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Formation of a Step-Free Ultrathin InN Layer on a Step-Free GaN Surface

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1. Introduction

Atomically flat hetero-interfaces are crucial for developing high-performance semiconductor devices with single- or double-heterojunctions or quantum wells. Recently, we have succeeded in fabricating step-free GaN surfaces with a diameter of 50 µm by selective area metalorganic vapor phase epitaxy (SA-MOVPE) [1]. The step-free GaN surfaces are atomically flat without any monolayer steps over the entire selective-area.

The atomically flat GaN surfaces may provide a good opportunity for examining a recently proposed approach to nitride-based visible light-emitting devices [2], where ultrathin InN quantum wells (QWs) play a crucial role. Since the ultrathin InN QWs are typically 1-ML thick, any thickness fluctuations result in broadening of the emission peaks. In this study, we investigated the growth of step-free ultrathin InN layers on the step-free GaN surfaces to achieve abrupt hetero-interfaces in InN QWs and therefore highly monochromatic emissions.

2. Experimental

GaN and InN films were grown by SA-MOVPE on GaN (0001) bulk substrates, which have hexagonal-shaped selective-areas with diameters of 16 µm. The density of threading dislocations in the GaN template was less than $5x10^6$ cm^{-2}. The source gases were NH_3, trimethylgallium (TMG), and trimethylindium (TMI). Substrate temperatures (T_s's) were approximately 950 and 530-660°C for GaN and InN, respectively. The surfaces of the GaN films were investigated by optical microscopy, atomic force microscopy (AFM), and Auger electron spectroscopy (AES).

3. Results and discussion

Figure 1(a) shows an AFM image of the surface of a GaN film grown within a hexagonal-shaped selective-area having no screw-type dislocations. The GaN surface has a wide atomic terrace without any monolayer steps (step-free surface). Then, we deposited InN on the step-free GaN surfaces for a very short time to investigate the nucleation of InN. Partially coalesced two-dimensional (2D) islands were formed on a step-free GaN surface after the simultaneous supply of TMI and NH_3 for deposition time (t_D) of 10 s at 620°C [Fig. 1(b)]. The height of the islands is approximately 0.3 nm, corresponding to 1-ML thickness of InN. A longer t_D of 30 s revives the step-free surface by lateral growth and coalescence of 2D nuclei as shown in Fig. 1(c). Figure 2 shows an AES chart obtained for this step-free surface. The scan size of the incident electron beam was 10 x 10 $µm^2$, which selectively irradiated the hexagonal area. AES signals from N (378 - 387 eV) and In

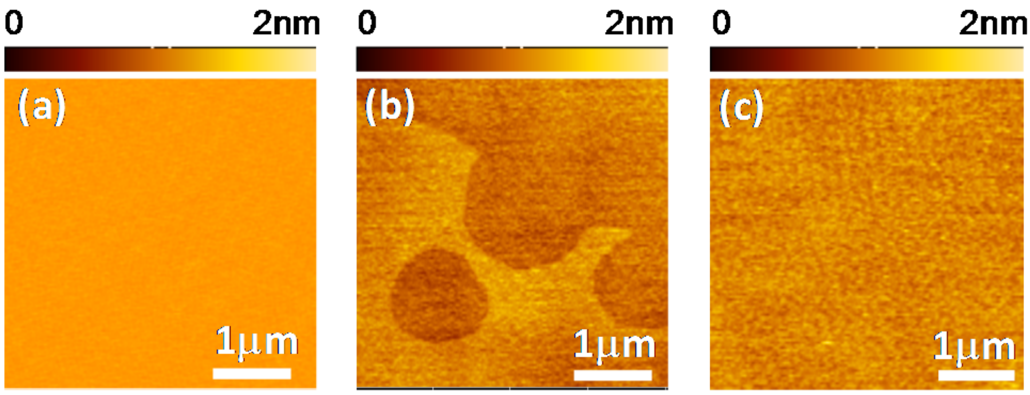

Fig.1: AFM images of (a) step-free GaN surface formed within a hexagonal-shaped selective-area having no screw-type dislocations, (b) partially coalesced 2D islands of InN formed on a step-free GaN surface using t_D of 10 s at 620 °C, and (c) step-free InN surface formed using t_D of 30 s at 620 °C.

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(398 - 412 eV) can be clearly seen, indicating that the step-free surface is composed of InN. Additionally, signals from Ga atoms are also discernible at around 1070 eV. This indicates that the step-free InN layer is very thin since the escape depth of Auger electrons is very limited: it is approximately 2 nm when the kinetic energy of the Auger electrons is ~ 1000 eV. Figure 3(a) shows the surface of InN grown at the lower T_s of 530 °C for t_D of 5 s. Partially coalesced 2D nuclei with the height of 2-MLs are formed. Longer t_D of 10 s, however, resulted in the formation of three-dimensional (3D) dots as shown in Fig. 3(b). These results indicate that InN grows in the Stranski–Krastanov (S-K) mode at the T_s of 530°C.

The morphologies of InN layers are summarized as functions of t_D and T_s in Fig. 4. At low T_s of around 530°C, 3D dots appear for t_D from 10 to 600 s, while at T_s higher than 580°C, 2D nuclei and step-free surfaces are observed. We confirmed by AES measurements that at 580°C the InN layers was 3-MLs at the thickest even for the longest t_D (300 s), indicating that the growth of InN is self-limited at high T_s [3].

4. Conclusions

Step-free ultrathin InN layers were successfully formed on step-free GaN surfaces at T_s of 620°C by lateral growth and coalescence of 2D nuclei. At lower T_s (530°C), 2D nucleation was followed by 3D-dot formation by the S-K growth mode. InN layers were 3-MLs at the thickest even for the longest t_D (300 s) at 580°C, indicating the self-limitation of InN growth at higher T_s.

Acknowledgements

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References

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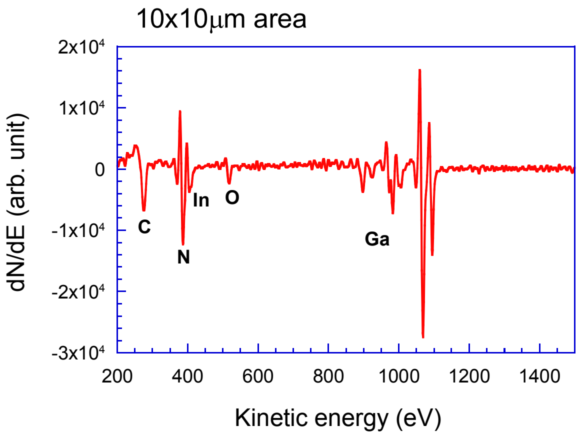

Fig. 2: AES chart of step-free InN ultrathin layer formed on step-free GaN surface.

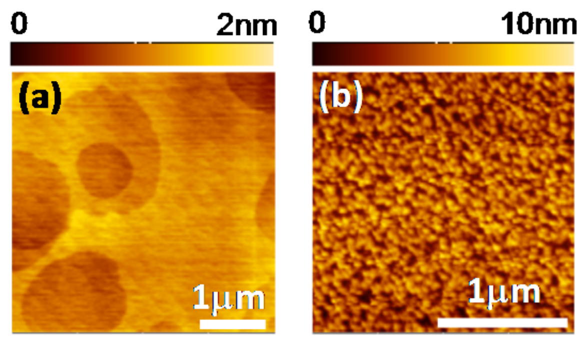

Fig.3: AFM images of (a) partially coalesced 2D islands of InN formed on a step-free GaN surface using t_D of 5 s at 530 °C and (b) 3D dots of InN formed using t_D of 10 s at 530 °C.

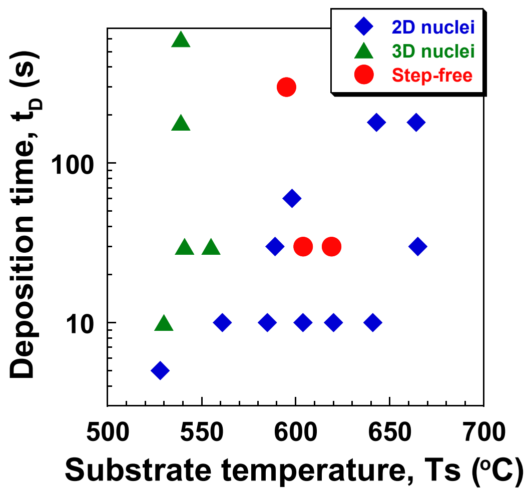

Fig.4: Morphologies of InN layers plotted as functions of t_D and T_s. Closed diamonds, triangles, and circles correspond to 2D nuclei, 3D nuclei, and step-free surfaces of InN, respectively.