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Interruption-free growth of 10 μm-thick GaN film prepared on sputtered AlN/PSS template by hydride vapor phase epitaxy

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ABSTRACT

GaN films (10 μm-thick) of high crystalline quality were prepared on sputtered AlN/PSS template by hydride vapor phase epitaxy (HVPE). By introducing the two-step growth method into HVPE, one can reduce the steps in the procedure, realize uninterrupted growth, and improve the crystal quality of the films. The effects of initial GaN growth on the AlN/PSS template by HVPE were also investigated.

In this study, 10 μm-thick GaN films prepared on sputtered AlN/PSS template by HVPE showed improved crystal quality using X-ray diffraction and etching pits density. Compared with conventional undoped GaN film grown by metal organic chemical vapor deposition, the full width at half maximum of the (0 0 2) and (1 0 2) peaks of GaN decreased from 450 arcsec to 290 arcsec and from 376 arcsec to 344 arcsec, respectively. Transmission electron microscopy results showed that the gaps observed between the convex regions would eventually turn into dislocations during coalescence, because the number of dislocations increased with the number of gaps observed between the convex regions after step-1 growth.

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1. Introduction

GaN is a promising material for light-emitting diodes (LEDs) because of its direct bandgap characteristics and wide range of spectrums [1]. However, given the relatively high price of GaN substrates, GaN films are generally grown on foreign substrates, such as sapphire, which leads to a high density of threading dislocations (TDs) in the epitaxial layer caused by lattice mismatch. TDs have been proven to decrease radiative recombination and deteriorate light output power [2]. In addition, the thermal conductivity of sapphire is much lower than that of GaN films, preventing heat dissipation from the epilayer and leading to a low injection current durability.

Many growth techniques have been developed to solve these problems. Such techniques include low-temperature GaN buffer layer [3], patterned sapphire substrate (PSS) [4], epitaxial lateral overgrowth (ELOG) [5], flip chip package [6], and cantilever epitaxy [7]. However, low-temperature GaN buffer layer and PSS have been widely used in the LED industry to reduce TDs and improve the light extraction efficiency. Recently, an ex situ sputtered AlN nucleation layer was invented. The ex situ sputtered AlN nucleation layer cannot only improve the crystal quality compared with the in situ nucleation layer, but also realize one-step GaN growth, thereby reducing the fabrication time [8]. An interruption-free ELOG technique was also realized using the ex situ sputtered AlN nucleation layer with the template [9]. However, to satisfy next-generation applications in lighting systems, the TD density and heat durability of the GaN-based LED still require much improvement.

Thick GaN films grown by hydride vapor phase epitaxy (HVPE) have been recently reported to enhance crystal quality and heat dissipation, and reduce strain. Compared with metal organic chemical vapor deposition (MOCVD) and molecular beam epitaxy, HVPE has a high growth rate, and it is generally used to grow GaN substrates [10]. The flat sapphire substrate with sputtered AlN buffer layer has been introduced to the HVPE growth in the former research [11]. However, PSS with sputtered AlN buffer layer has not yet been applied to the HVPE. It's well known that PSS has been widely used to improve the crystal quality and the light extraction efficiency in the LED industry.

In this work, we combined the advantages of the ex situ sputtered AlN nucleation layer and PSS to realize uninterrupted GaN epitaxy of high crystal quality in HVPE. In addition, PSS can further improve the light extraction efficiency in lighting applications.

2. Experimental procedure

At the beginning of the experiments, a 25 nm-thick AlN buffer layer was deposited on PSS by sputter. The AlN plates on the separated sputtering guns were used as the sputtering targets for

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AlN buffer layer deposition. The pattern diameter, spacing, and height of the PSS were 2.6, 0.4, and 1.6 μm, respectively, as shown in Fig. 1(a). Based on the GaN film grown on PSS by MOCVD, the initial growth mode dominates the crystal quality and surface roughness of the film [12]. Thus, we introduced a two-step growth method into HVPE. The initial growth was step-1 uGaN growth, which was characterized by a slow growth rate (Fig. 1(b)). Step-1 uGaN growth was followed by step-2 uGaN growth, which utilized the advantages of HVPE to grow the thick uGaN layer under high growth rates, as shown in Fig. 1(c).

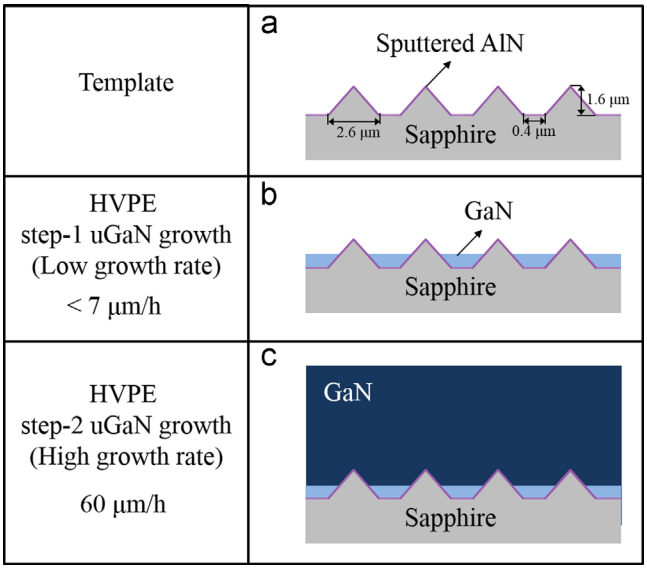

Fig. 1. (a) Cross-sectional structure of AlN/PSS template. (b) Cross-sectional structure of sample-1, sample-2 and sample-3 after step-1 uGaN growth. (c) Cross-sectional structure of sample-1, sample-2 and sample-3 after step-1 and step-2 uGaN growth.

The growth rates of step-1 uGaN growth on the AlN/PSS template by HVPE of sample-1, sample-2, and sample-3 were 3.6, 5.0, and 6.4 μm/h, respectively. The time of step-1 uGaN growth for each sample was 6 min. The time of step-2 uGaN growth, which had a relatively higher growth rate of 60 μm/h, for each sample was 10 min. Sample-R was grown by Thomas Swan (3 × 2″) using MOCVD as a comparison. The growth rate of step-1 uGaN growth on the AlN/PSS template by MOCVD of sample-R was 1.2 μm/h, and the time of step-1 uGaN growth was 20 min. The growth rate of step-2 uGaN growth was 2.0 μm/h, and the time of step-2 uGaN growth was 60 min.

The samples were examined and characterized by optical microscopy (OM), scanning electron microscopy (SEM), X-ray diffraction (XRD), atomic force microscopy (AFM), and transmission electron microscopy (TEM).

3. Results and discussion

Fig. 2 shows the cross-sectional SEM images of the samples after step-1 uGaN growth. Considering that the samples comprised different combinations between step-1 uGaN growth time and step-1 uGaN growth rate, we obtained various step-1 uGaN thicknesses. The step-1 uGaN thicknesses of sample-R, sample-1, sample-2, and sample-3 were 1.0, 1.0, 1.3, and 1.5 μm, respectively.

To further study the initial growth mode of step-1 uGaN growth, OM images were also prepared. Fig. 3(a)–(d) shows the top-view OM images of sample-R, sample-1, sample-2, and sample-3, respectively. Numerous gaps were observed in the OM images of sample-1, sample-2, and sample-3. The top-view SEM image of sample-1 was also prepared (Fig. 3(e)) to clearly discuss the formation of gaps. The OM images showed that the number of

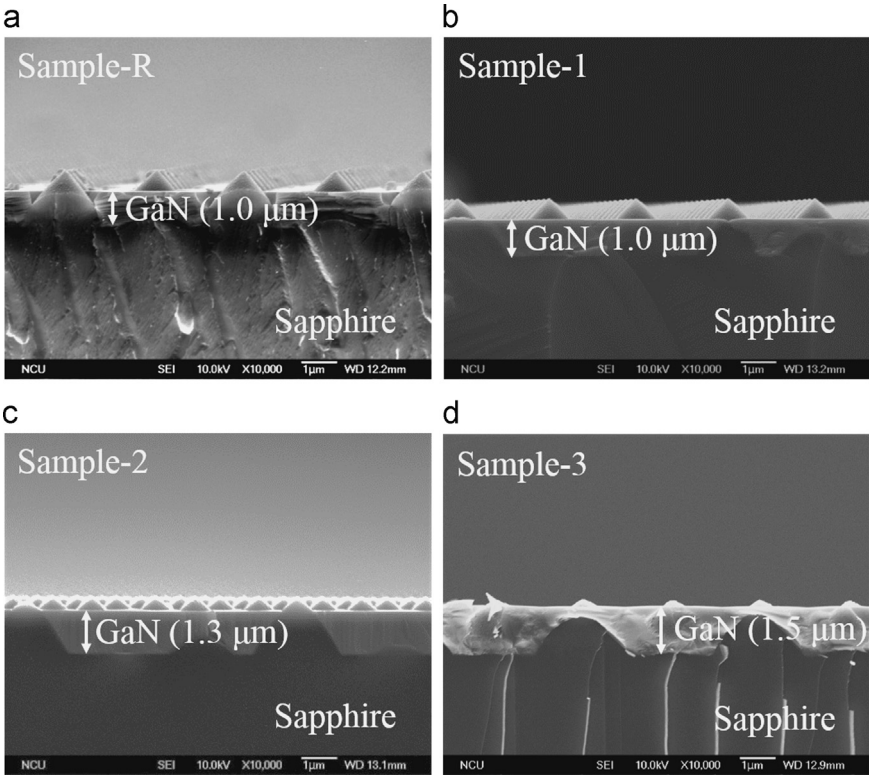

Fig. 2. Cross-sectional SEM images of the samples after step-1 uGaN growth.

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