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Study of epitaxial lateral overgrowth of semipolar (1 1 − 2 2) GaN by using different SiO_2 pattern sizes

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ABSTRACT

We investigated the growth mode and the crystal properties of lateral epitaxial overgrowth (LEO) semipolar (1 1 − 2 2) GaN by using the various SiO_2 pattern sizes of 6, 8, 10 and 12 μm with the window width of 4.0 μm. By using three-step growth technique, we successfully obtained the fully-coalescenced semipolar (1 1 − 2 2) LEO-GaN films regardless of the SiO_2 pattern sizes. However, the coalescence thickness of LEO-GaN film was decreased with decreasing SiO_2 pattern size, indicating that the coalescence of semipolar (1 1 − 2 2) GaN was easily formed by decreasing the pattern size of SiO_2 mask. The full width at half maximums (FWHMs) of X-ray rocking curves (XRCs) of LEO-GaN films decreased with increasing SiO_2 pattern size. In the pattern size of 4×10 μm, we achieved the minimum XRCs FWHM of 537 and 368 arc s with two different X-ray incident beam directions of [1 1 − 2 − 3] and [1 − 1 0 0], respectively. Moreover, the photoluminescence bandedge emission of semipolar (1 1 − 2 2) GaN was 45 times increased by LEO process. Based on these results, we concluded that the LEO pattern size of 4×10 μm would effectively decrease crystal defects of semipolar (1 1 − 2 2) GaN epilayer, resulting in an improvement of the optical properties.

1. Introduction

GaN-based semiconductors have been promising materials for applications in light-emitting devices covering from ultraviolet to visible range [1]. However, there are important physical limits to achieve high power GaN-based laser diodes (LDs) and light emitting diodes (LEDs), which are quantum confinement Stark effect due to their spontaneous and piezoelectric polarizations fields [2,3]. Therefore, it has reported that the limits of emission efficiency of conventional *c*-plane GaN-based LEDs could be overcome by using semipolar or nonpolar GaN films which represented small (~30%) or no polarization field of the one existing in *c*-plane GaN, respectively [4–8]. In particular, semipolar (1 1 − 2 2) GaN-based LEDs represented superior green emission properties to nonpolar *a*- and *m*-plane GaN due to its higher In incorporation.

In general, it is known that the semipolar (1 1 − 2 2) GaN film exhibited the tilt angle of 58.4° with respect to the normal direction of *c*-plane surface [7,8]. Therefore, heteroepitaxial semipolar (1 1 − 2 2) GaN film has been still reported on poor crystal quality because of anisotropic crystallographic mismatch between semipolar (1 1 − 2 2) GaN and *m*-plane sapphire, resulting in high crystal defects such as threading dislocations (TDs) of $\sim 10^{10}/cm^2$ and basal stacking faults (BSFs) of $\sim 10^5/cm$ which could be acted as non-radiative recombination centers [9]. To improve the crystalline quality of the hereroepitaxial semipolar (1 1 − 2 2) GaN film, the lateral epitaxial overgrowth (LEO) technique has been employed [10,11]. However, most research groups have focused on the growth mode and the dislocation behaviors of semipolar (1 1 − 2 2) LEO-GaN with the constant SiO_2 pattern size [12–14] because of the severe difficulties in coalescence and planarization process during the lateral growth step. In this study, we systematically investigated the growth behavior and the structural characterization of semipolar (1 1 − 2 2) LEO-GaN films by using the different SiO_2 pattern sizes which would affect the surface morphology and crystal defects.

2. Experimental details

We prepared 2.0 μm-thick semipolar (1 1 − 2 2) GaN films by growing them on *m*-plane sapphire substrates, using a high temperature one-step growth method instead of a conventional two-step growth technique [7,10,15]. The growth temperature and pressure were 1030 °C and 80 Torr, respectively, under the same V/III ratio of 1165. After that, 240 nm-thick SiO_2 film was deposited on semipolar (1 1 − 2 2) GaN templates by using plasma-enhanced chemical vapor deposition system. The SiO_2 stripes patterns were formed by a standard photolithography and

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wet etching process, which consisted of 6, 8, 10 and 12 μm-width SiO_2 masks toward the [1 − 1 0 0] direction and 4.0 μm-width opening regions. By using these templates, the semipolar (1 1 − 2 2) LEO-GaN films were grown by three-step method [10]. During LEO process, the growth temperature was fixed at 1030 °C. The first step was the growth of seed GaN layer from the window regions, which was the identical growth condition of semipolar (1 1 − 2 2) GaN templates. The second step was coalescence step, whose growth pressure and V/III ratio were 300 Torr and 580, respectively. Last one was the planarization step of semipolar (1 1 − 2 2) LEO-GaN film with partially non-merged surface. In this step, we increased the V/III ratio from 580 to 1165 under the same growth pressure of 300 Torr.

The microscopic surface morphologies of semipolar (1 1 − 2 2) LEO-GaN films were analyzed by optical microscope (OM) and atomic force microscope (AFM). Furthermore, the growth mode of semipolar (1 1 − 2 2) LEO-GaN films has been studied by the cross-sectional images of scanning electron microscope (SEM). The crystal qualities of semipolar (1 1 − 2 2) LEO-GaN films were characterized by high-resolution X-ray diffraction (HR-XRD) by using the different X-ray incident beam directions of [1 − 1 0 0] and [−1 − 1 2 3]. To analyze the optical properties of semipolar (1 1 − 2 2) LEO-GaN films, room temperature micro-photoluminescence (PL) was used to measure their bandedge emissions. For PL measurement, LEO-GaN films were focused by the 325 nm line of He–Cd laser with the beam diameter of 4.0 μm and the excitation power of 10.0 kW/cm^2.

3. Results and discussion

Fig. 1(a)–(d) shows OM images of semipolar (1 1 − 2 2) LEO-GaN films with SiO_2 pattern widths varying from 6 to 12 μm before coalescence step. The macroscopic surface morphology of semipolar (1 1 − 2 2) LEO-GaN film with the pattern size of 4 × 6 μm exhibited partially coalescence-surface structure, whereas that of semipolar (1 1 − 2 2) LEO-GaN with pattern size of 4.0 × 12.0 μm clearly showed non-merged coalescence boundaries. In particular, the width of non-merged coalescence boundaries was increased with SiO_2 pattern size. It indicated that the coalescence time of semipolar (1 1 − 2 2) LEO-GaN film was increased by increasing SiO_2 pattern size, which implied that the length of lateral growth on SiO_2 mask was one of major parameters to merge the semipolar (1 1 − 2 2) LEO-GaN film. Inset images of Fig. 1(a)–(d) show the surface morphologies of semipolar (1 1 − 2 2) LEO-GaN film with SiO_2 pattern widths changing from 6 to 12 μm after the planarization step. The macroscopic surface morphology of semipolar (1 1 − 2 2) LEO-GaN with the SiO_2 pattern size of 4 × 6 μm was smoother than that with the SiO_2 pattern size of 4 × 12 μm. It means that the surface morphology of semipolar (1 1 − 2 2) LEO-GaN is significantly affected by the width of SiO_2 pattern due to the lateral growth toward $[1\ 1\ -2\ -3]_{GaN}$ across the SiO_2 stripe patterns along the $[1\ -1\ 0\ 0]_{GaN}$. In particular, the coalescence thickness of semipolar (1 1 − 2 2) LEO-GaN film with the SiO_2 pattern size of 4 × 6 μm was much thinner than that with 4 × 12 μm due to the short lateral growth length across SiO_2 mask [16]. Based on these results, we guessed that the planarization step of semipolar (1 1 − 2 2) LEO-GaN with SiO_2 pattern size of 4 × 6 μm was long enough to produce a smooth surface. To analyze microscopic surface properties, we performed AFM measurements. Fig. 2 shows the RMS roughness of semipolar (1 1 − 2 2) LEO-GaN films as a function of the width of SiO_2 mask. The RMS roughness of semipolar (1 1 − 2 2) LEO-GaN film was increased from 6.5 to 14.0 nm by increasing the width of SiO_2 pattern from 6 to 12 nm, respectively, which was consistent with

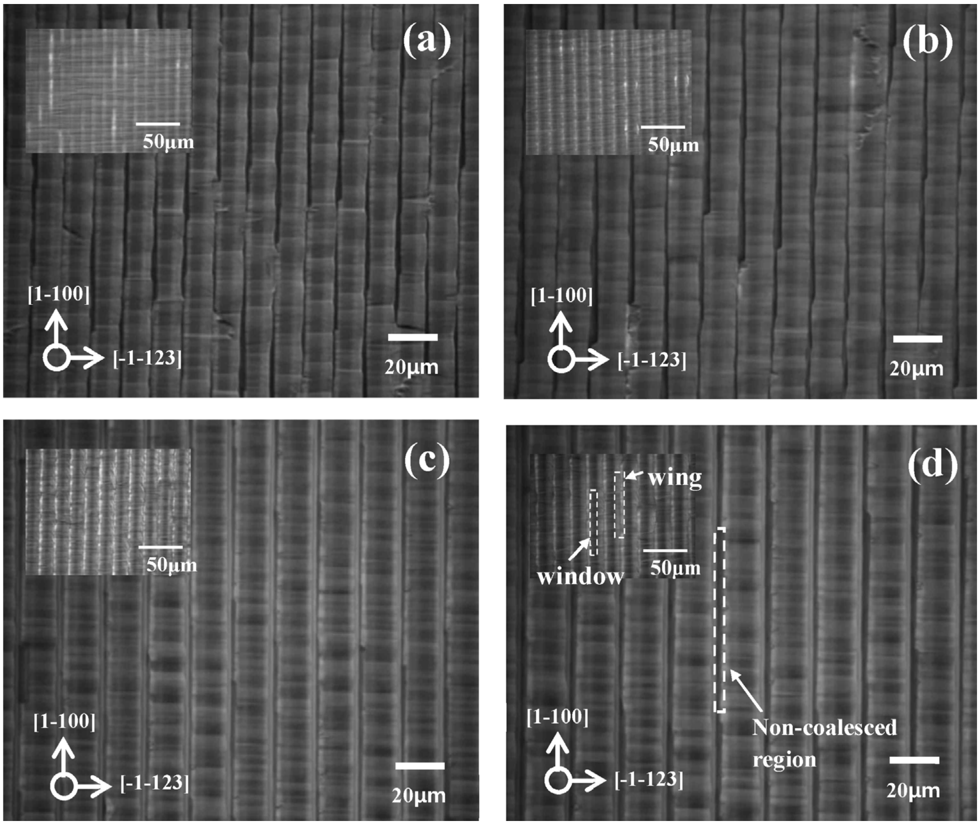

Fig. 1. OM images of the non-merged semipolar (1 1 − 2 2) LEO-GaN films with the SiO_2 pattern size of 4 × 6 (a), 4 × 8 (b), 4 × 10 (c), and 4 × 12 μm (d). Inset images show surface morphologies of fully coalescenced semipolar (1 1 − 2 2) LEO-GaN films for each pattern size.