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III 族原料流量変調エピタキシーによる N-face GaN(000-1)成長

N-face GaN (000-1) grown by flow-rate modulation epitaxy of group-III precursors

日本電信電話㈱ NTT 物性科学基礎研　○林 家弘，赤坂　哲也，山本　秀樹
NTT Corp. NTT Basic Research Lab., °Chia-Hung Lin, Tetsuya Akasaka, Hideki Yamamoto
E-mail: ChiaHung.Lin@lab.ntt.co.jp

The use of N-face (000-1) InGaN/GaN multiple quantum wells is a promising way to achieve a wide range of emission wavelengths from blue to red regions in III-nitride-based optoelectronic devices because of enhanced In incorporation into N-face compared to Ga-face InGaN [1]. On the other hand, the crystalline quality of N-face (000-1) Ga-containing nitride thin films has been poor, with a high density of hillocks on the surface, mainly due to the lower surface migration of Ga adatoms on N-face (000-1) surface [2]. Flow-rate modulation epitaxy (FME) is expected to solve this problem by enhancing the surface migration of Ga adatoms. In typical FME sequences, *e.g.*, that for GaAs, the trimethylgallium (TMG) supply is switched on and off alternately [3]. However, this sequence is not suitable for GaN because GaN decomposes at typical growth temperatures (~1000°C) in the absence of TMG supply. In this study, we investigated a modified FME with Ga precursors and their flow rate modulations using TMG and triethylgallium (TEG) for N-face GaN (000-1) growth.

GaN films were grown on N-face (000-1) GaN bulk substrates using metalorganic vapor phase epitaxy. The source gases were TMG, TEG and NH_3, and the carrier gas was purified H_2. NH_3 was continuously supplied with the flow rate of 6.7×10^{-2} mol/min, while TMG (20.8 μmol/min) and TEG (10.4 μmol/min) were alternately supplied [Fig. 1(a)]. The duration of TMG for one cycle was kept constant (1 s), whereas that of TEG (t) was varied from 0 to 10 s. Totally 900 cycles of the FME sequence were repeated at the growth temperature of 1015°C. For comparison, we also grew samples using typical FME [Fig. 1 (b)].

Figure 2 shows the influence of duration (t) on the growth rate d (Å/cycle). The d value is almost unchanged with t for FME with TEG, whereas that in typical FME decreases with increasing t. This indicates that desorption of Ga adatoms is actually suppressed by the TEG supply. Namely, neither growth nor etching of GaN occurs during the TEG supply period at the designated rate of 10.4 μmol/min. Figure 3 plots hillock density as a function of t for the films grown by FME with TEG. The density decreases monotonically with increasing t, indicating that our modified FME method is effective for improving the surface morphology of N-face (000-1) GaN due to the enhancement of the surface migration of Ga adatoms.

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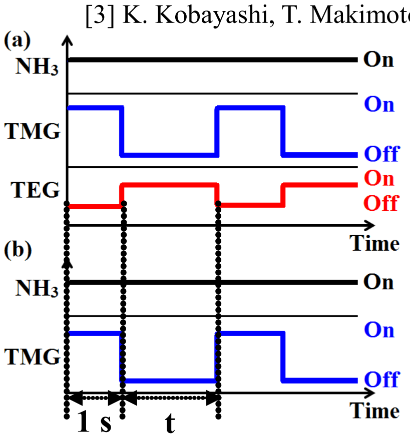

Fig. 1. Gas flow sequences in FME.

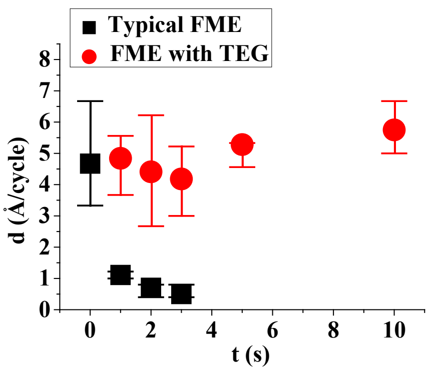

Fig. 2. TEG duration dependence of growth rate.

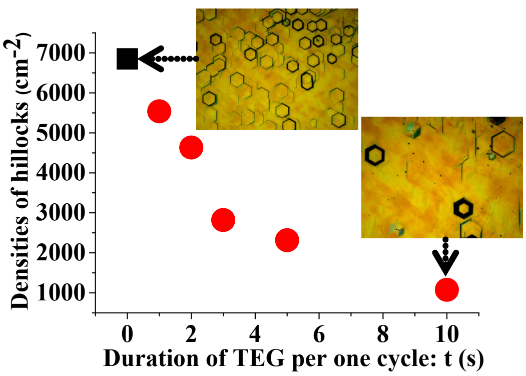

Fig. 3. Densities of hillocks on N-face GaN (000-1). The insets are plan-view optical microscopic images with t = 0 and 10 s, respectively.

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