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Growth of high-quality hexagonal InN on 3C-SiC (001) by molecular beam epitaxy

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We have grown hexagonal InN (h-InN) films on 3C-SiC (001) substrates by RF-N_2 plasma molecular beam epitaxy taking account of small lattice mismatch between h-InN (10-10) and 3C-SiC (110). It was found from X-ray diffraction (XRD) measurements that h-InN grows with h-InN (0001) || 3C-SiC (001) and h-InN (1-100) || 3C-SiC (110). XRD measurements also revealed that the h-InN epitaxial layers grown on 3C-SiC (001) are composed of single domain. Strong and sharp photoluminescence from the h-InN was clearly observed at around 0.69 eV.

1 Introduction InN has recently attracted much attention owing to its small electron effective mass, high electron mobility, and small band gap among III-nitride semiconductors. However, it has been less investigated than other nitride semiconductors such as GaN and AlN because of difficulty in growing high-quality InN. We have reported on the epitaxial growth of InN films on 3C-SiC (001) substrates with and without cubic GaN underlayers and found that in the case of direct growth on 3C-SiC (001), hexagonal InN (h-InN) grows with the crystal orientation as h-InN (10-10) || 3C-SiC (110) while cubic InN grows on cubic GaN underlayers [1]. In the present study, taking account of the lattice mismatch between h-InN (10-10) and 3C-SiC (110) as small as 0.6%, we have grown h-InN on 3C-SiC substrates by RF-N_2 plasma molecular beam epitaxy.

2 Experimental InN films were grown on 3C-SiC (001)/Si substrates by molecular beam epitaxy using a RF-N_2 plasma source. 3C-SiC (001) epitaxial layers were obtained by CVD growth on Si (001) substrates at 1300 ºC. Details of the growth of 3C-SiC on Si have been described elsewhere [2]. First, InN buffer layers were grown directly on 3C-SiC (001) substrates at 300 °C for 2 min, and then InN epitaxial layers were grown at 400-550 °C for 1 hour. The typical growth rate was 0.3 μm/hour. In order to examine the effect of buffer layers grown at a low temperature, InN was also grown on 3C-SiC at 470 °C, from the start, without using a buffer layer. We have studied the crystal structures and surface morphologies by X-ray diffraction (XRD) and scanning electron microscope (SEM), respectively. Photoluminescence (PL) spectra were measured at 5 K using the 632.8 nm line of a He-Ne laser as an excitation source and an InSb photovoltatic device as a detector.

3 Results and discussion Figures 1(a) and (b) show reflection high energy electron diffraction (RHEED) patterns during the growth of h-InN layers on 3C-SiC (a) with and (b) without a buffer layer

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observed at the 3C-SiC <110> azimuth, respectively. As seen in this figure, the RHEED patterns showed a sharp streak feature during growth, indicating that the InN layer has a smooth surface. The SEM observation also confirmed that the surface of the InN layers obtained in this study was flat although pits were observed in some cases. When buffer layers were grown at 300 °C, the RHEED pattern like that shown in Fig. 1(a) always appeared in approximately 1 min. This pattern became sharp with increasing substrate temperature and during the succeeding growth. On the other hand, the RHEED pattern as shown in Fig. 1(b) was observed unless the buffer layer was used, suggesting that two kinds of domains with different in-plane directions coexist in the InN layer.

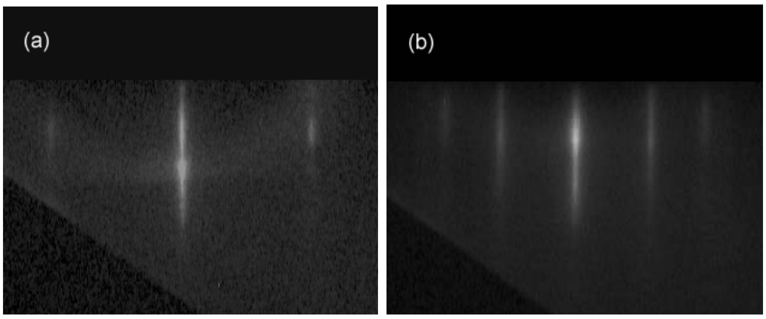

Fig. 1 RHEED patterns of h-InN grown on 3C-SiC (001) (a) with and (b) without a buffer layer observed at the 3C-SiC <110> azimuth.

Figure 2 shows the θ-2θ scan XRD curve of h-InN grown on 3C-SiC (001) at 550 °C. The XRD peak from h-InN (0002) is seen as well as that from 3C-SiC (002). This shows that h-InN grows with h-InN (0001) || 3C-SiC (001). In spite of using the cubic substrate, XRD peaks due to cubic-phase InN were not observed at all in the θ-2θ XRD profile. Large lattice mismatch (13%) between cubic InN (001) (a=0.499 nm) and 3C-SiC (001) (a=0.436 nm) may hinder the growth of cubic phase. Similar results were obtained independently of the growth temperature or use of buffer layers.

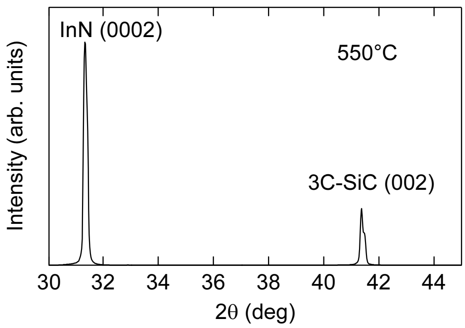

Fig. 2 Typical θ-2θ XRD profiles of hexagonal InN grown on a 3C-SiC (001) substrate.

Figures 3(a) and (b) show XRD pole-figures of (10-12) h-InN grown with and without a buffer layer, respectively. The rotation angle ϕ=0 corresponds to the <110> direction of 3C-SiC. As shown in Fig. 3(a), the crystal orientation of h-InN grown on 3C-SiC (001) is not 12-fold but 6-fold symmetry, i.e., h-InN grows preferentially with either h-InN (10-10) || 3C-SiC (110) or h-InN (10-10) || 3C-SiC (1-10), which is consistent with the RHEED pattern shown in Fig. 1(a). This result indicates that the h-InN epitaxial layers grown on 3C-SiC (001) are composed of single domain. This crystal orientation reflects anisotropy between [110] and [1-10] of 3C-SiC because the crystal structure of 3C-SiC is zincblende and the 3C-SiC substrates we used are composed of single domain [2]. Sapphire substrates are widely used for the growth of InN, and nitridation prior to growth is essential to obtaining InN which has 6-fold symmetry[3]. On the contrary, nitridation is not needed for the h-InN growth on 3C-SiC substrates.

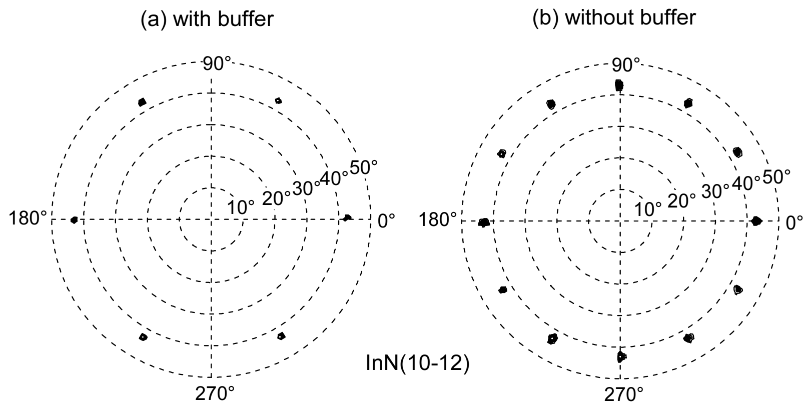

Fig. 3 XRD pole-figures of (10-12) h-InN grown (a) with a buffer layer and (b) without a buffer layer.

If the buffer layer was not used, however, the XRD peak of h-InN (10-12) has 12-fold symmetry, as shown in Fig. 3(b). This indicates h-InN layers grown without the buffer layer are composed of two kinds of domains with h-InN (10-10) || 3C-SiC (110) and h-InN (10-10) || 3C-SiC (1-10), which coincides with the RHEED pattern shown in Fig. 1(b) and that using the buffer layer is crucial to the single domain growth of h-InN on 3C-SiC (001).

XRD rocking curves for h-InN (0002) and (10-12) are shown in Fig. 4 (a) and (b), respectively. Full-widths at half maximum (FWHM) of the XRD rocking curves are also listed in Table 1. As shown in Fig. 4(a), FWHM of the XRD rocking curves are almost the same for the (0002) peak of h-InN layers grown with and without the buffer layer. On the other hand, for the (10-12) peak, the FWHM in the case of no buffer layer is larger than that in the case of using a buffer layer. It was also found that the FWHM for the (10-12) peak of h-InN grown with a buffer layer were not too large considering that the FWHM for the (0002) peak are around 900 arcsec [4, 5]. When the buffer layer is used and the h-InN layer grown is composed of single domain, the twist of the crystal is considerably restricted due to the small lattice mismatch between h-InN(10-10) and 3C-SiC(110).

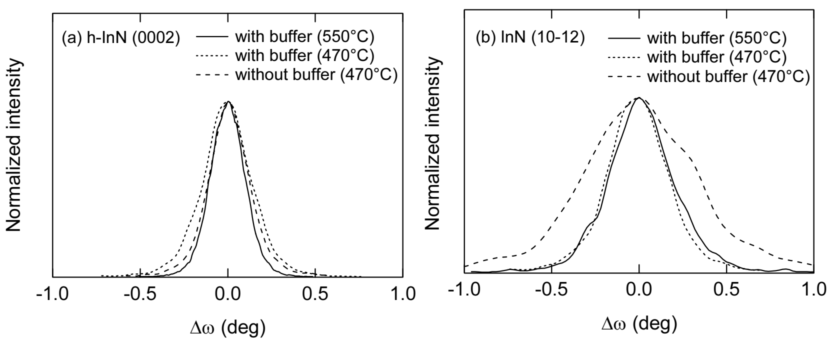

Fig. 4 XRD rocking curves for (a) hexagonal InN (0002) and (b) hexagonal InN (10-12).

Table 1 FWHM of XRD rocking curves.

	FWHM (0002) (arcsec)	FWHM (10-12) (arcsec)
with buffer 550°C	820	1490
with buffer 470°C	1100	1340
without buffer 470°C	910	2510

Figure 5 shows the PL spectrum of h-InN grown at 550 °C. A strong and sharp PL peak was clearly observed at 0.688 eV with FWHM of 34 meV. The PL peak energy obtained in this study supports that the bandgap energy of h-InN is less than 0.7 eV at 5 K [6]. In addition, the electron concentration in the h-InN flim is estimated as low as $2\text{-}3\times10^{18}$ cm^{-3} from the PL peak energy according to the report by Higashiwaki et al. [7].

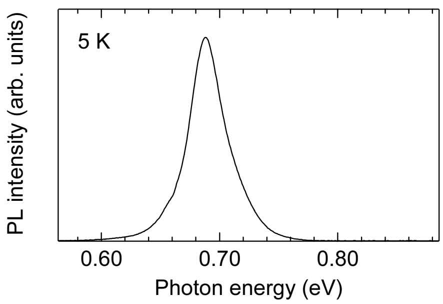

Fig. 5 Photoluminescence spectrum of hexagonal InN grown at 550 °C.

4 Conclusions We have successfully grown high-quality h-InN on 3C-SiC (001) substrates utilizing the small lattice mismatch between h-InN (10-10) and 3C-SiC (110). XRD measurements revealed that h-InN grows with h-InN (0001) || 3C-SiC (001) and h-InN (1-100) || 3C-SiC (110) and also that the h-InN flims grown on 3C-SiC (001) are composed of single domain. The twist of h-InN crystal was considerably suppressed due to the small lattice mismatch. Strong and sharp photoluminescence was clearly observed at around 0.69 eV. Considering that the thickness of the InN films we have grown were about 0.3 μm, the quality is expected to improve for thicker flms.

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