SELECTIVE AREA GROWTH (SAG) AND EPITAXIAL LATERAL OVERGROWTH (ELO) OF GaN USING TUNGSTEN MASK

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ABSTRACT

Selective area growth (SAG) and epitaxial lateral overgrowth (ELO) of GaN using tungsten (W) mask by metalorganic vapor phase epitaxy (MOVPE) and hydride vapor phase epitaxy (HVPE) have been studied. The selectivity of the GaN growth on the W mask as well as the SiO_2 mask is excellent for both MOVPE and HVPE. The ELO-GaN layers are successfully obtained by HVPE on the stripe patterns along the $<1\bar{1}00>$ crystal axis with the W mask as well as the SiO_2 mask. There are no voids between the SiO_2 mask and the overgrown GaN layer, while there are triangular voids between the W mask and the overgrown layer. The surface of the ELO-GaN layer is quite uniform for both mask materials. In the case of MOVPE, the structures of ELO layers on the W mask are the same as those on the SiO_2 mask for the $<11\bar{2}0>$ and $<1\bar{1}00>$ stripe patterns. No voids are observed between the W or SiO_2 mask and the overgrown GaN layer by using MOVPE.

INTRODUCTION

Wide band gap GaN and related nitrides have shown potential use in light emitting diodes (LEDs) and laser diodes (LDs) in green to blue light regions [1,2]. These materials have also shown usefulness in electronic devices as an AlGaN/GaN heterostructure field effect transistors (HFETs) [3,4]. The HFET structures have received interest because of the high performance with a high output power in microwave frequencies. The static induction transistors (SITs) also have a possibility for the power device at microwaves and have been expected to show ultimate performance at high temperatures because of no saturation of the drain current and the negative temperature coefficient of the leakage current [5]. For the past decades, various efforts have been done to realize power devices at high frequencies. One of the main difficulties have been on the formation of high quality metal-semiconductor contact with an embedded structure.

Selective area growth (SAG) and epitaxial lateral overgrowth (ELO) of GaN has attracted much attention in the fabrication of optical and electrical devices with high performance [6,7]. Nishinaga *et al*. developed the idea of the SAG/ELO technique further and named this technique micro-channel epitaxy (MCE), that the lateral overgrown region on the mask will be free from dislocations which might be originated at the hetero-interface [8]. Recently, Sakai *et al*.[9], Matsushima *et al*.[10] and Nam *et al*.[11] demonstrated that the SAG/ELO technique of GaN gives us an embedded structure of amorphous SiO_2 stripes in a high crystalline quality

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epitaxial layer. This technique will provide us embedded metal electrodes in an epitaxial GaN layer. If we could realize an embedded metal gate electrode in the epitaxial GaN layer, we might realize SITs made from GaN, which will show high performance at high temperature, high frequency and high power operations.

In a previous study, we attempted the SAG of GaN using tungsten (W) masks by metalorganic vapor phase epitaxy (MOVPE) for the first time [12]. In this study, we compare the SAG of GaN using W mask to that of SiO_2 mask by MOVPE by means of scanning electron microscope (SEM) and cathodoluminescence (CL) measurements. Furthermore, the SAG/ELO of GaN using W masks by hydride vapor phase epitaxy (HVPE) are demonstrated for the first time.

EXPERIMENTAL METHODS

The SAG of GaN using W masks was performed by atmospheric HVPE and MOVPE system on 3.0-4.5 μm thick (0001) GaN layer grown on a (0001) sapphire substrate with an low temperature (LT) buffer layer by MOVPE. A 120-nm-thick W film was deposited on the GaN surface by RF sputtering at R.T. Stripe windows of 10 μm wide with a periodicity of 20 μm was developed on the W film with conventional photolithography and wet chemical etching. The etching of W was performed with H_2O_2 at R.T. In the case of HVPE, GaCl and NH_3 were used as the source gases, and N_2 was used as the carrier gas. The flow rates of HCl and NH_3 were 10 cc/min and 0.5 *l*/min, respectively. The growth temperature was 1090°C. In the case of MOVPE, TMG and NH_3 were used as the source gases, and H_2 was used as the carrier gas. The flow rates of TMG and NH_3 were 18.7 μmol/min and 2.5 *l*/min, respectively. The growth temperature was 1060°C. More details of the preparation and growth processes by MOVPE were described in Ref. [12].

RESULTS AND DISCUSSION

The advantage of HVPE is at the high growth rate, which allows us to get a thick homogeneous layer and to obtain the GaN layer with good crystalline quality. According to previous results of the SAG/ELO using SiO_2 mask by HVPE, the selectivity of the GaN growth on window regions was excellent and the thick ELO GaN layers had good crystalline quality [9,13,14]. Figures 1(a)-1(c) show typical SEM images of the SAG-GaN by HVPE using $<1\bar{1}00>$ stripe W masks. At the growth time of 3 min (Fig. 1(a)), the growth of GaN only within the window region indicates good selectivity with the W mask as well as the SiO_2 mask. We obtained trapezoidal shapes in cross-section with the smooth (0001) surface on the top. The sidewalls formed rough surfaces. At 30 min (Fig. 1(b)), the ELO of GaN occurred. The ELO-GaN layer did not contact to the W mask and ELO-GaN layer over the W mask had the reverse-mesa shapes. At the overgrown GaN region, the top (0001) surfaces vanish and it has triangular cross-sectional shape with rough sidewalls. As a result, the structure of the SAG is characterized by combination of the reverse-mesa and the ordinary-mesa shaped planes. By increasing the growth time, the overgrown GaN region became wider and finally coalesced. After the growth time of 60 min (Fig. 1(c)), the ELO-GaN region coalesced one another and formed continuous, flat and specular surface. We could see triangular voids formed on the W mask owing to the reverse-mesa formation during the initial overgrowth stage. On the other hand, by using the SiO_2 mask, there were no voids on the SiO_2 mask.

In the previous work, we succeeded in the SAG of GaN using W masks by MOVPE for the first time [12]. In this work, we compare the W mask and the SiO_2 mask in terms of shape

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and crystalline quality of the SAG-GaN. Figures 2(a)-2(d) show the typical SEM images of the

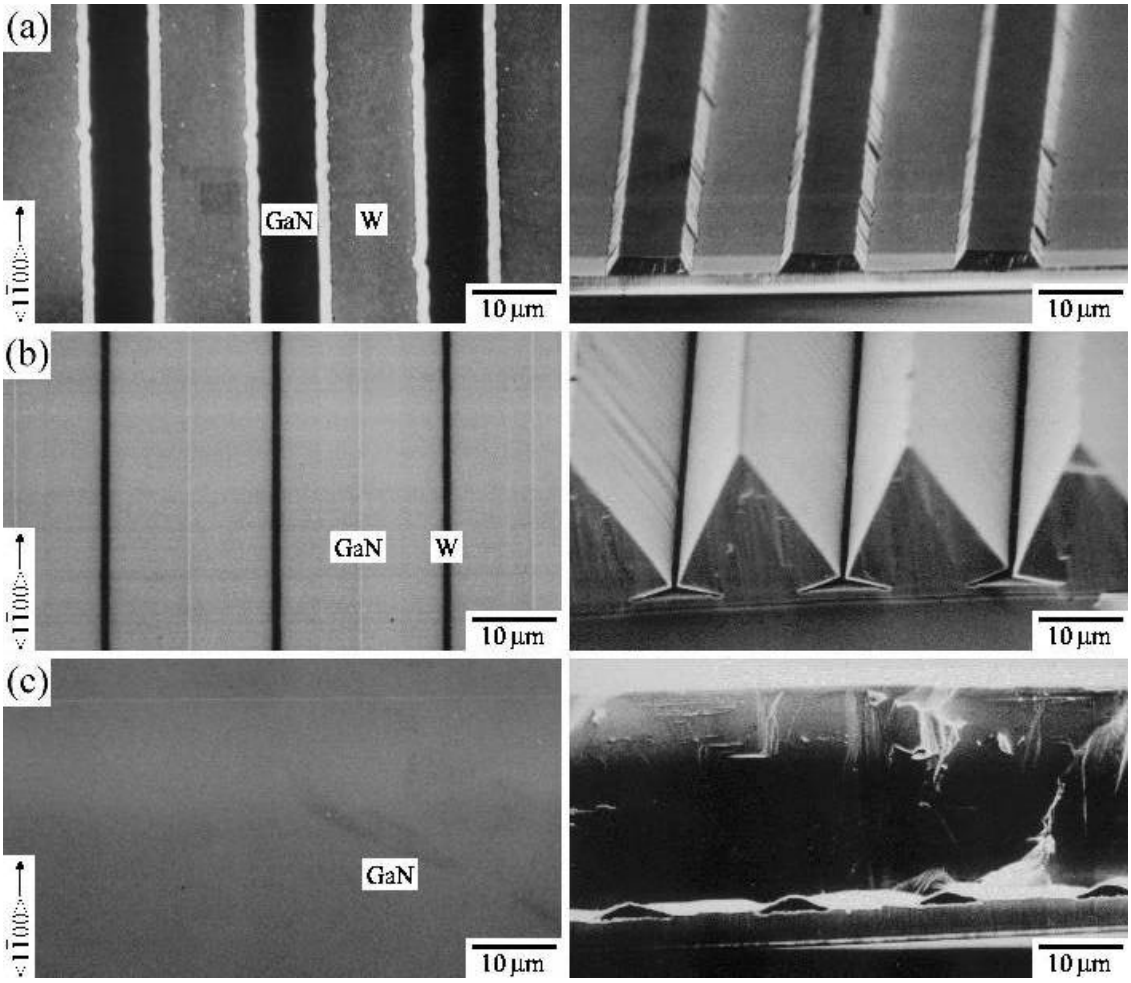

Fig. 1 SEM images of the SAG-GaN by HVPE using the W mask along the $<1\bar{1}00>$ crystal axis. The growth time of the SAG is (a) 3 min, (b) 30 min and (c) 60 min.

SAG-GaN at the growth time of 120 min. No GaN polycrystals are observed on the W and SiO_2 mask regions. Triangular voids were not observed on the W mask in comparison with ELO-GaN grown by HVPE (Figs. 1(b) and 1(c)). It is not clear at present why these differences occurs. There are several differences in growth conditions between MOVPE and HVPE such as growth atmosphere (H_2 or N_2), and source gases (TMG or Ga and HCl), which might cause the formation of voids on the W mask. The ELO of GaN is seen in the lateral direction. In the stripe pattern along the $<11\bar{2}0>$ crystal axis of GaN on the (0001) surface (Figs. 2(a) and 2(c)), we obtained triangular shapes in cross-section, which comprised $\{1\bar{1}01\}$ facets at both sides. The cross-sectional shapes were the same for both mask materials. In the $<1\bar{1}00>$ stripe pattern (Figs. 2(b) and 2(d)), we obtained trapezoidal cross-sectional shapes with a smooth (0001) surface on the top and rough surfaces on both sides. The lateral overgrowth width on the SiO_2 mask have 3.5 μm, which is larger than 2.6 μm on the W mask. The difference in lateral overgrowth rates by the W and SiO_2 mask materials might be in relation to the difference in the shapes of the sidewalls, the surface migration of source materials on the masks or the interface energy between the ELO-GaN layer and masks.

To compare crystalline qualities of the SAG-GaN grown by MOVPE with the growth

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time of 120 min, we measured CL spectra at 133 K for the area of 10 μm × 10 μm on the surface,

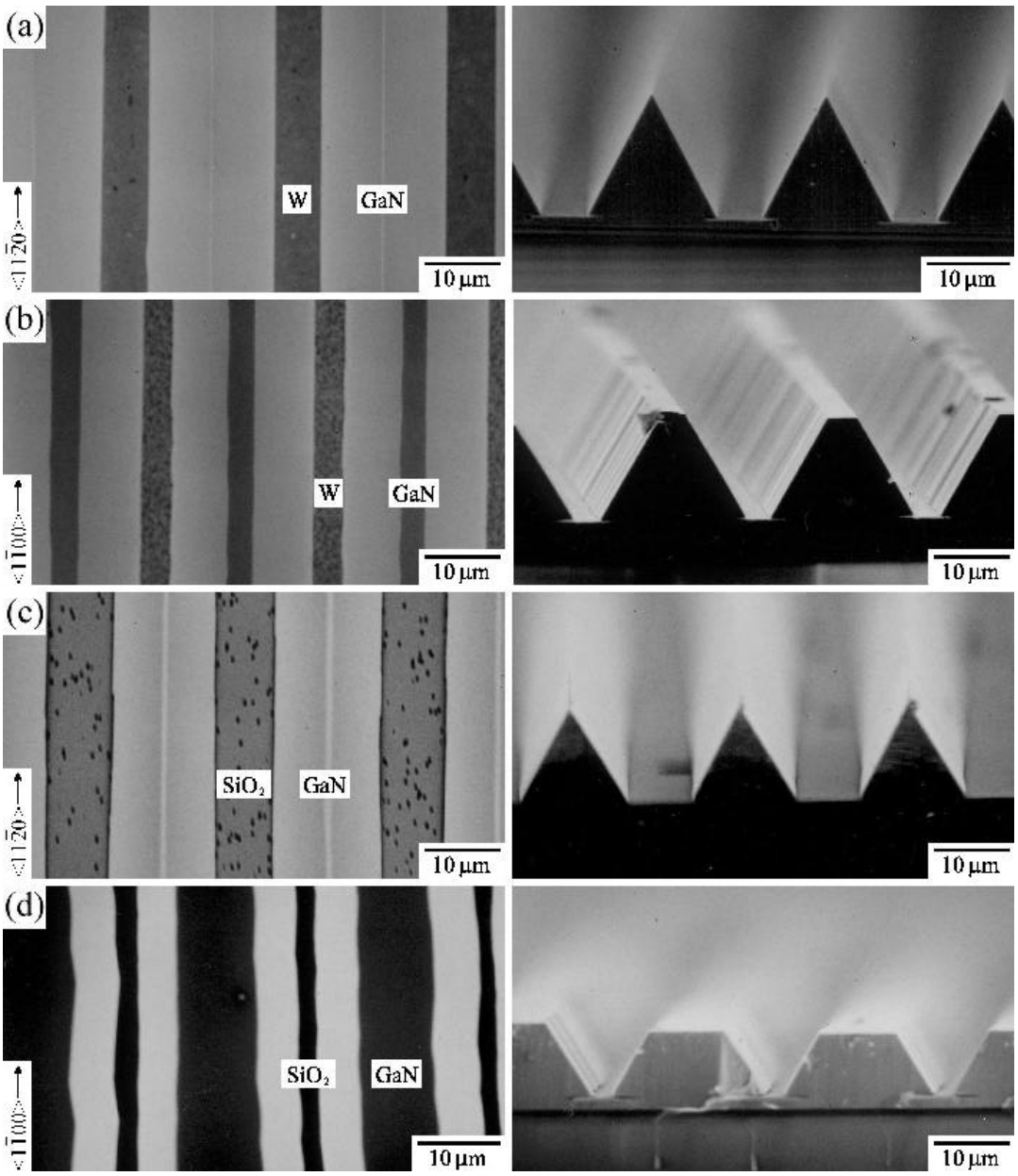

Fig. 2 SEM images of the SAG-GaN by MOVPE with the growth time of 120 min. The SAG was carried out using the W mask along (a) the $<11\bar{2}0>$ axis and (b) the $<1\bar{1}00>$ axis, and using the SiO_2 mask along (c) the $<11\bar{2}0>$ axis and (d) the $<1\bar{1}00>$ axis.

which schematically shows in Fig. 3. Figure 4 shows the CL spectra by the SAG-GaN using the W mask along (a) the $<11\bar{2}0>$ axis and (b) the $<1\bar{1}00>$ axis, and using the SiO_2 mask along (c) the $<11\bar{2}0>$ axis and (d) the $<1\bar{1}00>$ axis, and (e) high quality GaN underlying layer for the SAG. Near-band-edge emission peak is observed in every SAG-GaN sample, however, which shows red-shift about 25 meV as compared to the result shown in a GaN thin layer. The GaN layer grown on the sapphire substrate is given a compressive strain, while the SAG-GaN is relaxed this strain and then the peak energy shifted low energy side. It is still to be studied how the strain is effective SAG-GaN. Full-width at half-maximum on CL spectra by SAG-GaN are

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about 60 meV and these value are equal to that obtained in the GaN layer. This suggests that the crystalline qualities of GaN obtained by the SAG is excellent.

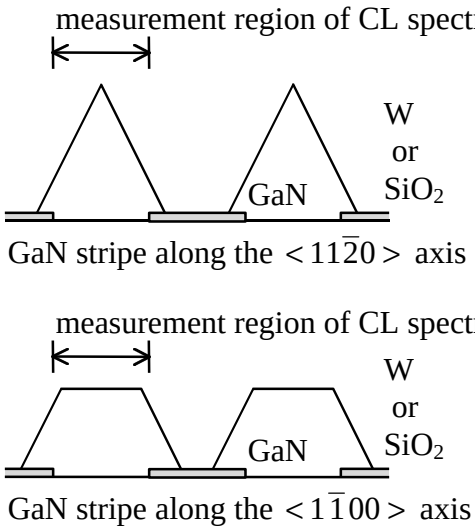

Fig. 3 Schematic diagrams of CL measurements. CL spectra measured from the GaN stripe region of 10 μm × 10 μm on the surface.

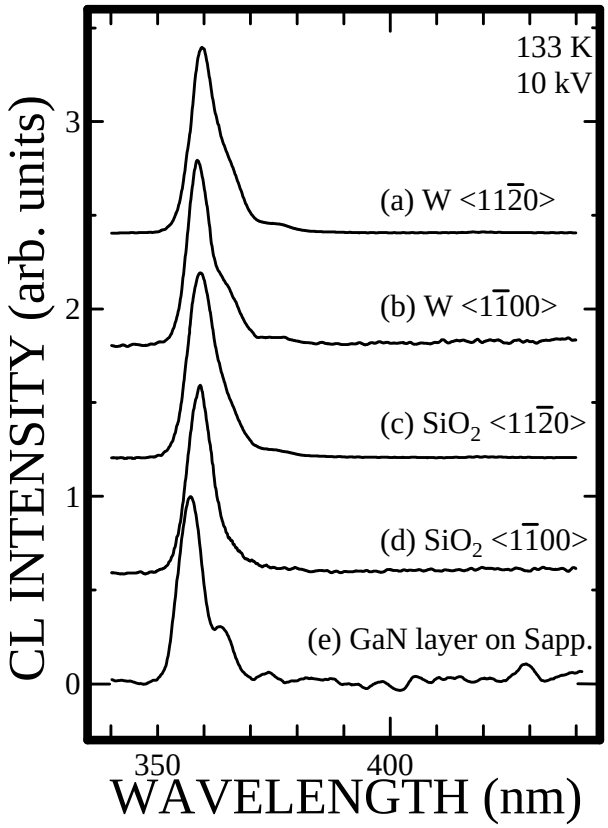

Fig. 4 CL spectra at 133 K from the GaN stripe obtained by the MOVPE-SAG using the W mask along (a) the <11$\bar{2}$0> axis and (b) the <1$\bar{1}$00> axis, and using the SiO_2 mask along (c) the <11$\bar{2}$0> axis and (d) the <1$\bar{1}$00> axis, and (e) high quality GaN underlying layer for the SAG.

CONCLUSIONS

The SAG/ELO of GaN using W mask by MOVPE and HVPE was studied. In both growth methods, GaN polycrystals were observed neither on the W mask region nor on the SiO_2 mask region. In the case of HVPE, the overgrown GaN region became wider, coalesced and finally formed continuous, flat and specular surface. Triangular voids were formed on the W masks due to reverse-mesa formation during the initial overgrowth stage. In the case of MOVPE, we obtained triangular cross-sectional shapes with {1$\bar{1}$01} facets at both sides for the W and SiO_2 masks along the <11$\bar{2}$0> crystal axis, while the trapezoidal cross-sectional shapes with smooth (0001) surface on the top and rough surfaces on both sides along the <1$\bar{1}$00> crystal axis. The lateral overgrown rate on the W mask was higher than that on the SiO_2 mask There were no voids between the W or SiO_2 mask and the overgrown GaN layer by using MOVPE.

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