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In-Situ STM Observation of GaAs Surfaces after Nitridation

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Abstract

Scanning tunneling microscopy is used to study (001), (111)B and (111)A GaAs surfaces after nitridation. For the (001) surface, 3-nm-wide stripes are observed along [110]. A smooth surface densely covered with small GaN grains is observed for (111)A, while large GaN grains with some voids are observed for (111)B. The root-mean-square roughness of the surface after nitridation is determined to be 0.21 nm for (111)A, 0.26 nm for (001), and 0.38 nm for (111)B. These results suggest that the (111)A surface is promising for the growth of GaN on GaAs. The surface roughness of GaAs after nitridation was found to have a major effect on the selectivity of GaAs growth.

1. Introduction

Recently, GaN-based III-V semiconductors have been developed for their applications to blue-light-emitting devices[1,2]. A thin GaN film on GaAs can also be used as an *in-situ* mask layer for GaAs selective growth[3]. Because GaN substrates are not widely available, GaN-based devices must be grown on other kinds of substrates such as GaAs substrates. These substrates have advantages in that they can be easily cleaved and the GaN can be deposited on a high-quality homoepitaxially grown GaAs surface with few impurities and defects. It is difficult, however, to grow GaN on GaAs due to the large lattice mismatch of about 20 %. Therefore, the initial stage of nitridation of GaAs substrates must be studied to obtain two-dimensional nucleation. In this conference, we report the *in-situ* scanning tunneling microscopy (STM) and reflection high-energy electron diffraction (RHEED) observation of (001), (111)A, and (111)B GaAs surfaces after nitridation. We also show the characteristics of the GaAs selective growth on these nitrided GaAs surfaces as a mask layer.

2. Experiment

In this experiment, we used a metal organic molecular beam epitaxy (MOMBE) growth chamber combined with an STM chamber[4]. For the nitridation of the GaAs surface, the nitrogen molecules (N_2) were supplied on GaAs substrates through a hot W filament[5,6]. The background As pressure was below $1x10^{-8}$ Torr. The substrate temperature during nitridation, the W filament temperature and N_2 pressure are 450 °C, 2100 °C and $4x10^{-5}$ Torr, respectively. The GaN thickness is estimated to be about 7 monolayers (ML). Trimethylgallium (TMG) and tertiarybutylarsine (TBAs) were used to grow GaAs layers. The substrate temperature and the growth rate were 550 °C and 1.1 Å/sec.

3. Results and discussion

First, we observed RHEED pattern changes before and after nitridation. Before nitridation at 450 °C, the surface reconstructions of (001), (111)A, and (111)B showed (2 x 4), (2 x 2), and ($\sqrt{19}$ x $\sqrt{19}$), respectively. After nitridation of a (001) GaAs surface, the [110] RHEED pattern showed the lattice spacing of GaN, while a streaky pattern having the spacing of a GaAs lattice was observed at the [$\bar{1}$10] azimuth as reported before[5]. In contrast to the (001) surface, streaky patterns having the spacing of a GaN lattice were observed at both [10$\bar{1}$] and [1$\bar{2}$1] azimuths for (111)A and (111)B surfaces. After the RHEED observation, the substrate was transferred to the STM chamber. Figures 1 (a), 1 (b), and 1 (c) show the STM images of (001), (111)A, and (111)B GaAs surfaces after nitridation. The scan area and vertical scale are 100 nm x 100 nm and 1.15 nm, respectively. For (001), the 3-nm-wide stripes were observed along [110], which was also observed in cross-sectional transmission electron microscopy (TEM) images for the GaAs/GaN/GaAs structure. Similar but wider [110] stripes have been reported after the growth of GaN on (001) GaAs by MOVPE[7]. A smooth surface densely covered with small GaN grains was observed for (111)A, while large GaN grains with some voids were observed for (111)B. The root-mean-square roughness of the surface after nitridation was determined to be 0.21 nm for (111)A, 0.26 nm for (001), and 0.38 nm for (111)B. These results suggest that the (111)A surface is promising for the growth of GaN on GaAs. They also support the reported experimental results[8,9].

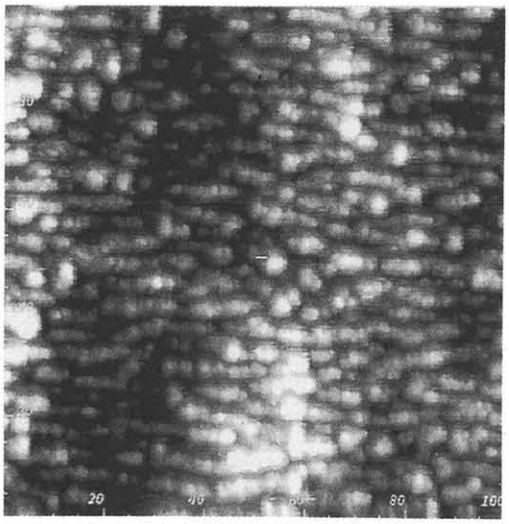
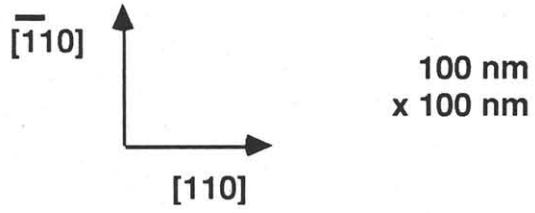


Fig. 1 (a).
STM image of (001) GaAs surface after nitridation. The 3-nm-wide stripes were observed along [110].



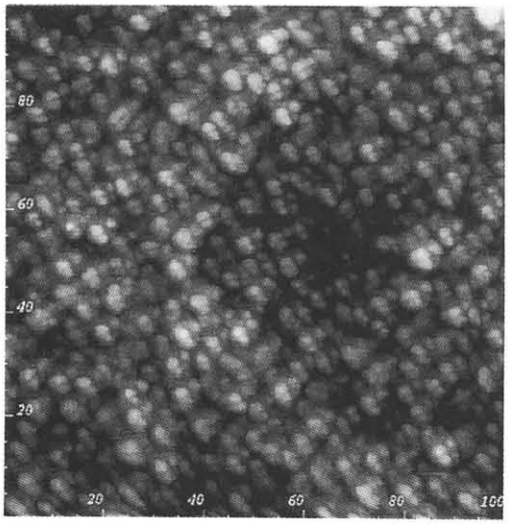
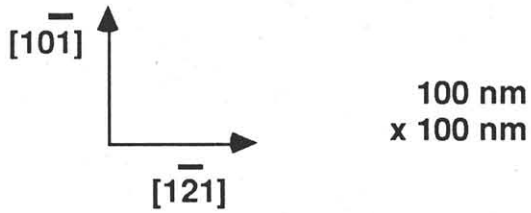


Fig. 1 (b).
STM image of (111)A GaAs surface after nitridation. A relatively smooth surface with small GaN grains was observed.



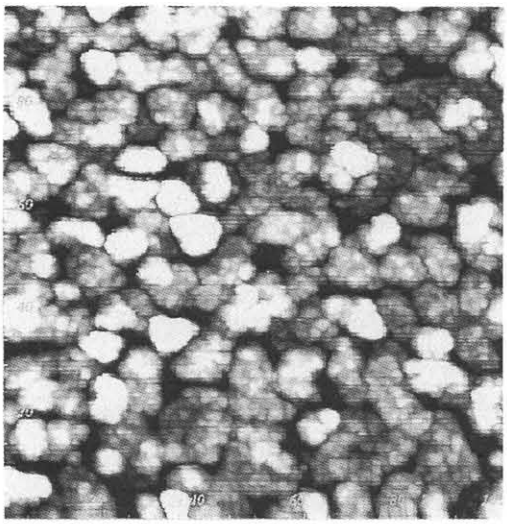
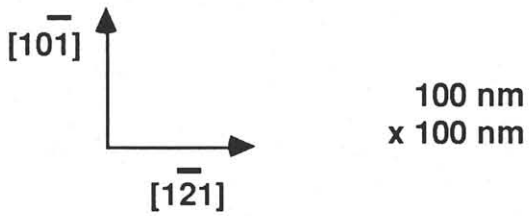


Fig. 1 (c).
STM image of (111)B GaAs surface after nitridation. Large GaN grains with some voids were observed.



Next, we supplied TMG and TBAs on the surfaces after nitridation to check their selectivity by using the RHEED pattern change. The substrate temperature was 550 °C. Figure 2 shows the RHEED pattern change as a function of the time for supplying TMG and TBAs. The RHEED pattern was observed every 15 sec. As the GaAs deposited on the surfaces, the RHEED pattern changed from those of GaN to those of GaAs. For (111)B, a mixed GaAs and GaN RHEED pattern was observed after 15-sec supply, and the GaN pattern disappeared after 30 sec. In contrast, the RHEED pattern for (111)A retained GaN streak for 45 sec. These results suggest that the surface roughness of the GaAs surfaces after nitridation has a major effect on the selectivity.

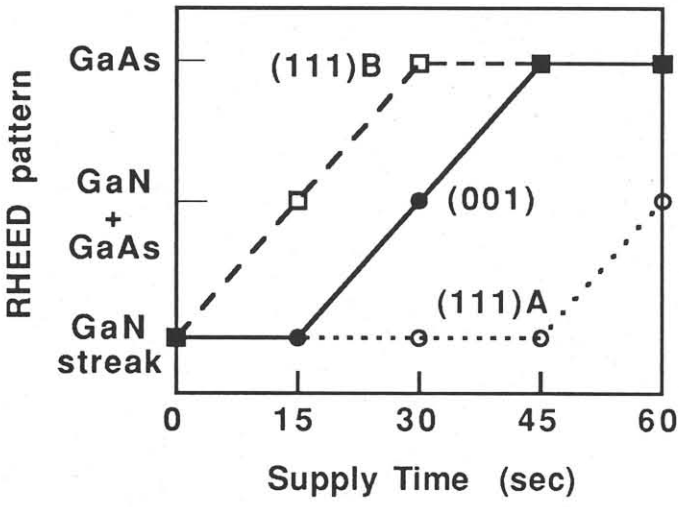


Fig. 2.
RHEED pattern change as a function of the time for supplying TMG and TBAs. For (111)B, a mixed GaAs and GaN RHEED pattern was observed after 15-sec supply, and the GaN pattern disappeared after 30 sec. In contrast, the RHEED pattern for (111)A retained GaN streak for 45 sec.

4. Conclusion

(001), (111)B and (111)A GaAs surfaces after nitridation is characterized using STM. For the (001) surface, the 3-nm-wide stripes are observed along [110]. A smooth surface densely covered with small GaN grains is observed for (111)A, while large GaN grains with some voids are observed for (111)B. The root mean square roughness of the surface after nitridation is determined to be 0.21 nm for (111)A, 0.26 nm for (001), and 0.38 nm for (111)B. These results suggest that the (111)A surface is promising for the growth of GaN on GaAs. The surface roughness of GaAs after nitridation was found to have a major effect on the selectivity of GaAs growth.

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