Reduction of Dislocation Density in GaN by Facet Controlled ELO

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Epitaxial lateral overgrowth (ELO) with selective area growth (SAG) via metalorganic vapor phase epitaxy (MOVPE) and hydride vapor phase epitaxy (HVPE) are promising techniques to obtain a high-quality epitaxial GaN layer with low threading dislocation density. Usui et al. are performed the ELO by HVPE and achieved a low dislocation density of the order of 10^7 cm^{-2} in a thick GaN [1]. And Sakai et al. are reported the dislocation bending caused by the facet places in ELO, so that the dislocation density is reduced [2].

Recently, it was found that two-step ELO growth of GaN is a useful technique to improve crystalline quality of the ELO GaN through the facet control [3, 4]. Hereafter, we call this technique FACELO (Facet Controlled ELO). It is based on the control of GaN structures by changing growth conditions during the ELO process [5].

In this paper, the typical two kinds of FACELO techniques of GaN are demonstrated via LP-MOVPE and the distribution of the threading dislocations are investigated by the growth pit density (GPD) method [6]. In order to reduce the dislocation density further, double FACELO was employed.

The ELO of GaN via an LP-MOVPE system using a horizontal reactor was performed on a 4.0 μm thick (0001) GaN layer which had been prepared on a (0001) sapphire substrate with a low-temperature GaN buffer layer. After the deposition of a 80 nm thick SiO_2 film by RF sputtering on the underlying GaN, stripe patterns along <1$\bar{1}$00> direction of GaN were fabricated by a conventional photolithographic method. TMG and NH_3 were used as the source gases, and H_2 was used as the carrier gas. The typical flow rates of TMG and NH_3 were 46 μmol/min and 1.0 - 1.5 slm, respectively. For control of the facet structure in ELO process, the growth temperature and the reactor pressure were varied from 950 to 1070°C and from 80 to 500 Torr, respectively. In order to characterize distribution and density of the threading dislocations, InGaN of 50 nm thickness was grown on the surface.

Fig. 1 shows two typical models of FACELO which includes two-step ELO processes with different growth conditions. In the Model A, the first step ELO has vertical facets of {11$\bar{2}$0}, and then in the second step ELO the lateral growth rate is increased by changing the growth conditions, and hence consequently the SiO_2 mask is buried easily. The dislocations penetrate the ELO layer and come up to the surface, so they exist only on the window area, as seen in Fig. 5. On the other hand, in the Model B, the first step ELO has inclined facets of {11$\bar{2}$2}, and then in the second step ELO the lateral growth rate is increased by changing the growth conditions. In this case, the threading dislocations bend towards the mask area during the ELO process, since the fronts of the dislocations terminate on the inclined {11$\bar{2}$2} facets. Therefore, some dislocations may disappear in the coalescence region because of interaction between the dislocations and others come up to the surface. In this way, the dislocation density on the window area is reduced.

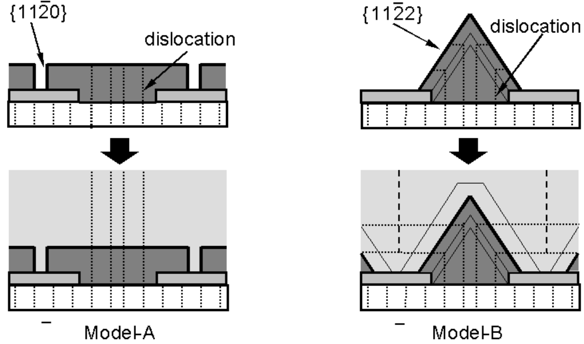

Fig.1. Growth Models of FACELO (Facet Controlled ELO). Two different types of models, A and B, are shown.

The FACELO of GaN for the Model A and B were performed via LP-MOVPE. Fig. 2 shows SEM images of the GaN layer grown by means of the Model A FACELO. In order to observe the threading dislocations, the InGaN thin layer was grown on the FACELO GaN. Pits appearing on the InGaN surface correspond to the threading dislocations. The dislocation density is relatively high on the window area and very low on the mask area. Fig. 3 shows SEM images of the GaN layer grown by the Model B FACELO, where an InGaN thin layer was also grown on the FACELO GaN. The dislocations are observed only in straight lines above the center of the masks, where is attributed to the coalescence of ELO. The dislocation density is dramatically reduced in the wide area including both mask and window areas, compared with the Model A. The distribution of the dislocation is quite similar to the predicted Model B in Fig. 1

In order to reduce the dislocation density further, the double FACELO is demonstrated. Fig. 4 shows SEM images of surface and cross-section of the double FACELO. The first FACELO with stripe SiO_2 masks along $\langle 1\bar{1}00\rangle$ direction was performed by the 2-step process of the Model B, and then the second FACELO with stripe SiO_2 masks along $\langle 10\bar{1}0\rangle$ direction was also performed by the same growth process. The estimated GPD is $2\text{-}10\times10^{6}$ cm^{-2} depending on the position of the surface, indicating remarkable reduction with good reproducibly.

References

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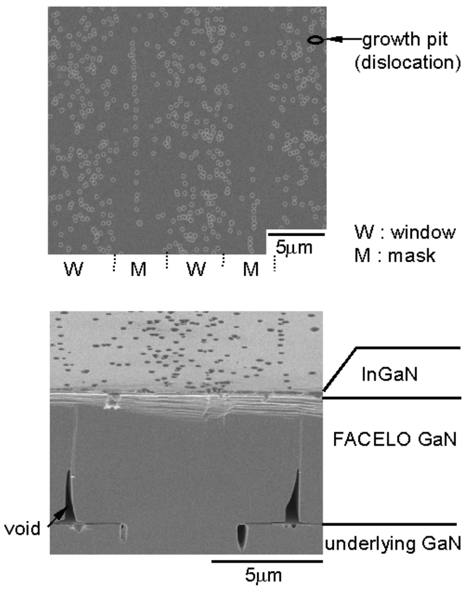

Fig.2. SEM images of FACELO using the Model A. (80 Torr, 1000°C, 30min + 500 Torr, 1050°C, 90min).

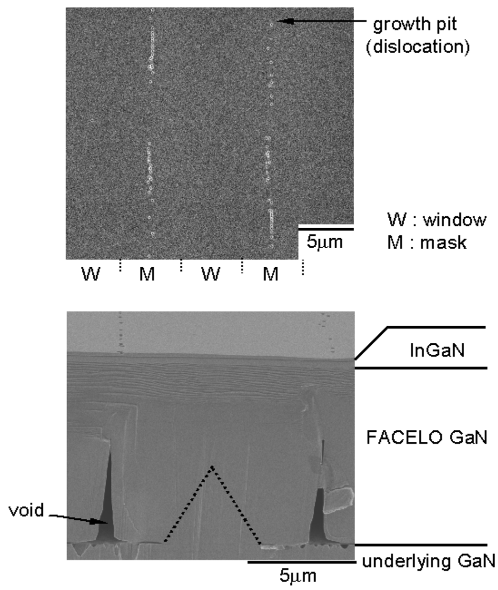

Fig.3. SEM images of FACELO using the Model B. (500 Torr, 950°C, 45min + 500 Torr, 1050°C, 105min).

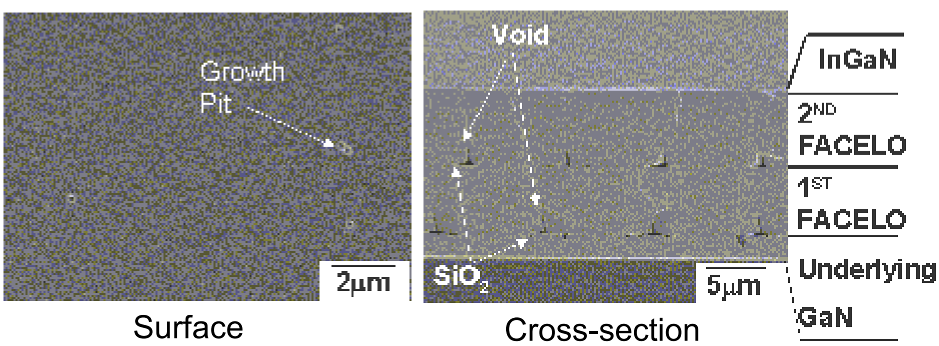

Fig.4. SEM images of double FACELO GaN. Each FACELO was performed at 500 Torr, 950°C, 45min + 500 Torr, 1050°C, 105min.