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P5-6

Improvement of crystal quality of GaN by modulated molecular beam epitaxy

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GaN and related group III-nitrides have proved useful for various device applications including light emitting devices and high power, high speed transistors[1,2]. High quality crystals, however, have been grown at relatively high temperatures, probably due to the fact that these compounds have very high melting points. Indeed, highly efficient light emitting devices have been fabricated from the wafers grown at temperatures higher than 900℃ by metalorganic vapor phase epitaxy (MOVPE) on sapphire substrates.

Such high temperature growth results in a considerable diffusion of impurity atoms during growth which makes the formation of sharp impurity profiles difficult. However, lowering the growth temperature deteriorates considerably the quality of grown layers. The GaN layers grown on a sapphire (0001) substrate at temperatures below 800℃ by RF plasma assisted molecular beam epitaxy(RF-MBE) often exhibit vertical striations in their cleaved section indicating that the growth predominately occurs in the vertical direction to form a dense column structure[3].

In this paper, an experimental evidence is presented that the modulation of molecular beam intensities in RF-MBE improves the quality of GaN layers gown on (0001) substrates at low temperatures (600℃～800℃). The dense column structure observed under low temperature growth conditions is probably caused by very low growth rate in the lateral directions compared with that in the vertical (0001) direction. Therefore, the enhancement of lateral growth is very important to solve this problem.

Under the stoichiometric, and N-enriched growth conditions, flat surfaces can be obtained. However, the column structure appears distinctly. Although the Ga-enriched growth conditions enhance the lateral growth rate, the resulting surfaces are quite rough. Thus, the modulated beam growth using RF-MBE is performed so as to produce alternately the N-enriched surfaces and Ga-enriched surfaces. Before GaN growth, approximately 20 monolayers of AlN are deposited on the (0001) sapphire substrate at 640℃ using the N_2 gas flow rate and applied RF power of 1.5sccm and 300W. In the GaN epitaxial growth, two Ga effusion cells with different temperatures are employed to produce two different beam intensities, while the N supply rate is kept constant. Throughout the GaN growth, the N_2 gas flow rate and the RF power are fixed at 8 sccm and 470 W. The total grown thickness is approximately 3 μ m.

One of the Ga-effusion cell shutter is kept open during GaN growth, while the other is opened intermittently. The period of shutter operation is chosen to be 60 sec. The RHEED observation reveals that the Ga-enriched and N-enriched surfaces appear alternately along this sequence. The best result is achieved when the Ga flux during the N-enriched growth is approximately 80% of the stoichiometric value, and the average Ga flux is equal to the stoichiometric one. Figure 1 demonstrates the SEM views of cleaved cross section of GaN layers grown under stoichiometric condition (a), and under Ga-flux modulated condition (b). The sample grown under stoichiometric condition shows vertical striations, while they disappear in the sample grown using the modulated method.

Figure 2 compares the X-ray diffraction rocking curves of the stoichiometry grown and modulated beam grown samples. The diffraction linewidth of the modulated beam grown GaN is much smaller than that of the stoichiometry grown sample, indicating that the Ga-flux modulation drastically improves the crystal quality. Indeed, improved photoluminescence characteristics are observed as shown in Fig. 3.

In conclusion, the modulation of Ga-flux during GaN growth induces the periodic surface reconstruction change, i.e., Ga-enriched and N-enriched reconstructions. This process enhances the lateral growth, and as a result, vertical striations or column structures disappear from the cross sectional views of grown GaN. Improved X-ray diffraction and PL characteristics are also demonstrated. The work was partly supported by the Japan Society for the Promotion of Science "Research for the Future" Program (JSPS-RFTF96P00103), and also COE Program "Molecular Nano-Engineering" from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

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a)

b)

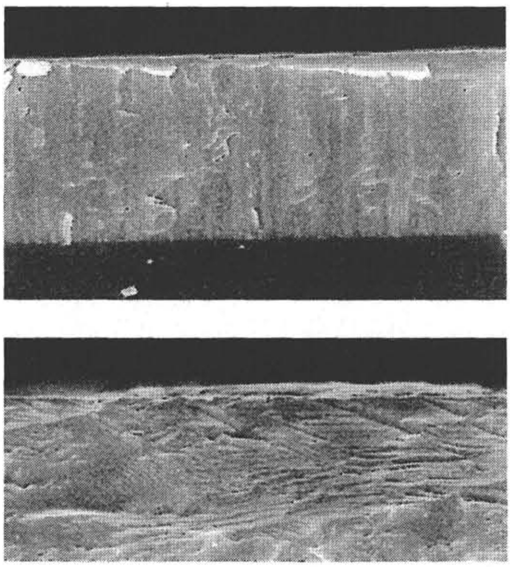

Fig. 1 SEM views of cleaved cross sections for the stoichiometry grown (a) and modulated beam grown sample(b)

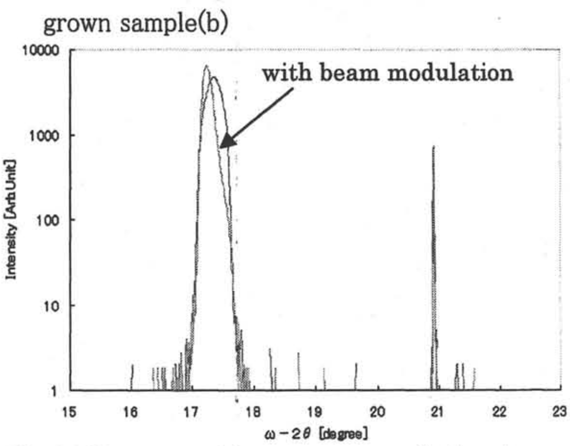

Fig.2 X-ray rocking curves of the layers grown with and without the beam modulation

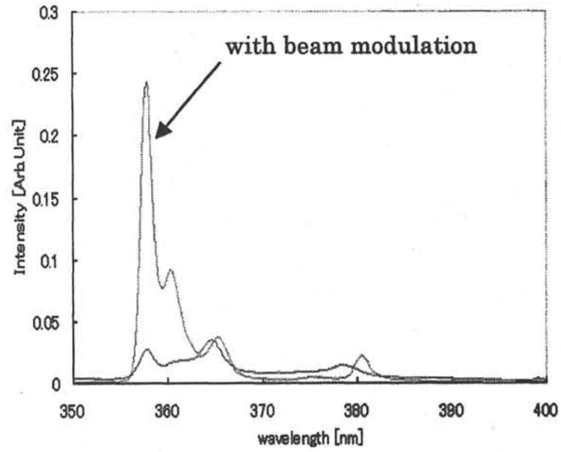

Fig.3 Improvement of PL spectra by the modulation method