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Droplet elimination process by radical beam irradiation for the growth of InN-based III-nitrides and its application to device structure

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1. Introduction

InN-based III-nitrides are currently attracting considerable attention for application to infrared-light-emitting devices, high-efficiency tandem solar cell devices and high-frequency electronic devices. The crystal qualities of InN-based III-nitrides, however, hinder the application of these materials to actual devices, as these materials are the most difficult to grow due to a low InN dissociation temperature and a high equilibrium N_2 vapor pressure over InN.

In the MBE growth of nitrides, it is well known that the growth under a N-rich condition results in a poor–quality film with a rough surface due to the lack of migration. The growth under a metal-rich condition leads to a high-quality film, but metal droplets are formed on the surface. In the case of GaN, Ga droplets formed on the surface can easily be removed by thermal treatment process, as Ga droplets are evaporated before GaN decomposes. In the case of InN, on the other hand, it is impossible to remove In droplets by thermal treatment process, as InN decomposes before In droplets are evaporated. [1]

In this paper, a new method, named droplet elimination by radical beam irradiation (DERI) [2], is proposed for the reproducible growth of high-quality InN. This method is also applied to the growth of Mg-doped InN and undoped InGaN toward the application to device structure.

2. DERI Method for InN Growth

The DERI method consists of two series of growth processes; metal-rich growth process (MRGP) and droplet elimination process (DEP). In MRGP, InN is grown under an In-rich condition and excess In becomes droplets on the surface. Sometimes, In irradiation without nitrogen radical-beam irradiation is utilized as MRGP in order to understand simply the growth mechanisms because the growth rate of InN in MRGP can be considered to be approximately zero and whole the supplied In becomes droplets. These droplets are eliminated by transforming to InN epitaxially on the underlayer in DEP, which consists of nitrogen-radical beam irradiation.

This method can be simply monitored using *in-situ* observation by reflection high-energy electron diffraction (RHEED) and optical reflection. An example of *in-situ* monitoring technique with RHEED intensity variation in a diffraction pattern of InN through MRGP and DEP is shown in Fig. 1. Detailed explanation on this RHEED intensity variation is described in ref. 2.

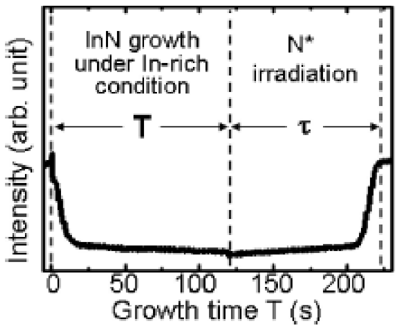

Fig. 1 RHEED intensity variation in a diffraction pattern of InN through MRGP (InN growth under In-rich condition) and DEP (N* irradiation). [2]

The advantages of DERI method for the growth of high-quality InN are followings;

(1) Reproducible (using *in-situ* monitoring technique)
(2) Simple (using *in-situ* monitoring technique)
(3) Capability for thicker InN growth (by repeating MRGP and DEP)
(4) Point defect control (especially at interface)
(5) Stable growth (almost independent on growth condition)

3. Application of DERI Method to Mg-doped InN Growth

The application of the DERI method to Mg-doped InN growth is also investigated. Here, In irradiation is utilized as MRGP. Mg can be supplied in either MRGP or DEP. Figure 2 shows an example of cross-sectional transmission electron microscopy (TEM) image for Mg-doped InN, where InN is grown by repeating 6 cycles of MRGP and DEP and Mg is supplied in MRGP and DFP in the first and next 3 cycles, respectively. Periodic interface is not observed in the region where Mg was supplied in DEP (Region A), while three interfaces corresponding to the growth cycles are clearly observed in the region where Mg was supplied in MRGP (Region B). Secondary ion mass spec-

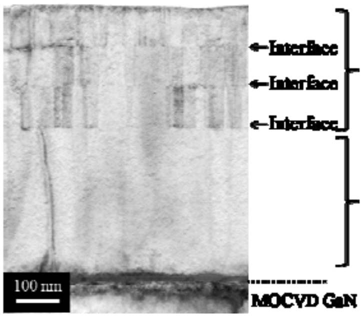

Fig. 2 Cross-sectional TEM imgage for Mg-doped InN, where InN is grown by repeating 6 cycles of MRGP and DEP and Mg is supplied in DEP and MRGP in the first and next 3 cycles, respectively.

trometer (SIMS) result also indicates that Mg concentration is almost constant in region A, while that is fluctuated in region B. By supplying Mg in DEP, we have reproducibly achieved Mg-doped InN films that exhibit p-type conductivity in thermopower measurements.

4. Application of DERI Method to InGaN Growth and Formation of InN/InGaN Periodic Structure

The application of the DERI method to InGaN alloy growth is also investigated. When InGaN is grown under a metal-rich condition (In+Ga>N*) in MRGP, Ga is preferentially captured from Ga and In mixture at growth steps and In is preferentially swept out from the growing InGaN surface. [3] In DEP, this swept In is eliminated by transforming to InN epitaxially on InGaN, as is the same as the case of InN growth. The schematic diagram is shown in Fig. 3. By repeating these processes, InN/InGaN periodic structure can be fabricated. Figure 4 shows an example of 2θ-ω X-ray diffraction (XRD) profiles of InN/InGaN periodic structure, which was fabricated by repeating 10 times of the MRGP and DEP.

Thus, InN/InGaN periodic structure can be successfully fabricated by using DERI method, where preferential capturing process between Ga and In is enhanced.

5. Conclusions

A new method, named DERI, is proposed for the reproducible growth of high-quality InN. This method can be simply monitored using *in-situ* observation. This method is also applied to grow Mg-doped InN. By taking care of Mg-supplied timing, Mg-doped InN films that exhibit p-type conductivity can be reproducibly achieved. This method is also applied to grow InGaN. Using the phenomena that Ga is preferentially captured from Ga and In mixture at growth steps and In is preferentially swept out from the growing InGaN surface, InN/InGaN periodic structure can be successfully fabricated by repeating MRGP and DEP.

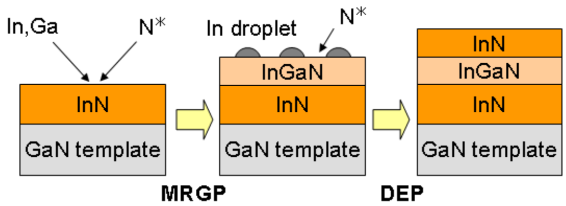

Fig. 3 Schematic diagram of InGaN and InN growth by MRGP and DEP, respectively.

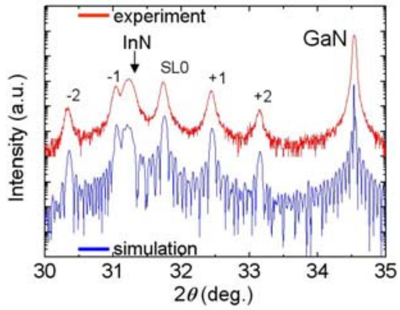

Fig. 4 XRD 2θ-ω experimental (upper) and simulated (lower) profiles of InN/InGaN periodic structure, fabricated by repeating 10 times of the MRGP and DEP.

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