Fabrication of GaN with Buried Tungsten (W) Structures Using Epitaxial Lateral Overgrowth (ELO) via LP-MOVPE

Hideto Miyake[1], **Motoo Yamaguchi**[1], **Masahiro Haino**[1], **Atsushi Motogaito**[1], **Kazumasa Hiramatsu**[1], **Shingo Nambu**[2], **Yasutoshi Kawaguchi**[2], **Nobuhiko Sawaki**[2], **Yasushi Iyechika**[3], **Takayoshi Maeda**[3] **and Isamu Akasaki**[4]
[1]Dept. of Electrical and Electronic Engineering, Mie University, 1515 Kamihama, Tsu, Mie, 514-8507, Japan
[2]Dept. of Electronic Engineering, Nagoya University, Furo, Chikusa, Nagoya, 464-8603
[3]Tsukuba Research Laboratory, Sumitomo Chemical Co., Ltd, 6 Kitahara, Tsukuba, 300-3294, Japan
[4]Dept. of Electrical and Electronic Engineering, Meijo University, 1-501 Shiogamaguchi, Tempaku, Nogoya 468-8502, Japan

ABSTRACT

A buried tungsten (W) mask structure with GaN is successfully obtained by epitaxial lateral overgrowth (ELO) technique via low-pressure metalorganic vapor phase epitaxy (LP-MOVPE). The selectivity of GaN growth on the window region vs. the mask region is good. An underlying GaN with a striped W metal mask is easily decomposed above 500 °C by the W catalytic effect, by which radical hydrogen is reacted with GaN. It is difficult to bury the W mask because severe damage occurs in the GaN epilayer under the mask. It is found that an underlying AlGaN/GaN layer with a narrow W stripe mask width (mask/window = 2/2 μm) leads the ELO GaN layer to be free from damage, resulting in an excellent W-buried structure.

INTRODUCTION

The group III-nitride semiconductors are promising materials for applications in opto-electronic devices such as light emitting diodes and laser diodes [1], and in field effect transistors[2]. Although these devices are fabricated mainly on sapphire substrate, it is not easy to achieve a high performance because of a high dislocation density in the crystal originating from the large differences in lattice constants between GaN and sapphire. An attempt to reduce the dislocation density of crystal using epitaxial lateral overgrowth (ELO) technique was employed in GaAs[3]. Recently, Usui *et al*. achieved a thick GaN epitaxial layer with a dislocation density as low as 10^7cm^{-2} using ELO by hydride vapor phase epitaxy (HVPE) [4].

SiO_2 or SiN_x insulator has been normally used as the mask material for ELO-GaN. Besides those materials, ELO-GaN with tungsten (W) metal mask was investigated to fabricate optical and electronic devices with higher performance. It was reported that the ELO-GaN layers are successfully obtained with the W mask as well as SiO_2 or SiN_x masks via HVPE and have a better crystalline quality than that with SiO_2 mask[5].

https://doi.org/10.1557/S1092578300004087

In the ELO of GaAs, the W metal mask was employed and the W-buried structure was obtained to fabricate a permeable base transistor (PBT) or static induction transistor (SIT) [6]. The fabrication of the electronic devices such as PBTs or SITs via the ELO technique in GaN is very attractive for the use as high power and/or high frequency devices under crucial environments such as at high temperature or at highly radioactive environment. Recently, Kawaguchi *et al*. performed the selective area growth (SAG) of GaN using the W mask by metalorganic vapor phase epitaxy (MOVPE) and achieved high selectivity[7].

In this work, we demonstrate the ELO of GaN using the W mask by MOVPE and obtain the W-buried structure with GaN. The characteristics of ELO-GaN were also investigated by means of atomic force microscopy (AFM) and x-ray rocking curve (XRC).

EXPERIMENTAL PROCEDURE

MOVPE of GaN using a W mask was performed on two types of samples. The sample is a 4.0 µm-thick (0001) GaN epilayer, which had been grown on sapphire (0001) substrate using an GaN low temperature buffer layer by MOVPE. Another sample is a 40-100 nm thick AlGaN epilayer on the 4.0 µm-thick (0001) GaN epilayer. The 30 - 50 nm thick W mask was deposited by electron beam evaporation method. Stripe windows of 2 or 5 µm width with a periodicity of 4 or 10 µm, respectively, were developed in the <1$\bar{1}$00> direction of the GaN by conventional photolithographic method and then wet etching with a hydrogen peroxide (H_2O_2) and an ammonia solution. The source gases were trimethylgallium (TMG) and ammonia (NH_3), respectively. Hydrogen gas was used as a carrier gas during the growth process. ELO of GaN was performed by LP (low pressure) - MOVPE system with a horizontal reactor. Two steps ELO technique was carried out to bury W mask completely. In the first step, a low temperature (950^{o}C) growth was performed for 30 min to prevent the underlying GaN from being decomposed. In the second step, a high temperature (1050^{o}C) growth was done for 90 min to bury W mask. Here, it is expected in both steps that the GaN with {11$\bar{2}$2} facets are grown selectively in the first step and that the W mask is easily covered with GaN because of the fast ELO rate at a higher growth temperature in the second step, based on the results of ELO-GaN using SiO_2 mask[8].

RESULTS AND DISCUSSION

In order to investigate effects of the W mask which affects the underlying GaN and AlGaN layers in hydrogen ambient at a high temperature, we attempted thermal annealing at 500 to 700 ^{o}C of GaN and AlGaN with a striped W mask. Consequently, the surface of GaN window regions was roughened, including Ga droplets and GaN whiskers. This phenomenon occurred above 500^{o}C. It is reported that an underlying GaN layer with a striped SiO_2 mask is decomposed higher than 900 ^{o}C in hydrogen ambient and there is no damage less than 900 ^{o}C[9]. Therefore, the W mask works as a catalyst to enhance decomposition of GaN. It is thought that W may produce radical hydrogen that can decompose GaN easily. On the other hand, the surface of AlGaN is not roughened even though the annealing temperature is 700^{o}C. Any Ga droplets and GaN whiskers are not observed on the AlGaN layer. Hence, the catalytic effect of the W mask does not work in the AlGaN layer. Thus, it is found that the top AlGaN layer plays an important role to protect the bottom GaN from decomposition.

The ELO was performed using the W mask with stripe windows of 5 μm width. Figure 1 shows the cross sectional SEM images of ELO GaN with the underlying GaN (a) and AlGaN/GaN (b). About 5 μm-thick ELO GaN layers are obtained in both cases.

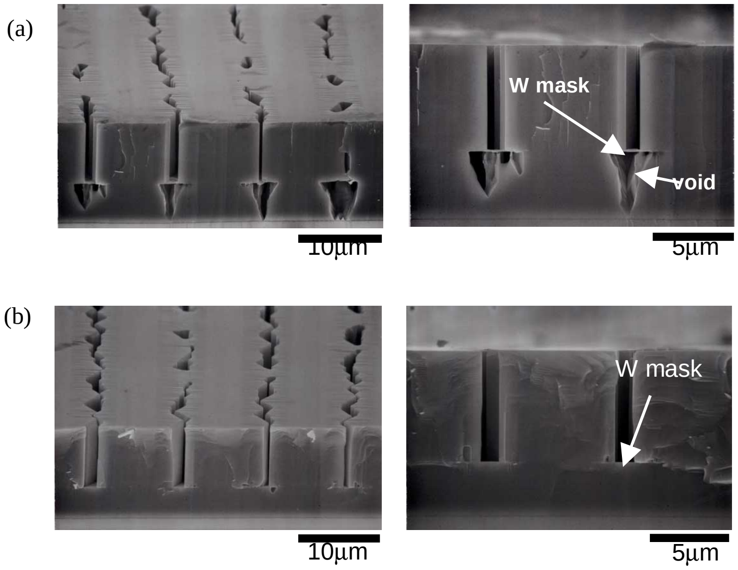

Figure 1 *The cross sectional SEM photographs of ELO GaN with underlying GaN (a) and AlGaN (b). The width of stripe window is 5 μm.*

Large voids occurs under the W mask as seen in Fig.1(a), indicating that the underlying GaN is decomposed during the ELO process owing the catalytic effect of the W mask. On the contrary, there are no voids in Fig.1(b). Therefore, the underlying AlGaN layer can prevent the bottom GaN from being decomposed.

The W masks are not buried completely after the growth process in the case of the 5 μm wide mask. The width of stripe was narrowed to bury the W mask completely. Figure 2 shows the cross sectional SEM images of ELO GaN with the underlying AlGaN/GaN layer. The widths of mask and window are 2 μm and 2 μm, respectively. This result clearly shows that the W mask is buried completely and the surface is smooth.

To characterize the surface morphology and the tilting of c-axis of the ELO GaN, we carried out x-ray diffraction and atomic force microscope (AFM). Figure 3 shows the results of AFM for the sample of Fig. 2. In this figure, atomic step structures with 0.1 μm-width and 0.3 nm-height are observed. This means that the step flow growth occurs in the ELO of the GaN layer. Figure 4 shows the XRCs of the (0004) reflection for $\phi = 0\,^{o}$ and $90\,^{o}$ of the ELO GaN layer with the stripe directions of the masks along the direction of $<1\bar{1}00>$, where ϕ is the azimuth angle between the stripe direction of the mask and the scattering plane. The full width of half maximum (FWHM) is about 230 arcsec for each ϕ. There are no satellite peaks near the main peak, which suggests no tilting of c-axis. Thus, it is found that the ELO GaN with the W mask has high crystalline quality as well as a good surface morphology.

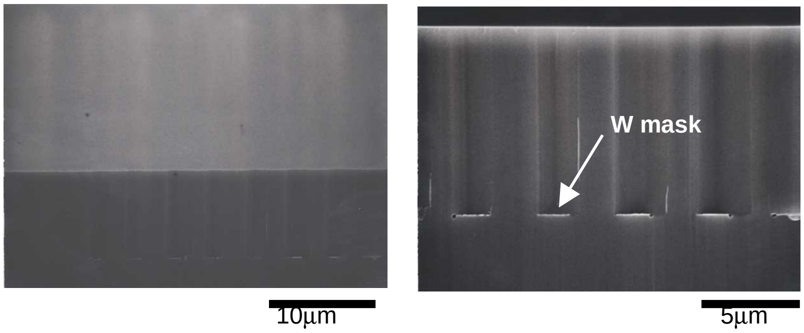

Figure 2 *The cross sectional SEM photographs of ELO GaN with underlying AlGaN. The width of stripe window is 2 μm.*

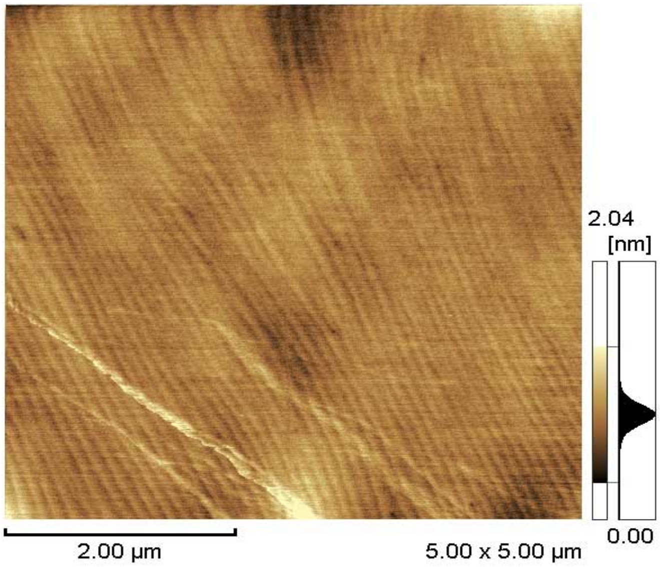

Figure 3 *The results of AFM for the sample of Fig.2.*

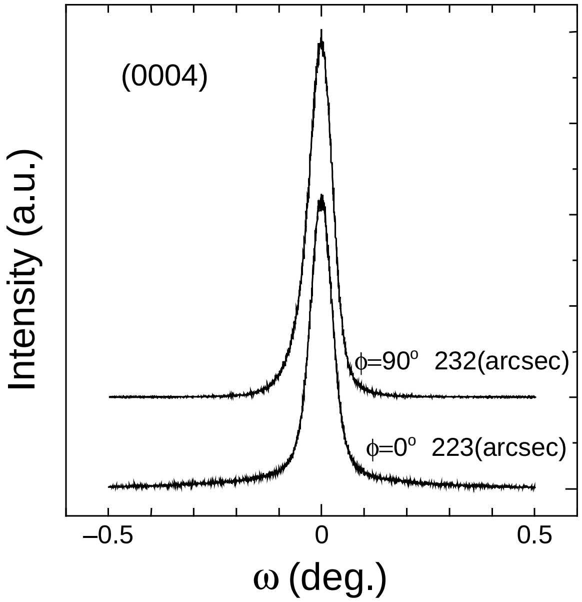

Figure 4 *The XRCs of the (0004) reflection of the sample of Fig.2.*

https://doi.org/10.1557/S1092578300004087

CONCLUSION

The two step ELO of GaN using W mask was performed by LP- MOVPE. GaN with a striped W metal pattern is easily decomposed above 500 °C by the W catalytic effect that causes radical hydrogen to attack the GaN layer. It is difficult to bury the W mask because severe damage occurs in the GaN epilayer under the mask. By employing the AlGaN/GaN underlying layer with the narrow W stripe mask of 2 µm, the excellent W-buried structure can be obtained free from damage.

ACKNOWLEDGEMENTS

This work was partly supported by "Research for the Future" program of Atomic Scale and Interface Dynamics of JSPS, "Light of the 21st Century" program of NEDO, the Proposed-Based R&D Program of NEDO (97S02-015) and Grant-in-Aid for Scientific Research from the Ministry of Education, Science, Sports and Culture (No.11450012).

REFERENCES

1 S. Nakamura, M. Senoh, S. Nagahama, N. Iwasa, T. Yamada, T. Matsushita, H. Kiyoku, Y. Sugimoto, T. Kozaki, H. Umemoto, M. Sano and K. Chocho, *Jpn. J. Appl. Lett.* **36** (1997) L1568.
2 R. Vetury, H. Marchand, G. Parish, P. T. Fini, J. P. Ibbetson, S. Keller, J. S. Speck, S. P. DenBaars and U. K. Mishra, *Inst. Phys. Conf. Ser.* No. 162: Chapter5 (1999) 177.
3 Y. Ujiie and T. Nishinaga, *Jpn. J. Appl. Phys.* **28** (1989) L327.
4 A. Usui, H. Sunakawa, A. Sakai and A. Yamaguchi, *Jpn. J. Appl. Phys.* **36** (1997) L899.
5 H. Sone, S. Nambu, Y. Kawaguchi, M. Yamaguchi, H. Miyake, K. Hiramatsu, Y. Iyechika, T. Maeda and N. Sawaki, *Jpn. J. Appl. Phys.* **38** (1999) L356.
6 H. Asai, S. Adachi, S. Ando and K. Oe, *J. Appl. Phys.* **55** (1984) 3868
7 Y. Kawaguchi, S. Nambu, H. Sone, M. Yamaguchi, H. Miyake, K. Hiramatsu, and N. Sawaki, *Jpn. J. Appl. Phys.* **37** (1998) L845.
8 H. Miyake, A. Motogaito and K. Hiramatsu, *Jpn. J. Appl. Phys.* **38** (1999) L1000.
9 K. Hiramatsu, H. Matsushima, H. Hanai and N. Sawaki : *Mat. Res. Soc. Symp. Proc.* **482** (1998) 991.