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Influence of the PALE growth temperature on quality of MOVPE grown AlN/Si (111)

Ismail Altuntas [a,b], Merve Nur Kocak [b], Gamze Yolcu [b], Hasan Feyzi Budak [c], A. Emre Kasapoğlu [c], Sabit Horoz [d], Emre Gür [e], Ilkay Demir [a,b,*]

[a] *Department of Nanotechnology Engineering, Sivas Cumhuriyet University, 58140, Sivas, Turkey*
[b] *Nanophotonics Research and Application Center, Sivas Cumhuriyet University, 58140, Sivas, Turkey*
[c] *East Anatolia High Technology Application and Research Center, Atatürk University, 25240, Erzurum, Turkey*
[d] *Department of Electrical &Electronics Engineering, Siirt University, 56100, Siirt, Turkey*
[e] *Department of Physics, Faculty of Science, Ataturk University, 25240, Erzurum, Turkey*

A R T I C L E I N F O

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A B S T R A C T

In the present study, the PALE-AlN (pulsed atomic layer epitaxy) epilayers were grown on the Si (111) substrates at different growth temperatures by metal organic vapor phase epitaxy (MOVPE) technique. The oxygen (O) and silicon (Si) concentrations of grown PALE-AlN epilayers and interface between epilayer and substrate were investigated by secondary ion mass spectroscopy (SIMS). It was observed that O and Si concentration change with growth temperature of epilayers as well as the interface significantly. HRXRD (high-resolution x-ray diffraction) analyses showed that the highest growth temperature results with the lowest full width at half maximum (FWHM) value for both ω scans. Scanning electron microscope (SEM) and atomic force microscopy (AFM) analyses indicated that relatively low growth temperature grown samples gave rise to 2D-like growth mode with openings while increased growth temperature resulted in change the growth mode to a columnar mode with increasing V-shape pits because of the increasing diffusion coefficient of O impurities and Si atoms in AlN epilayers.

1. Introduction

III-nitride semiconductors have been taking remarkable attention due to their wide bandgap energy and, their high performance optoelectronic applications [1–3]. AlN, one of the III-nitride semiconductor materials, has the widest energy bandgap in the III-nitride semiconductors with an effective mechanical strength, and high chemical and thermal stability [4–8]. These extraordinary properties provide wide application areas in optoelectronic and electronic devices such as UV photodetectors-light emitting diodes, quantum cascade lasers, missile-warning systems, etc. [9–18]. Moreover, the AlN buffer layer has played a crucial role in GaN/Si high-power/high-frequency devices in recent years to be used in electric vehicles, wind tribunes, fast-chargers, etc. Since it is not possible to grow high quality GaN directly on Si substrate because of the reaction between Ga and Si, commonly known as melt back etching [19–24], it is bypassed effectively via the use of AlN buffer layers. But, several important inquiries stay unanswered about the initial phases of buffer AlN growth by metal organic vapor phase epitaxy (MOVPE) and how pre-growth exposure and other growth parameters affect the film quality. All mentioned devices above require high-quality AlN templates and there are two options to have high quality films; homoepitaxy on AlN substrate and heteroepitaxy on Si and Al_2O_3 substrates. Apparently, the most suitable option for the development of high-efficiency, long-lifetime, and high-performance devices is homoepitaxial growth on AlN substrates, but they are not generally preferred due to the limited size and extremely high cost [25,26]. One of the sustainable and affordable options for heteroepitaxial growth is to use Si as a substrate because of its scalability, low cost, and the opportunity to combine III-nitride devices on a single wafer with silicon microelectronics [1,27,28]. However, there are many challenges in epitaxial growth of AlN on Si such as high thermal expansion coefficient difference, high lattice-mismatch (19%), Si diffusion to the epilayer, low mobility of Al adatoms, and parasitic reaction between precursors, etc. [19,29–32]. There are some reports which demonstrate that it is inevitable to supply the TMAl (trimethylaluminum) to the reactor first to prevent the possible amorphous layers which occur at the interface [30,

* Corresponding author. Department of Nanotechnology Engineering, Sivas Cumhuriyet University, 58140, Sivas, Turkey.
E-mail address: idemir@cumhuriyet.edu.tr (I. Demir).

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