future development of high efficiency resonant cavity UV LEDs.

1. Introduction

High-performance ultraviolet (UV) light emitting diodes (LEDs) and laser diodes (LDs) have wide application potentialities in high-density optical recording, lighting, photocatalysis, and microbiophotonics [1–3]. GaN-based composites are considered as ideal materials for the preparation of UV LEDs or LDs because of their wide direct transition bandgaps in the UV region and good thermal and chemical stability [4]. The high-reflectivity AlGaN/GaN DBRs has played an important role in the preparation of near-ultraviolet resonant cavity LEDs whose light output is brighter, more pure, and more directional than the light from non-resonant UV LEDs [5]. In order to realize a high reflective DBRs, the contrast of refractive index between two materials constituting DBRs multilayer structure should be significant, because larger refractivity contrast can provide a higher reflection with relatively few layer amounts. Hence, a relatively high aluminium mole fraction of AlGaN material is required to produce a large refractive index contrast and achieve a highly reflective AlGaN/GaN DBRs. However, it is difficult to obtain a crack-free AlGaN/GaN DBRs because the lattice mismatch between AlGaN with high AlN composition and GaN causes tensile stress accumulation with the pairs of DBRs increasing. And the overlarge strain inevitably induces a mass of cracks in the DBRs, which seriously decrease the DBRs reflectivity due to scattering, diffraction and absorption effect [6]. Therefore, it is necessary to prevent crack generation for obtaining a smooth DBRs surface and a high reflectivity. There are some approaches to be used to reduce mismatch-induced tensile stress and to suppress the formation of cracks in the DBRs. For examples, Dartsch et al. obtained a 20-pair $Al_{.41}Ga_{.59}N$/GaN DBRs with 90% reflectivity by using a $Al_{.21}Ga_{.79}N$ buffer layer [7]. Moudakir et al. adopted an AlN/GaN/AlN multilayer template during the growth to overcome the problem of cracks generation and achieved 20 pairs of $Al_{.27}Ga_{.73}N$/GaN DBRs with a high reflectivity [3]. Wang et al. grew the 30 periods of crack-free $Al_{.2}Ga_{.8}N$/GaN DBRs with measured reflectance of over 92% on AlN/AlGaN double buffer layers [8]. Nakada et al. got 30-pair GaN/$Al_{.41}Ga_{.59}N$ DBRs by introducing a GaN/AlGaN superlattice prior to the DBRs growth to suppress generation of cracks [9]. Huang et al. reported the growth of a crack-free 20-pair GaN/AlN DBR with inserting three sets of 5.5 periods of GaN/AlN superlattices [10]. In this paper, we report that different pairs of AlGaN/GaN DBRs were grown by using metal organic chemical vapor deposition (MOCVD). A crack-free $Al_{.32}Ga_{.68}N$/GaN DBRs was obtained by only inserting a single low-temperature AlN layer between DBRs structures and GaN templates on sapphire substrates. We also detailedly investigated the stress accumulation in films, study the DBRs surface morphologies evolution and analyse the discrepancy between experimental and simulated reflective spectra.

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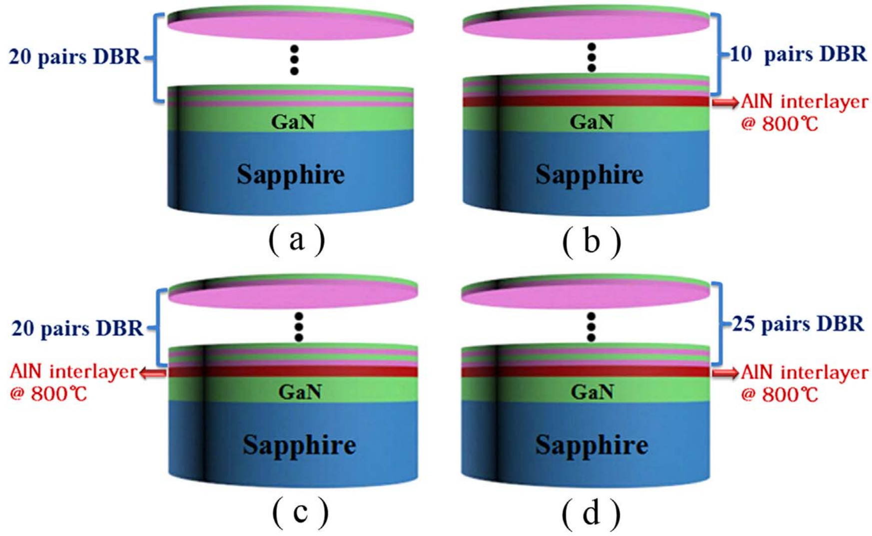

Fig. 1. The epitaxial structures of sample A (a), sample B (b), sample C (c), and sample D (d).

2. Experimental

AlGaN/GaN DBRs were grown by using AIXTRON CCS 3 × 2" FT MOCVD with GaN template on *c*-Al_2O_3 substrates. Trimethylgallium (TMGa) and trimethylaluminium (TMAl) were used as group-III precursors, and ammonia as group-V precursor. Hydrogen was used as the carrier gas. Before the deposition, sapphire substrates were heat-treated in hydrogen ambient at 1150 °C for 5 min. Then, a 3.5-μm-thick GaN template was prepared using the standard two-step growth process, in which a thin initial GaN nucleation layer was grown at 500 °C, followed by a thick high-temperature (1050 °C) GaN buffer. And, 20 periods of $Al_{.32}Ga_{.68}N$ (42 nm)/GaN (37 nm) DBRs were grown on the GaN/sapphire templates. The resulting sample was denoted as sample A, and the corresponding epitaxial structure was shown in Fig. 1(a). To prevent the formation of cracks in DBRs, an AlN layer with a thickness of about 50 nm was inserted between GaN template and DBRs at a growth temperature of 800 °C. Finally, three samples with different pairs (10, 20 and 25) of DBRs were fabricated and defined as sample B, C and D, respectively, and the corresponding schematic configurations were shown in Fig. 1(b–d). Note that all the AlGaN/GaN quarter-wavelength DBRs were grown at 1050 °C with a pressure of 300 mbar.

Real time in-situ stress monitoring based on wafer curvature measurements was performed with a multibeam optical stress sensor (MOSS) modified for use on our reactor. In addition, an in-situ laser interferometer (405 nm) was used to monitor the growth process. Surface morphology of DBRs was investigated by a optical microscope (Olympus, BX51M) and a atomic force microscope (AFM; Icon, Veeko). The structural property of samples were analyzed using a high resolution X-ray diffraction (HR-XRD; Rigaku Ultima IV) and a scanning electron microscopy (SEM; Jeol-7500F). The reflectivity of the DBRs was measured by UV–Visible Spectrophotometer using Shimadzu UV-1700.

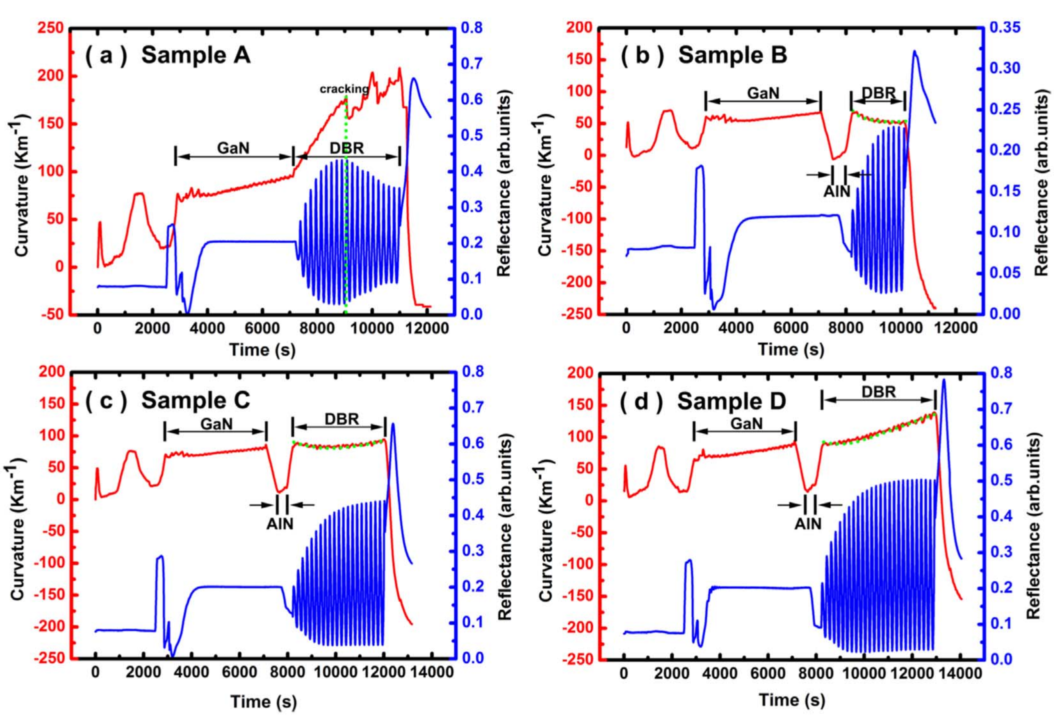

Fig. 2. In-situ reflectance signal and wafer curvature curves during growth processes of sample A (a), sample B (b), sample C (c), and sample D (d).