Phys. Status Solidi C **7**, No. 7–8, 2016–2018 (2010) / **DOI** 10.1002/pssc.200983441

physica status solidi pss c
www.pss-c.com
current topics in solid state physics

RF-MBE growth of InN on 4H-SiC (0001) with off-angles

Misao Orihara*,1, Shin Takizawa1, Takanori Sato1, Yuuki Ishida2, Sadafumi Yoshida2, Yasuto Hijikata1, and Hiroyuki Yaguchi1

[1] Department of Electrical and Electronic Systems Engineering, Saitama University, 255 Shimo-Okubo, Sakura-ku, Saitama 338-8570, Japan

[2] National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba Central 2, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan

Received 29 September 2009, accepted 27 January 2010
Published online 18 May 2010

Keywords InN, MBE, growth, structure, photoluminescence

* Corresponding author: e-mail orihara@mail.saitama-u.ac.jp, Phone: +81 48 858 3769, Fax: +81 48 858 3769

We have grown InN on 4H-SiC (0001) substrates with various off-angles by RF-N_2 plasma molecular beam epitaxy (RF-MBE). Scanning electron microscope observation revealed that InN films grown on 4H-SiC (0001) substrates with off-angles of 4° and 8° are very smooth and that there are no voids which have often observed for InN epitaxial layers. X-ray diffraction reciprocal space maps for InN grown on 4H-SiC (0001) showed that the c-axes of InN grown on 4H-SiC 4° and 8° off substrates are inclined by 0.35° and 0.8°, respectively, toward the misorientation of the substrate while the c-axis of InN is parallel to that of 4H-SiC for the on-axis substrate. Strong PL peak was observed from InN grown on 4° off substrate at 0.68 eV at 15 K. The PL peak was clearly observed even at room temperature and simply shifted to lower energies with increasing temperature. The difference in the PL peak energy between at 15 K and 300 K was 20 meV, which is reasonable taking into account the difference in the thermal coefficients of InN and SiC.

1 Introduction

In recent years InN has been extensively studied because it has a fundamental bandgap of 0.6-0.7 eV [1], which is suitable for the applications in optoelectronic devices in the optical fiber communication wavelengths. While sapphire has been widely used as the substrate for the growth of InN, SiC [2-4] is also a promising candidate because of its electrical conduction and high thermal conductivity, which are useful for device applications. In the present paper, we have investigated the direct growth of InN on 4H-SiC (0001) substrates with off-angles (4° and 8°) by radio-frequency plasma-assisted molecular beam epitaxy (RF-MBE), and succeeded in improving the surface morphology as well as the luminescence properties of InN. In addition, we have found that the c-axis of InN is not parallel to that of 4H-SiC but inclined toward the misorientation of the substrate.

2 Experimental procedures

The substrates used in this study were 4H-SiC (0001) misoriented toward (11-20) by 4° and 8°. For comparison, on-axis substrates were also used. InN films were grown by RF-MBE. Following the thermal cleaning of the substrate at 1100 °C for 30 min, an InN buffer layer was grown at 350 °C for 1 min, and an epitaxial layer was grown at 500 °C for 90 min. The growth rate was 5.5 nm/min. The surface morphology was characterized by scanning electron microscopy (SEM). Atomic force microscopy (AFM) was also used for evaluating the surface roughness of InN films. The crystalline quality and the relation of the crystal axis between InN and 4H-SiC were studied by x-ray diffraction (XRD) rocking curve measurements and reciprocal space mapping, respectively. Photoluminescence (PL) measurements were carried out at between 15 K and 300 K. An InSb photovoltaic device and a frequency doubled Nd:YVO_4 laser operating at 532 nm were used as the detector and the excitation source, respectively. The optical power density used for the sample excitation was 4 W/cm^2.

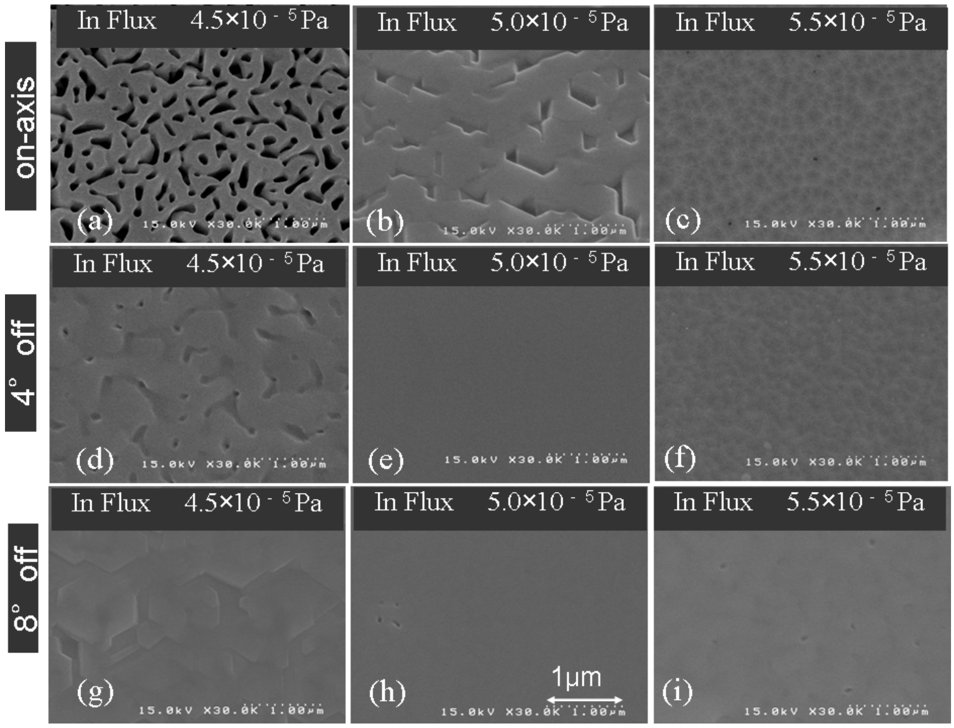
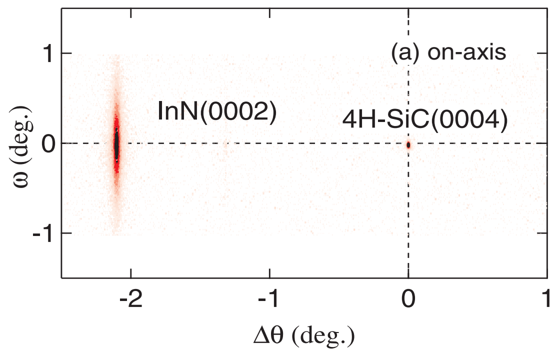


Figure 1 SEM images of InN grown on 4H-SiC(0001): (a)-(c) on-axis, (d)-(f) 4° off, and (g)-(i) 8° off.

3 Results and discussion

Figures 1(a)-(i) show the SEM images of InN grown on 4H-SiC (0001): (a)-(c) on-axis substrate, (d)-(f) substrate with 4° off angle, and (g)-(i) substrate with 8° off angle. Indium flux was set at 4.5×10^{-5} Pa for (a), (d) and (g), at 5.0×10^{-5} Pa for (b), (e) and (h), and at 5.5×10^{-5} Pa for (c), (f) and (i), respectively. As can be seen from the SEM images, the surface morphology of InN films is strongly dependent on both the off-angle of the substrate and In flux. As shown in Fig. 1(e) and (h), for instance, the surface of InN grown on substrates with off angles is smooth, and there are no voids. By using AFM, the surface roughness was evaluated to be 1.8 nm and 1.2 nm for the off-angle of 4° and 8°, respectively. On the contrary, when using on-axis substrate, there exist some voids which have often been observed for InN epitaxial layer [2, 4, 5] although the surface is smooth, as shown in Fig. 1(b). This clearly indicates that the use of misoriented substrates leads to the elimination of voids. With regard to the In flux dependence, while the voids are more highly visible for a smaller In flux, as can be seen in Fig. 1(a) and (d) , a larger In flux results in rougher surface shown in Fig. 1(c) and (f). The full-widths at half maximum of XRD rocking curve of InN (0002) were 0.38°, 0.36° and 0.33° for substrate off-angles of 0°, 4° and 8°, respectively, indicating that the larger off-angle tends to improve the crystalline quality. XRD reciprocal space maps for InN grown on 4H-SiC (0001) with various off-angles are shown in Fig. 2(a)-(c). As shown in Fig. 2(a), the c-axis of InN is parallel to that of 4H-SiC for the on-axis substrate. On the other hand, it is found from Fig. 2(b) and (c) that the c-axis of InN grown on 4H-SiC 4° and 8° off substrates is inclined by 0.35° and 0.8° toward the misorientation of the substrate, respectively, as schematically shown in Fig. 3. This tendency is consistent with the result that the crystal axis of InGaAs grown on GaAs substrate is inclined [6]. The inclination of c-axis of InN possibly leads to the elimination of voids in the film, but further investigation is necessary for clarifying the reason.

PL spectra obtained from InN grown on 4H-SiC (0001) 4° off substrate under an In flux of 5.0×10^{-5} Pa is shown in Fig. 4. Strong PL peak was observed at 0.68 eV at 15 K. The PL peak shifted simply to lower energies with increasing temperature, which is reasonable taking account of the temperature dependence of the bandgap energy [1] and was clearly observed even at room temperature. The energy difference in the PL peak between at 15 K and 300 K



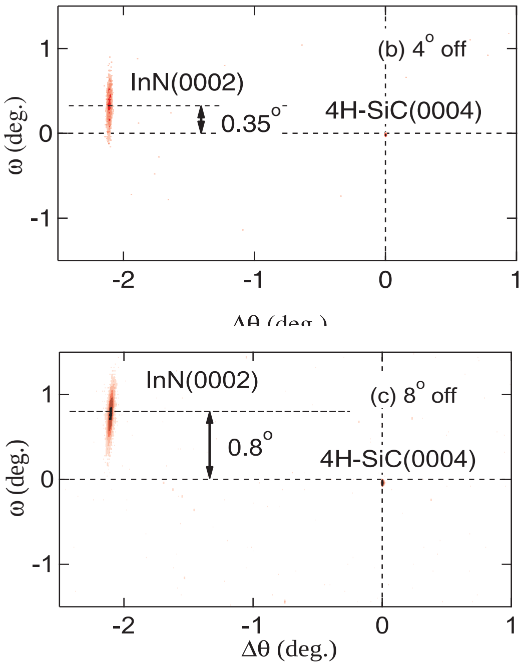


Figure 2 XRD reciprocal space maps for InN grown on 4H-SiC(0001) with various off-angles: (a) on-axis, (b) 4° off, (c)8° off.

is 20 meV, which is somewhat smaller than reported values of ~33 meV [7] and 32 meV [8] for InN grown on GaN template on sapphire substrate. This discrepancy can be explained by the difference in the thermal coefficients of InN (5.7×10^{-6} K^{-1}), SiC (4.2×10^{-6} K^{-1}) and sapphire (7.5×10^{-6} K^{-1}). When the sample is cooled down to low temperatures, InN is under tensile strain, and thus the increase in the bandgap with the temperature change is suppressed.

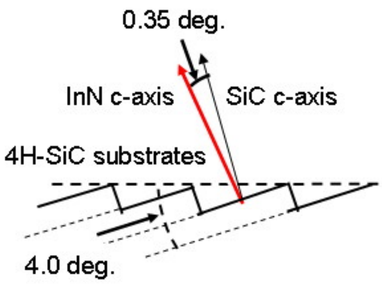


Figure 3 Schematic diagram of InN grown on 4H-SiC substrate with an off-angle of 4°.

4 Conclusions

InN films were grown on 4H-SiC(0001) substrates with various off-angles by RF-MBE. SEM observation showed that the InN films grown on 4H-SiC(0001) substrates with off-angles of 4° and 8° were very smooth and that there were no voids which have often observed for InN epitaxial layers. It was found from XRD reciprocal space maps that the c-axis of InN grown on 4H-SiC substrates with off-angles was inclined toward the misorientation of the substrate. Strong PL peak was observed from InN grown on the substrate with an off-angle of 4° at 0.68 eV at 15 K. The PL peak was clearly observed even at room temperature and simply shifted to lower energies with increasing temperature. The energy difference in the PL peak between 15 K and 300 K was somewhat smaller than reported values, which is reasonable taking into account the difference in the thermal coefficients of InN and SiC.

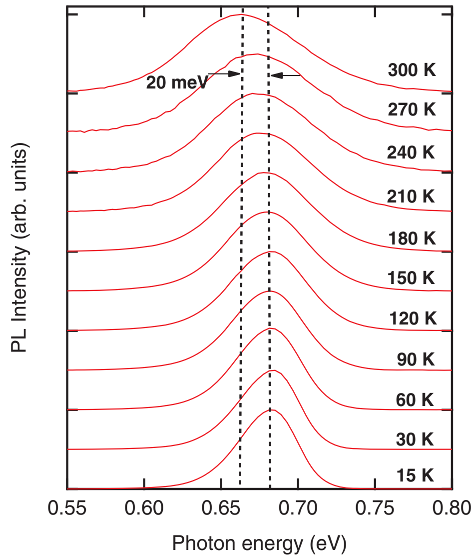


Figure 4 PL spectra obtained from InN grown on 4H-SiC(0001) 4° off substrate.

Acknowledgements This study was supported by Grant-in-Aid Encouragement of scientists (21920007).

References

[1] Y. Ishitani, H. Masuyama, W. Terashima, M. Yoshitani, N. Hasimoto, S. B. Che, and A. Yoshikawa, Phys. Status Solidi C **2**, 2276 (2005).
[2] T. Ive, O. Brandt, M. Ramsyeiner, M. Giehler, H. Kostial, and K. H. Ploog, Appl. Phys. Lett. **84**, 1671 (2004).
[3] H. Yaguchi, Y. Kitamura, K. Nishida, Y. Iwahashi, Y. Hijikata, and S. Yoshida, Phys. Status Solidi C **2**, 2267 (2002).
[4] S. Hirano, T. Inoue, G. Shikata, M. Orihara, Y. Hijikata, H. Yaguchi, and S. Yoshida, J. Cryst. Growth **301**/**302**, 513 (2007).
[5] D. Muto, T. Araki, H. Naoi, F. Matsuda, and Y. Nanishi, Phys. Status Solidi A **202**, 773 (2005).
[6] H. Nagai, J. Appl. Phys. **45**, 3789 (1974).
[7] D. Y. Song, M. E. Holtz, A. Chandolu, A. Bernussi, S. A. Nikishin, M. W. Holtz, and I. Gherasoiu, Appl. Phys. Lett. **92**, 121913 (2008).
[8] M. Feneberg, J. Däubler, K. Thonke, R. Sauer, P. Schley, and R. Goldhahn, Phys. Rev. B **77**, 245207 (2008).