Dry Thermal Oxidation of GaN with SEM, AFM and XPS Characterization

D. Wei¹, J.H. Edgar¹, H. M. Meyer II†

¹Department of Chemical Engineering, Kansas State University, Manhattan, KS, 66506
²Microscopy Group, Oak Ridge Nation Lab, 1 Bethel Valley Rd, PO Box 2008, Oak Ridge, TN 37831-6064

Abstract

The oxidation of group three nitride semiconductor is an important aspect in the fabrication of high power transistors with insulated gates. Gallium nitride (GaN) has electrical properties that are superior to silicon, thus resulting in better performance (greater efficiency, higher power, and higher frequency) in many electronic devices. Such devices will be greatly enhanced by adding a high quality electrically insulating layer, and this may be prepared by thermal oxidation.

Dry thermal oxidation of polycrystalline GaN powder and GaN epitaxial layers was studied, over the oxidation temperatures from 800°C to 1000°C for up to 6 hours. The physical and chemical properties of the oxides were characterized by scanning electron microscopy (SEM), atomic force microscopy (AFM) and x-ray photoelectron spectroscopy (XPS) respectively.

1. Introduction

Properties of GaN

Material Properties:

- Wide band gap (3.4 eV at room temperature)
- High electron mobility (from 440 to >1500 cm²/Vs)
- High Melting point (>2500°C)

Benefits to devices:

- Operating at high frequency (85 GHz)
- Smaller in size, more energy efficient

Motivation for Studying GaN Oxidation

- Gate leakage current can be suppressed by adding an insulating layer of oxide.
- Achieve high quality interface between GaN and its native oxide.

2. Experimental Procedures

Pressure: Atmospheric

Source gases: O₂, 70 SCCM

Growth temperature: 800-1000°C

Reactant: Polycrystalline GaN powder, GaN epitaxial layers

Reaction equation: 2GaN + 3/2O₂ → Ga₂O₃ + N₂

3. Results and discussion

3.1 Crystal structure of Ga₂O₃

Little oxidation of GaN occurred at 800°C for 6 hours, because the XRD pattern matches that of pure GaN (Fig. 4). Above 900°C, the patterns match that of β-Ga₂O₃, which has been reported to be the most thermodynamically stable of the several allotropes of Ga₂O₃.

3.2 Surface morphology of GaN and Ga₂O₃

The surface becomes rough after oxidation, and roughness increased with increasing temperature. The oxide layers were etched away in a HCl: H₂O (1: 1) solution in order to characterize the interface between GaN and Ga₂O₃. The surface of GaN was also roughen after 950°C. This deteriorates the electrical property of the material. By AFM characterization, the roughness of surface after oxidation is larger than 200 nm, which is difficult to make a device.

3.3 Surface characterization of XPS

The thickness increased at elevated temperature. The gallium to oxygen ratio is approximately 1:1, which may due to the different preference to the ion sputtering.

3.4 Reaction kinetics of GaN oxidation

The kinetics was calculated based on the XRD pattern intensity of Ga₂O₃. Above 800°C, the reaction is interfacial-controlled. At 1000°C, there are two reaction stages. Initially, the reaction follows an interfacial-controlled reaction mechanism. As the oxide layer thickens, the reaction mechanism changes to diffusion-controlled.

4. Conclusion

- The electrical properties of an oxide are affected by surfaces roughness and non-uniform layer thickness.
- The best oxidation temperature is between 900 and 950°C. This leads to a fast oxide growing rate and both smoother surface and oxide-semiconductor interface.

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