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Growth of AlGaN/GaN Quantum Wire Structures by RF-Radical Assisted Selective MBE on Pre-Patterned Substrates

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1. Introduction

In addition to blue/UV photonic and high-power electronic device applications, the AlGaN/GaN system is potentially suitable for high temperature operating quantum devices. This is due to wide energy gaps with a large ΔE_c and to availability of high density 2DEG even under non-doped conditions which avoids the doping fluctuation problem. Here, a key question is how to form the AlGaN/GaN based nanostructures in size- and position-controlled fashion. We have shown that the selective MBE growth on a pre-patterned substrate is a very powerful approach for formation of GaAs- and InP-based high density quantum nanostructures[1,2].

The purpose of this paper to investigate the basic behavior and feasibility of selective MBE growth of AlGaN/GaN quantum wire (QWR) structures on pre-patterned substrates for the first time.

2. Experimental

First, conditions for rf-radical assisted MBE growth of GaN and AlGaN were optimized, using planar (0001) GaN/sapphire substrates grown by MOVPE. Nitrogen was supplied by an rf radical source exited with a microwave power of 350W. As templates for selective growth, straight mesa stripes shown in **Fig. 1(a)** were formed by etching on (0001) GaN/ sapphire substrates. As the mesa orientation, <1-100>-and <11-20>-directions were compared. Since wet chemical etching is difficult for nitrides, etching was carried out by an electron cyclotron resonance reactive ion beam etching (ECR-RIBE) process developed for nitrides by our group [3]. It uses a methane-based gas mixture of $CH_4/H_2/Ar/N_2$ = 5/15/3/3 sccm where addition of N_2 is extremely important.

Prior to MBE growth, organic cleaning and HF treatment were applied in the atmosphere. Then, thermal cleaning under N_2 radical pressure was carried out in the MBE chamber just before the growth. Selective growth of GaN-based QWR structures was attempted by supplying materials for planar growth of an $Al_{0.24}Ga_{0.76}N$/ GaN/ $Al_{0.24}Ga_{0.76}N$ sandwiched layer shown in **Fig. 1(b)** onto the mesa-patterned substrate.

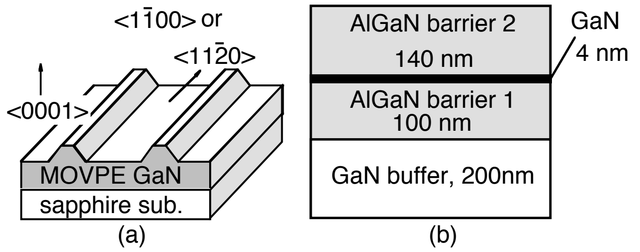

Fig.1 (a) Patterned substrate and (b) material supply used in this study for GaN/AlGaN quantum structures.

3. Results and Discussion

1)Optimization of MBE growth conditions

RHEED observation indicated that well-defined (2x2) streak patterns are observed and maintained during growth of both GaN and AlGaN layers by setting the substrate temperature, T_{sub}, at 800ºC with a growth rate around 150nm/hour.

Figure 2 shows the results of XRD measurements on the AlGaN layers grown at different supply rate of Al atom. Here, Ga source temperature, T_{Ga}, was fixed at 940ºC. Use of Vegard's law indicated that the Al composition of $Al_xGa_{1-x}N$ layers could be changed from x = 0.24 to 0.43 by changing Al source temperature, T_{Al}, while the total growth rate of AlGaN layer did not change. This rather surprising result can be explained in terms of the group-V limited growth mode where Ga incorporation rate is reduced with increase of Al atom supply in competition with the higher incorporation rate of Al adatom.

A minimum FWHM value of the XRD peak of 300 sec was obtained for both GaN and $Al_{0.24}Ga_{0.76}N$ layers grown at T_{Ga}=940°C and T_{Al}=980°C, respectively. This value was equal to or even smaller than that of the MOVPE GaN template used in this study.

2)Characterization of growth selectivity

Our ECR-RIBE etching process produced well defined crystalline facets as sidewalls of the mesa stripe.

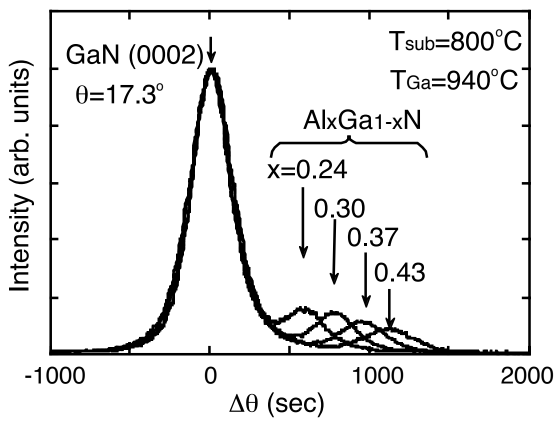

Fig.2 XRD spectra obtained from $Al_xGa_{1-x}N$ layers grown by rf-radical assisted MBE.

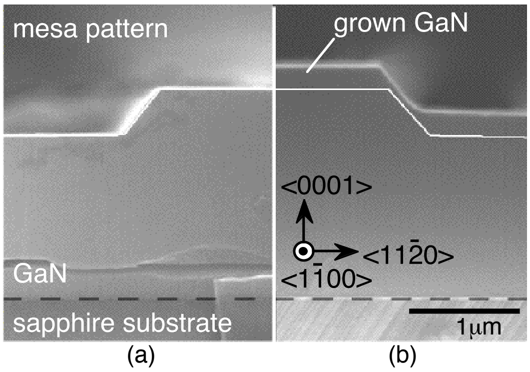

Fig.3 Cross-sections of (a) the <1100>-oriented mesa-patterned substrate and (b) the sample after growth.

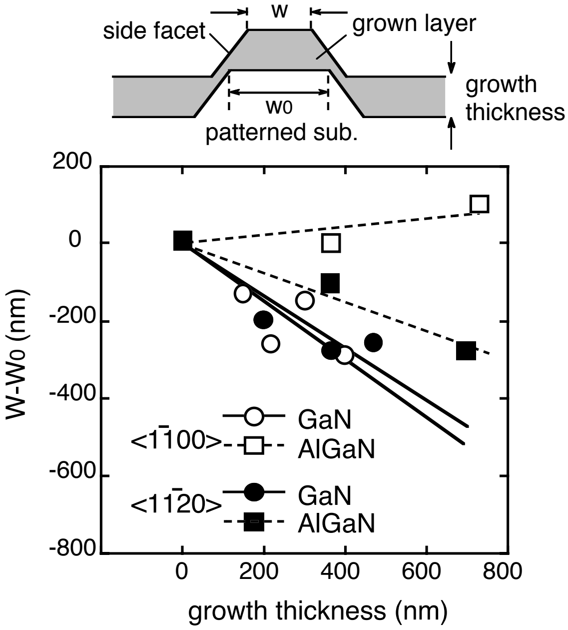

Fig.4 Plot of the top width of mesa vs. growth thickness.

Characterization of growth selectivity is vitally important for feasibility of the selective growth. Cross-sectional SEM images of a <1-100>-oriented GaN mesa stripe before and after MBE growth of a GaN layer are shown in **Fig.3 (a)** and **(b)**, respectively. The dry etching process produced a flat and smooth side facet with an angle about 60^o with respect to a (0001) mesa top. During growth, the side facet was maintained, as seen in **Fig. 3(b)**, but the top width of the mesa stripe changed.

Figure 4 plots the difference between the initial top width of mesa, W_0, and the top width of mesa after the growth, W, as a function of the grown thickness for two cases of growth on <1-100>-oriented mesa stripes and on <11-20>-orientated mesa stripes. In the case of the growth of GaN layer, the top width, W, decreased with the grown thickness in both mesa orientations. This indicates that the growth rate of GaN on the mesa top is much larger than that on the side facet. This is very similar to growth on GaAs (001) and (111)B patterned substrates [2].

Similarly, the mesa top width decreased with the grown thickness for growth of AlGaN on <11-20>-oriented GaN

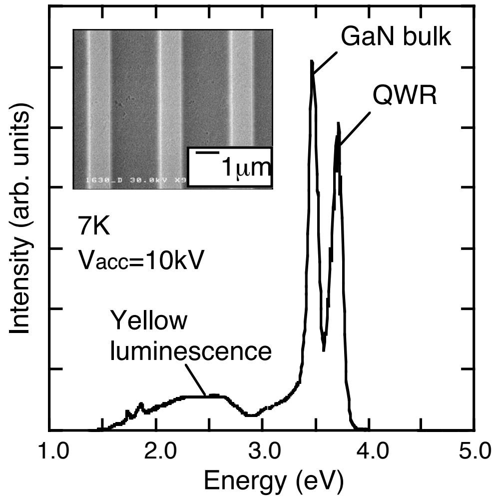

Fig.5 CL spectra obtained from the sample after growth of GaN/AlGaN layer on <11-20>-oriented mesa.

stripes. However, in the case of growth of AlGaN on <1-100>-oriented GaN stripes, the top width of mesa increased with the AlGaN supply thickness. The present results indicate that, reflecting complex growth kinetics involving reaction and diffusion, incorporation rates of III-group adatoms are different depending on the adatom species, crystalline facets and the growth conditions.

3) Selective growth of QWR structures

Based on the above growth selectivity measurements, selective growth of AlGaN/GaN QWR structure arrays was attempted on the <11-20>-oriented mesa substrates, using the material supply shown in **Fig. 1(b)**. After the growth of AlGaN/GaN/AlGaN sandwiched layer, the top width of the mesa reduced as expected, maintaining smooth surface morphology, as seen in the inset of **Fig. 5**. The QWR width was in excellent agreement with that calculated by the data shown in **Fig.4**.The result of CL measurements is shown in **Fig. 5**. Two sharp emissions were obtained at 3.49eV and 3.7eV in addition to a broad yellow luminescence peak from GaN. From monochromatic CL images, these two peaks were identified to be due to emission from the bulk GaN layer and from the QWR structures, respectively.

The result indicates that growth of AlGaN/GaN QWR is feasible with the present rf-radical assisted selective MBE growth technique. Further reduction of mesa width should lead to QWRs with strong lateral confinements that are useful for electronic and photonic device applications.

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