Chemical Beam Epitaxy Growth and Characterization of Ga(In)NAs/GaAs

 Kanji Takeuchi, Tomoyuki Miyamoto, Fumio Koyama and Kenichi Iga Precision and Intelligence Laboratory, Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama 226, Japan Phone : +81-45-924-5026, Fax : +81-45-921-0898, E-mail : kanji@pi.titech.ac.jp

1. Introduction

The GaN_xAs_{1-x} alloy has many attractive characteristics due to its large bandgap bowing. Kondow et al. obtained a bowing parameter of 18eV at $x < 1.6\%^{-1}$ from the sample grown by gas-source molecular beam epitaxy (GS-MBE) using N radicals, and also Weyer et al. obtained a bowing parameter of 14eV at $x < 1.5\%^{2}$ by plasma-assisted metalorganic chemical vapor deposition (MOCVD). By incorporating In into a GaNAs layer, the alloy of GaInNAs may have a potential for long-wavelength laser diodes and GaInNAs/GaAs lasers are expected to have good temperature characteristics due to large electron confinement ³⁾. We can use the technology established in 0.98µm GaInAs/GaAs vertical-cavity surface-emitting lasers (VCSELs), such as GaAs/AlAs semiconductor distributed Bragg reflectors (DBRs) and AlAs selective oxide confinements, and so on. The GaInNAs/GaAs longwavelength VCSEL^{4,5)} is very attractive, if realized.

In this study, we have succeeded in growing Ga(In)NAs epitaxial layers by chemical beam epitaxy (CBE) using a RF radical cell for the first time. We report on epitaxial growth and some characteristics of Ga(In)NAs.

2. Experiments

The CBE system used in this experiment is RIBER CBE-32. The radical beam cell of MPD21R made by Oxford Applied Research was mounted on the CBE system. As group III sources. triethylgallium (TEGa) and trimethylindium (TMIn) in hydrogen carrier gas was used. 100% AsH₃ and nitrogen gas were used as group V sources. AsH₃ was precracked at 900°C by a PBN cracking cell. The N radical was produced by RF discharge in the N radical cell. Epitaxial layers were grown on (100) oriented n-type GaAs substrates. After a GaAs substrate was thermally cleaned with an AsH₃ flux of 11sccm at 590°C for 5 minutes to remove the oxide, the epitaxial layers were grown at a fixed temperature of 500°C, which was calibrated by the melting point of InSb (525°C) using a pyrometer. The growth rate was 0.9-1.4µm/h for both GaAs and GaNAs. TEGa and TMIn flow rate were 0.7-1.3sccm and ~0.1sccm, respectively. AsH₃ and N₂ flow rate were 5-11sccm and 0.2-2.0sccm, respectively. The layer thickness of a GaAs buffer was 0.06-0.2µm. The epitaxial layer thickness of GaNAs was 0.5-0.7µm. The N radical was ignited to stabilize the radical condition while a GaAs buffer layer was grown.

The N composition of these layers was determined by Xray diffraction measurements and secondary ion mass spectroscopy (SIMS) measurements. In addition, an absorption spectrum measurement was carried out to estimate the band edge wavelength.

3. Results and Discussions

Figure 1 shows the depth profile of nitrogen atoms for the GaNAs sample analyzed by SIMS. The vertical axis represents a nitrogen concentration calibrated by a standard sample with a N-ion-implanted GaAs substrate, while the horizontal axis represents the etched depth of the specimen. The N composition of sample A, which was grown using a large size aperture (0.5mm ϕ ×37) of the N radical cell with a N₂ flow of 2sccm and a RF power of 400W, reaches approximately 20% (Fig. 1 (a)). The N composition of sample B, which was grown using a smaller size aperture (0.3mm ϕ ×21) with a N₂ flow of 0.5sccm and a RF power of 200W, is approximately 1.2% (Fig. 1 (b)).



Fig. 1 Results of SIMS measurement of GaNAs epitaxial layers. (a) with the large size aperture, N₂ flow: 2sccm and RF power: 400W, N~20%. (b) with the small size aperture, N₂ flow: 0.5sccm and RF power: 200W, N~1.2%.

We observed the surface morphology of GaNAs under growths with different aperture sizes of the N radical cell. We can see that the surface morphology is very rough in the case of large size aperture. On the other hand, for the small size aperture, we obtained a mirror-like surface. This reason is considered due not only to a difference in nitrogen content but also to a plasma-induced damage depending on the flow conductance of the aperture.

Furthermore, we investigated the surface morphology when a shutter of the N radical cell was closed for the large aperture size. In spite of closing the shutter, the surface morphology was degraded by an influence of floating N radicals in the growth chamber. Thus, the CBE technique whose sources are supplied by gas may be suitable for the growth of III-(N,V) material, because the surface of the solid source may be nitrized by floating N radicals.

The X-ray diffraction measurement was also used to estimate the N composition. There is no clear peak observed from the GaNAs epitaxial layer for the sample using the large size aperture. It may be because the crystal quality is degraded due to phase separation, or plasma bombardment effect. Figure 2 shows the result of X-ray diffraction of the sample using the small aperture. As can be seen in Fig. 2, the X-ray peak shift with an increasing N₂ flow rate indicates an increase of the N composition. The sharp X-ray diffraction peak indicates the high crystal quality of epitaxial layers. For the samples with a higher N flow rate, the X-ray FWHM was broadened due to a deterioration of crystal quality induced by its critical thickness. The sample in Fig. 1 (b) and Fig. 2 (b) are the same, the result indicates that the N composition measured by both SIMS and X-ray diffraction is in good agreement. Therefore, the N composition can be defined by X-ray diffraction measurement.



Fig. 2 X-ray diffraction pattern of GaNAs epitaxial layers with different N₂ flow rates at a RF power 200W.

To estimate the band edge energy, an absorption measurement was carried out. Figure 3 shows the transmissivity of the GaNAs and GaAs epitaxial layers. The samples were polished with a substrate thickness of about 100µm. The clear absorption edge is observed from the GaAs reference sample. The transmissivity reduction at a smaller photon energy side was observed with increasing a N₂ flow rate. It is found that the bandgap is decreased, resulting from increasing a N composition. However, the absorption band edge is slightly unclear for high N composition samples. It is considered that the crystal quality is deteriorated as shown in the X-ray diffraction measurement. Moreover, the nitrogen composition is fluctuated in the epitaxial layer. From the SIMS measurement in Fig. 1(a), a slight variation of the N composition is shown along the depth direction. As the bandgap bowing is very large, such small variation may influence the band edge fluctuation. Furthermore, inplane compositional clustering may have possibly occurred, although we have not studied the detail yet.

The bandgap bowing parameter was also predicted from Fig. 3. According to the result, it is shown that the bowing parameter of GaNAs is 19-22eV. However, if only the sample with the maximum N composition, N=2.7%, is considered, we can get a bowing parameter of 12-15eV. It implies that a fined bowing parameter may not be used for a wide range of N compositions of GaNAs.

We also successful grew the GaInNAs epitaxial layer, and confirm the band edge shift due to both nitrogen and indium.



Fig. 3 Transmissivity characteristics of the GaNAs and GaAs layers at room temperature. Each N composition shows a value which was determined by X-ray diffraction measurement.

4. Conclusions

In conclusion, we have succeeded in growing Ga(In)NAs epitaxial layers with a good controllability by CBE using a RF radical cell for the first time. The GaNAs epitaxial layer with a N composition up to 2.7% was successfully grown with a good crystal quality, and the maximum N composition of 20% was obtained. We also investigated the bandgap from an absorption measurement. A bowing parameter of GaNAs was estimated to be 19-22eV.

Acknowledgments

This study was supported by the Grant-in-Aid COE program #07CE2003, "Ultra-Parallel Optoelectronics" of the Ministry of Education, Science, Sports and Culture, and also partly supported by "Research for the Future", program #JSPS-RFTF96P00101 from the Japan Society for the Promotion of Science.

The authors thank T. Kageyama for assistance in absorption measurements, and N. Ikoma for help in SIMS measurements.

References

- M. Kondow, K. Uomi, K. Hosomi and T. Mozume: Jpn. J. Appl. Phys. 33 (1994) L1056.
- M. Weyers, M. Sato and H. Ando: Jpn. J. Appl. Phys. 31 (1992) L853.
- M. Kondow, K. Uomi, A. Niwa, T. Kitatani, S. Watahiki and Y. Yazawa: Jpn. J. Appl. Phys. 35 (1996) L1273.
- 4) K. Iga: IPRM'96 (1996) ThA1-1.
- T. Miyamoto, T. Takada, K. Takeuchi, F. Koyama and K. Iga: *Quantum Optoelectronics of 1997 OSA Technical Digest Series*, 9, (1997) 126.