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Effect of gas flow on the selective area growth of gallium nitride via metal organic vapor phase epitaxy

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Abstract

The effect of gas flow on the selective area growth (SAG) of gallium nitride (GaN) grown via metal organic vapor phase epitaxy (MOVPE) has been investigated. In this study, the SAG of GaN was carried out on a silicon dioxide striped pattern along the GaN $\langle 1\bar{1}00\rangle$ direction. SAG was initiated with the striped pattern oriented parallel and normal to the incoming gas flow in a horizontal reactor. The orientation of the pattern did not impact cross section of the structure after re-growth as both orientations resulted in similar trapezoidal structures bounded by the (0001) and $\{11\bar{2}n\}$ facets ($n\approx 1.7-2.2$). However, the growth rates were shown to depend on the orientation of the pattern as the normally oriented samples exhibited enhanced vertical and cross-sectional growth rates compared to the parallel oriented samples. All growths occurred under identical conditions and therefore the difference in growth rates must be attributed to a difference in mass transport of species.

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1. Introduction

Gallium nitride (GaN) is a promising semiconductor for use in a wide range of applications. The 3.4 eV band gap allows for emission of blue and ultraviolet (UV) wavelengths while the binary and ternary alloys in (Al, In, Ga)N can be engineered for emission over the entire visible spectrum. This makes the material useful for a number of optical applications such as solid-state lighting, biological sensing, and optical storage. Furthermore, the high electron saturation velocity and high breakdown field of GaN make it suitable for high-frequency and high-power applications [1].

GaN is typically grown heteroepitaxially on foreign substrates such as sapphire or silicon carbide [1]. The lattice mismatch between these materials leads to a large density of threading dislocations that reduce the lifetime [2] and efficiency of devices fabricated from this material by forming nonradiative recombination centers [3]. Typical films grown via metal organic vapor phase epitaxy (MOVPE) have dislocation densities ranging from 10^9 to $10^{11}\,\mathrm{cm}^{-3}$ [1,2]. Extensive research efforts have focused on reducing the dislocation density through methods such as epitaxial lateral overgrowth (ELOG) [1] and pendeoexpitaxy [4]. ELOG has been demonstrated to reduce the dislocation density a few orders of magnitude to $10^7\,\mathrm{cm}^{-3}$ [1,5].

The ELOG process involves partially masking a GaN layer with a striped dielectric pattern and then continuing GaN growth. Because GaN selectively grows only on the exposed GaN areas, growth begins in the pattern openings and extends laterally over the pattern. The ELOG process is heavily dependent on the selective area growth (SAG) of GaN, and therefore a complete physical model of GaN SAG would allow us to further utilize this technique by examining the dependence of morphology on growth parameters. A comprehensive model would also extend

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the possible applications of SAG techniques beyond dislocation reduction to directly implementing three-dimensional structures in device fabrication. For example, it has been demonstrated that GaN SAG structures with a square cross section could be implemented as low loss waveguides [6].

The effects of the various growth parameters on the morphology of GaN SAG on a striped dielectric pattern in rotational environments have been previously investigated. The majority of these studies investigated the effect of growth conditions for ELOG. Before coalescence, ELOG growths typically result in three-dimensional structures bounded by some combination of the (0001), $\{11\bar{2}2\}$, and $\{11\bar{2}0\}$ facets and exhibit square, triangular, or trapezoidal cross sections. Growth parameters investigated include temperature, pressure, V/III ratio, and the pattern fill factor. Low growth temperatures result in $\{1\bar{1}01\}$ sidewalls and poor surface morphology due to the decreased migration of gallium species. Increased growth temperature results in $\{11\bar{2}2\}$ sidewalls and improved morphology on the (0001) surface. Even higher growth temperatures lead to the formation of $\{11\bar{2}0\}$ sidewalls. Sidewall formation can be attributed to the number of dangling bonds on each surface. The $\{11\bar{2}0\}$ plane has fewer dangling bonds when compared to the $\{11\bar{2}2\}$ plane and therefore is energetically favored under high temperatures [7,8]. The $\{11\bar{2}2\}$ facet is comprised of rows of Ga–N dimmers with a probable configuration of two dangling bonds on the gallium atom and one dangling bond on the nitrogen atom indicating that this facet is most stable under low V/III ratios. Conversely, an equal number of gallium and nitrogen atoms, with one dangling bond each, exist on the $\{11\bar{2}0\}$ facet causing this facet to be stable under high V/III ratios [9]. The local V/III ratio increases as the ELOG growth laterally extends over the mask and the concentration of gallium species diffusing from the mask to the growth location decreases resulting in the transformation from $\{11\bar{2}2\}$ facets to $\{11\bar{2}0\}$ facets [10]. Furthermore, it has been demonstrated that flow modulation of ammonia (NH_3) can be used to control the morphology [11]. As the NH_3 interruption time increased, the lateral growth rate increases and is credited to the enhanced diffusion of the gallium species during the NH_3 interruption.

All of the studies mentioned have investigated the growth in rotational environments. It is the goal of this work to expand our initial investigation of the effect of gas flow [12,13] on the morphology of the SAG of the GaN in a nonrotating environment in order to further develop a complete physical model. In this study, the SAG of GaN was carried out on a silicon dioxide striped pattern via MOVPE.

2. Experimental procedure

Approximately a 1.5 μm thick GaN film was grown on a 2 in. diameter c-plane sapphire wafer via MOVPE using a two step process involving a ~30 nm aluminum nitride nucleation layer followed by a high-temperature GaN main layer in an AIXTRON 200/4 RF-S horizontal reactor. In this system, the metal organic and hydride source gases enter at the center of one end of the reactor and are separated by a quartz plate until mixing directly before the susceptor. Trimethylgallium and ammonia were used as the source gasses while hydrogen was used as the carrier gas. Next, a 130 nm layer of silicon dioxide was deposited via plasma enhanced chemical vapor deposition (PECVD) by an Oxford Plasma Lab 80 Plus system. Standard photolithography and wet etching techniques were used to create a striped pattern in the silicon dioxide layer along the GaN $\langle 1\bar{1}00\rangle$ direction as shown in Fig. 1a. Both the window opening and the stripe width were 5 μm. Two similarly sized pieces, each approximately 1/6 of a 2 in. wafer, were placed side by side in a line normal to the incoming gas flow in the reactor for re-growth. One sample was placed with the striped pattern oriented parallel to the incoming gas flow and the other with the striped pattern oriented normal to the incoming gas flow as shown in Fig. 1b. In roughly half of the growths, the samples with the striped pattern oriented parallel to the incoming gas flow were located on the left-hand side of the incoming gas, as shown in Fig. 1b. In the other growths, the samples with the striped pattern oriented parallel to the incoming gas flow were located on the right-hand side. This configuration was used in order to simultaneously fit two samples on the 2 in. susceptor and ensure similar growth conditions by eliminating the effects of uneven gas flow and substrate heating. The samples were grown with no rotation at 1115 °C, 200 mbar, and a V/III ratio around 1400. The ammonia and the carrier gas flow rates were around 1.2 and 4.0 slm, respectively. Table 1 summarizes the various growth parameters during the different stages of SAG.

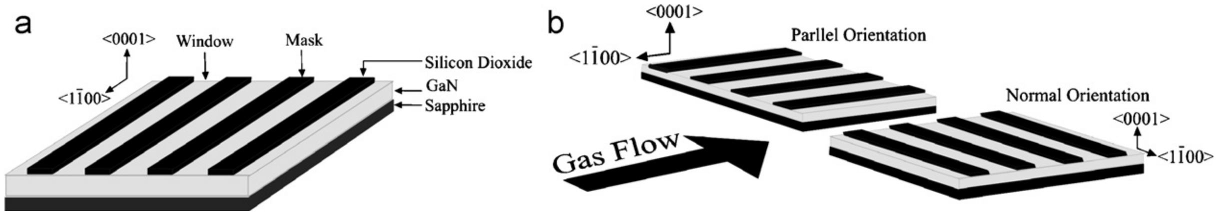

Fig. 1. (a) Striped pattern along GaN $\langle 1\bar{1}00\rangle$direction; (b) Samples oriented parallel and normal to the incoming gas flow during SAG of GaN.