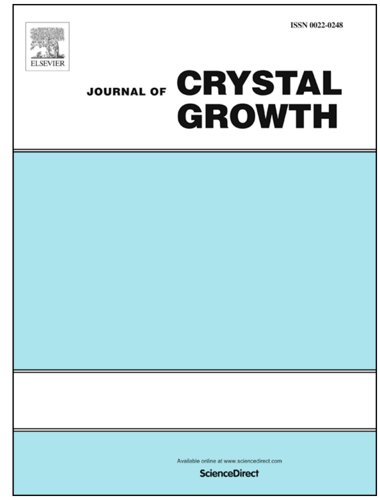
Accepted Manuscript



MOVPE growth of violet GaN LEDs on β-Ga_2O_3 Substrates

Ding Li, Veit Hoffmann, Eberhard Richter, Thomas Tessaro, Zbigniew Galazka, Markus Weyers, Günther Tränkle

PII: S0022-0248(17)30515-8
DOI: http://dx.doi.org/10.1016/j.jcrysgro.2017.08.023
Reference: CRYS 24274

To appear in: *Journal of Crystal Growth*

Received Date: 6 July 2017
Accepted Date: 17 August 2017

Please cite this article as: D. Li, V. Hoffmann, E. Richter, T. Tessaro, Z. Galazka, M. Weyers, G. Tränkle, MOVPE growth of violet GaN LEDs on β-Ga_2O_3 Substrates, *Journal of Crystal Growth* (2017), doi: http://dx.doi.org/10.1016/j.jcrysgro.2017.08.023

MOVPE growth of violet GaN LEDs on β-Ga_2O_3 Substrates

Ding Li, Veit Hoffmann, Eberhard Richter, Thomas Tessaro, Zbigniew Galazka, Markus Weyers, and Günther Tränkle

***Abstract*—We report that a H_2-free atmosphere is essential for the initial stage of metalorganic vapour phase epitaxy (MOVPE) growth of GaN on β-Ga_2O_3 to prevent the surface from damage. A simple growth method is proposed that can easily transfer established GaN growth recipes from sapphire to β-Ga_2O_3 with both (-201) and (100) orientations. This method features a thin AlN nucleation layer grown below 900 °C in N_2 atmosphere to protect the surface of β-Ga_2O_3 from deterioration during further growth under the H_2 atmosphere. Based on this, we demonstrate working violet vertical light emitting diodes (VLEDs) on n-conductive β-Ga_2O_3 substrates.**

***Index Terms*—B3. Light emitting diodes, B1. Oxides, A3. Metalorganic vapor phase epitaxy, A1. Nucleation**

I. Introduction

III-nitride semiconductor devices, such as light emitting diodes (LEDs), laser diodes (LDs), high electron mobility transistors (HEMTs), and field effect transistors (FETs), have attracted attention from both scientific and industrial communities for decades [1]. Some of their applications have already emerged in our daily life due to easy usage, high efficiencies and thus low carbon dioxide emission such as LED lighting, laser diodes for projector application, and efficient power convertors in electric vehicles. In general, nitride based devices are either heteroepitaxially grown on sapphire, Si, SiC etc. or homoepitaxially on GaN or AlN substrates. While sapphire is available in high quality at low costs it is not electrically conductive. Si, SiC, and GaN on the other hand are non-transparent in the deep ultra violet (UV) region. For devices with high Al content, a conductive substrate with transparency up to the deep UV and low lattice mismatch is desired.

Dr. Ding Li would like to thank the International Postdoctoral Exchange Fellowship Program of China under No. 20130042.

Ding Li, Veit Hoffmann, Eberhard Richter, Thomas Tessaro, and Markus Weyers are with the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany (e-mail: ding.li@fbh-berlin.de; veit.hoffmann@fbh-berlin.de; eberhard.richter@fbh-berlin.de; thomas.tessaro@fbh-berlin.de; markus.weyers@fbh-berlin.de).

Zbigniew Galazka is with the Leibniz-Institute for Crystal Growth (IKZ), Max-Born-Str. 2, 12489 Berlin, Germany (e-mail: zbigniew.galazka@ikz-berlin.de).

Günther Tränkle is with the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany, and also with the Leibniz-Institute for Crystal Growth (IKZ), Max-Born-Str. 2, 12489 Berlin, Germany (e-mail: guenther.traenkle@fbh-berlin.de).

Ga_2O_3 is an attractive substrate for III-nitride semiconductors since it is a transparent semiconducting oxide (TSO) [2] transparent down to 260 nm [3] . Its conductivity can be adjusted according to the demands [4]. Stable *β*-phase Ga_2O_3 bulk substrates can be achieved by the Czochralski method (CZ) [5, 6], edge-defined film-fed growth (EFG) [7], and floating zone growth (FZ) [4]. Bulk Ga_2O_3 substrates with high structural quality are commercially available up to 2 inch. *β*-Ga_2O_3 has a monoclinic structure with lattice constants of a = 12.214 Å, b = 3.037 Å, c = 5.798 Å, and *β* = 103.83° resulting in an in-plane lattice mismatch between c-plane GaN and *β*-Ga_2O_3 of 2.6-4.7 % [8]. The availability of bulk β-Ga_2O_3 single crystals with good electrical and optical properties [9-14] led to a demonstration of blue LEDs on β-Ga_2O_3 substrates [15, 16]. Deposition of a SiN_x mask on the substrate [15] or a thick AlN buffer layer [17] were employed to achieve high quality of the obtained structures. However, thick AlN layer would hinder the vertical transport of carriers while SiN_x potentially could lower the efficiency of light extraction from UV LEDs.

In this paper, we report on the thermal stability of (-201) β-Ga_2O_3 substrates in low pressure MOVPE in different growth environments by in-situ optical reflectance. Based on an optimized growth atmosphere, we have developed a growth procedure for GaN on both (-201) and (100) β-Ga_2O_3 substrates. Furthermore, vertical LED structures are demonstrated on conductive β-Ga_2O_3 substrate.

II. Experiments

β-Ga_2O_3 substrates used in the experiments are commercially available (-201) β-Ga_2O_3 wafers obtained by the EFG method with intentional Sn doping (n-type) [7] and (100) β-Ga_2O_3 substrates were prepared from crystals grown by the CZ method, which are available both semi-insulating and n-type states [5, 6]. They are all in stable *β*-phase. Thermal stability experiments were performed in an AIX200/4-RF-S reactor at 200 hPa using an Epicurve TT in-situ monitoring system, which allows to study the reflectance of the surface at 405 nm, 650 nm and 950 nm as well as the curvature during growth. In a first step, the (-201) β-Ga_2O_3 substrates were placed on a sapphire wafer in order to prevent contamination of the susceptor and heated up in different environments to 1150°C. β-Ga_2O_3 samples A, B and C were heated-up in pure H_2, pure N_2 atmosphere and N_2 + 2 % NH_3 atmospheres, respectively at temperatures 600, 710, 830, 880, 940, 990, 1050, 1100 and