Annealing effect of low temperature grown InN films by RF-MBE

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Within groupⅢ-nitride semiconductors, InN has the smallest effective mass(1), and highest electron drift velocity(2). Therefore, InN is expected to be the channel material for electronic devices such as HFET. However, InN tends to grow three-dimensionally because the lattice mismatch between the films the and substrates is very large. Therefore, the control of initial growth process is essential to grow high quality InN films. In this study, we will report low temperature (about 300℃)growth of InN films and its annealing effect. We will also report the film thickness dependence of electrical properties.

InN films were grown by radio-frequency plasma-excited molecular beam epitaxy (RF-MBE). The substrate used in this study was (0001)sapphire. Prior to the growth of InN, thermal cleaning of the sapphire substrate was carried out at 800℃ for 10 min to obtain a clean surface. Then the nitridation was carried out at 550℃ for 1 hour with nitrogen flow rate of 1 sccm and RF plasma power of 300W. Following the nitridation, InN films were grown for 10min. The beam equivalent pressure of the elemental In was 8.0×10^{-8}Torr. The N_2 flow rate and RF power were 2sccm and 330W, respectively and kept constant through the experiment. Only the substrate temperature was varied from 250℃ to 350℃. Film thickness of the InN films grown for 10 min were about 30 nm. Following the growth of InN, annealing was carried out at 550℃. To evaluate the crystallinity of the InN films, RHEED, XRD, and SEM were used. The mobility and carrier density were investigated by Hall measurements at room temperature. The growth rate was determined by mechanical profile-mater.

Figure 1 shows the RHEED patterns of InN films (a)before and (b) after annealing process, which are grown at various growth temperatures. Before annealing, all samples showed spot-streak patterns and changed into streak patterns after annealing. These results indicate that the surface flatness of InN films was clearly improved by annealing at 550℃. Fig.2 shows the SEM images of surface morphology for the same samples in Fig.1. Surface morphology of InN film grown at 350℃ showed discrete film surface. Surface morphology of InN film grown at 250℃ showed many In droplets. The electron mobility of InN film grown at 300℃ was the highest(61cm^2/Vs) among three samples. From these results, it was found that an optimum growth temperature was 300℃. The electron mobility for InN film grown at 300℃ before annealing was 9cm^2/Vs. Thus, the annealing improved not only the surface morphology but also the electron mobility.

To confirm the annealing effect, two identical InN films with 70nm film thickness were grown. All other growth conditions were the same with InN film growth temperature at 300℃. For one sample, annealing was carried out at 550℃. The electron mobility of the film with annealing was 237cm^2/Vs and that without annealing was 30cm^2/Vs. Fig.3 shows a typical XRD profile of the InN film grown on a (0001)sapphire substrate. In Fig.3, a strong diffraction peak corresponding to the (0002) diffraction from InN was observed together with sapphire(0006). The result indicates that InN films of single-crystal with wurtzite structure were grown. The full width at half maximum (FWHM) of (0002) diffraction of InN film with annealing process was 55min and that without annealing was 60min. From these results, the annealing process also improved the crystallinity of InN films, which is confirmed both for thinner (30nm) and thicker (70nm) samples.

In summary, to obtain high quality InN films, initial growth process was examined. In this examination, the InN films grown at low temperature (about 300℃) showed excellent surface morphology than usual growth temperature (about 550℃) as shown in the Fig.4. Moreover, it was found that the electrical properties, surface morphology and crystallinity were all improved by annealing at 550℃, even when film thickness was increased from about 30nm to about 70nm.

Acknowledgement

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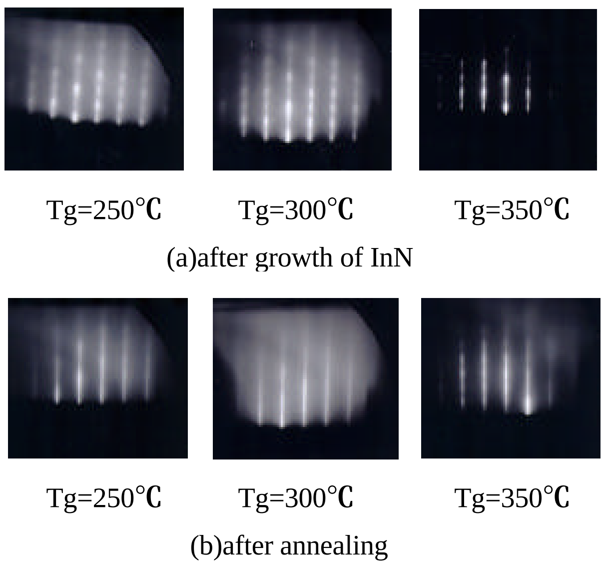

Fig.1 RHEED patterns of InN films grown on (0001) sapphire at different growth temperatures Tg.

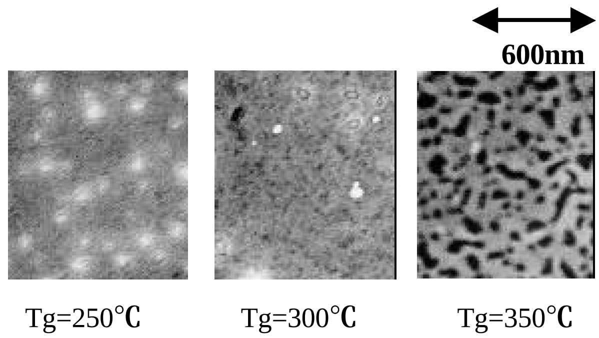

Fig.2 Surface morphology of the films grown at different temperatures: Tg=250℃, Tg=300℃ and Tg=350℃.

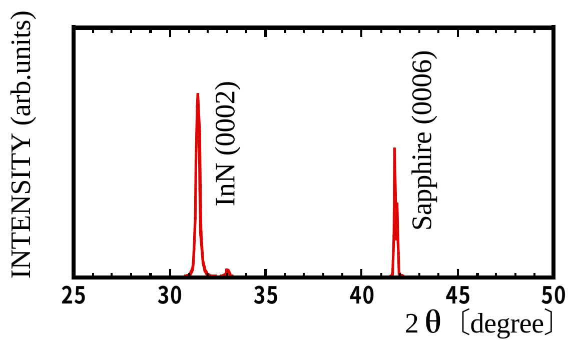

Fig.3 Typical XRD profile of the InN films grown On (0001)sapphire substrate.

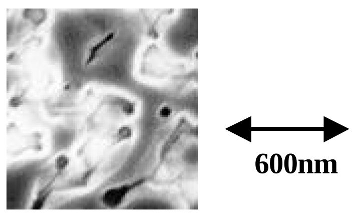

Fig.4 Surface morphology of InN film grown at 550℃.