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

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The Toughest

## 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 800̊C to 1000̊C 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 $cm^2$/Vs)

High Melting point (>2500̊C )

*Benefits to devices:*

Operating at high frequency (85 GHz)

Smaller in size, more energy efficient

→ Better semiconductor than Si for making transistors

### Motivation for Studying GaN Oxidation

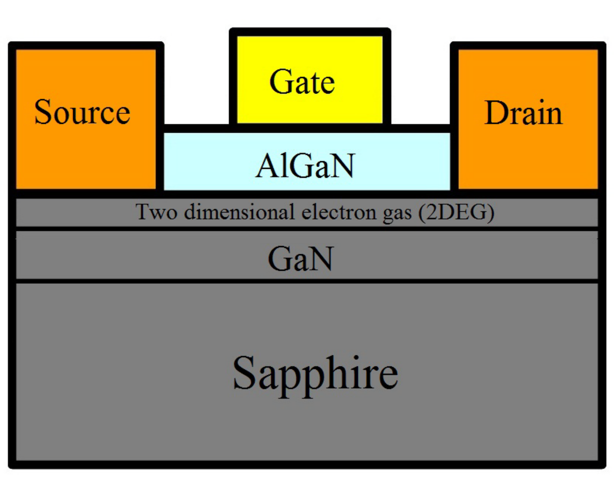



Figure 1. Schematic of a HEMT

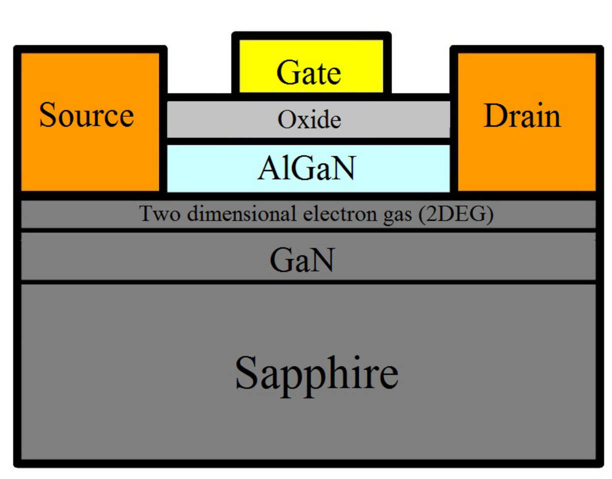



Figure 2. Schematic of a MOSHEMT

- 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

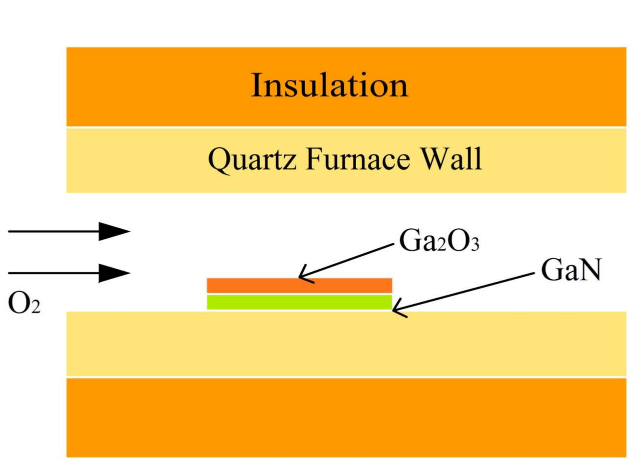



Figure 3. Schematic of GaN oxidation reaction

Pressure: Atmospheric

Source gases: $O_2$, 70 SCCM

Growth temperature: 800-1000̊C

Reactant: Polycrystalline GaN powder,
GaN epitaxial layers

Reaction equation: $2GaN+3/2O_2 \rightarrow Ga_2O_3+N_2$

## 3. Results and discussion

### 3.1 Crystal structure of $Ga_2O_3$

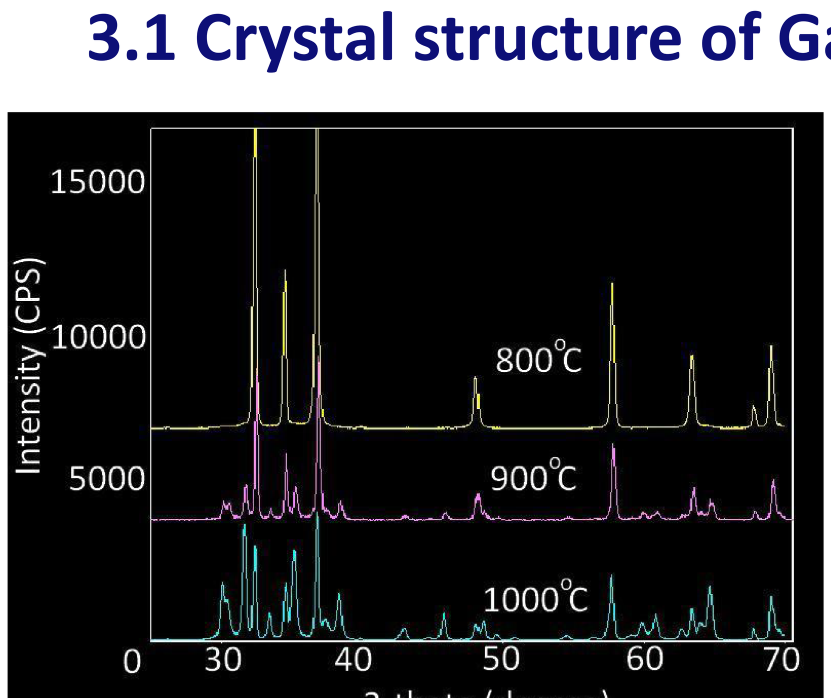


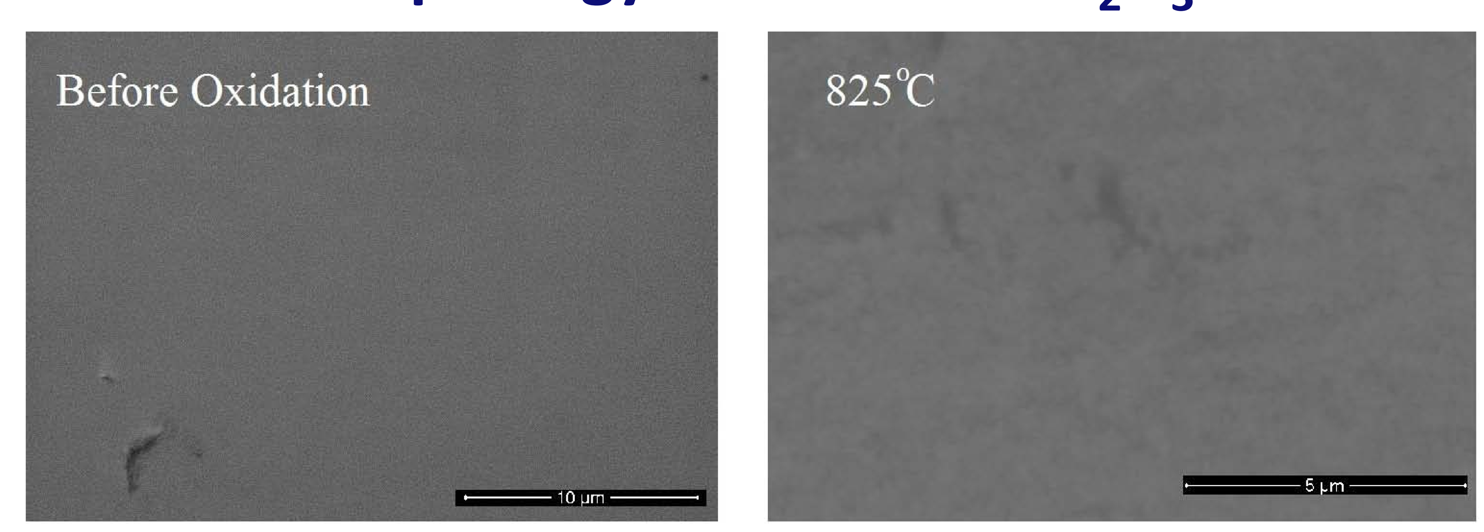

Figure 4. XRD spectrum of GaN after oxidation at 800, 900 and 1000̊C

Little oxidation of GaN occurred at 800̊C for 6 hours, because the XRD pattern matches that of pure GaN (Fig. 4). Above 900̊C, the patterns match that of β-$Ga_2O_3$ which has been reported to be the most thermodynamically stable of the several allotropes of $Ga_2O_3$.

| β- $Ga_2O_3$ | |
|---|---|
| Energy Bandgap (eV) | 4.7 |
| Breakdown voltage (MV/cm) | 2.1 |
| Specific resistivity (Ω cm) | $6\times10^{13}$ |
| Dielectric constant | 10.2-14.2 |
| Lattice constants at 300K (Å) | a=12.23±0.02<br>b=3.04±0.01<br>c=5.80±0.01 |

Table 1 Properties of β- $Ga_2O_3$

### 3.2 Surface morphology of GaN and $Ga_2O_3$



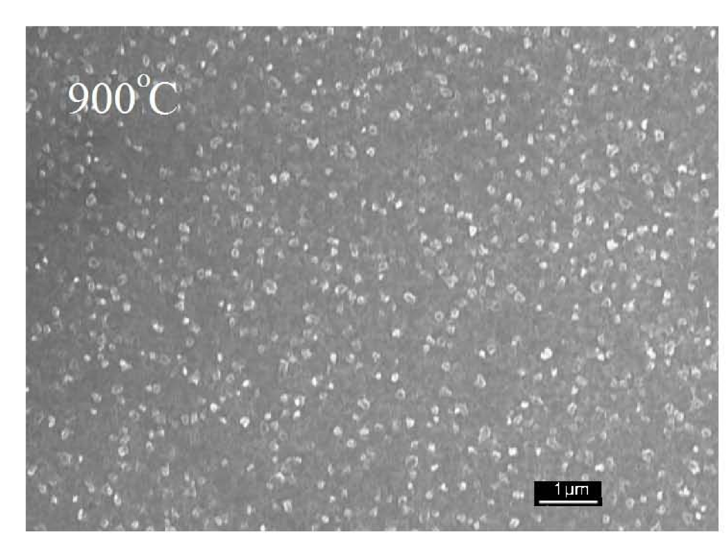
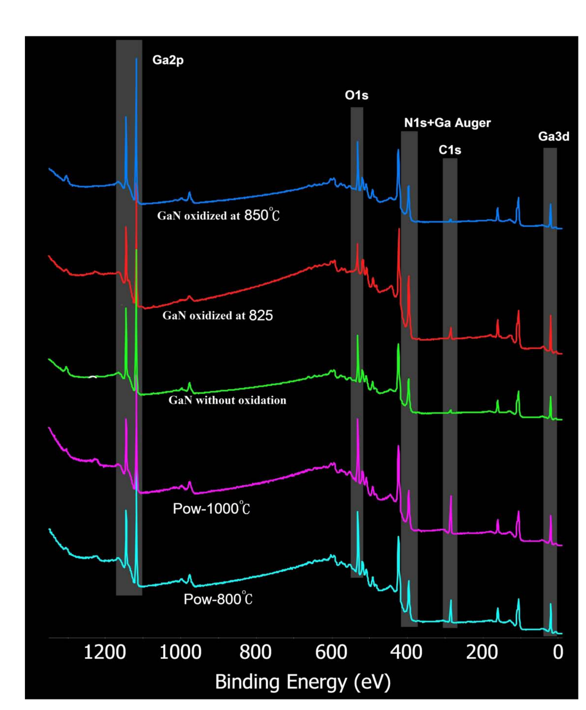




Figure 5. SEM images of $Ga_2O_3$ formed at different temperature

The surface becomes rough after oxidation, and roughness increased with increasing temperature. The oxide layers were etched away in a HCl: $H_2O$ (1: 1) solution in order to characterize the interface between GaN and $Ga_2O_3$. The surface of GaN was also roughen after 950̊C. 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



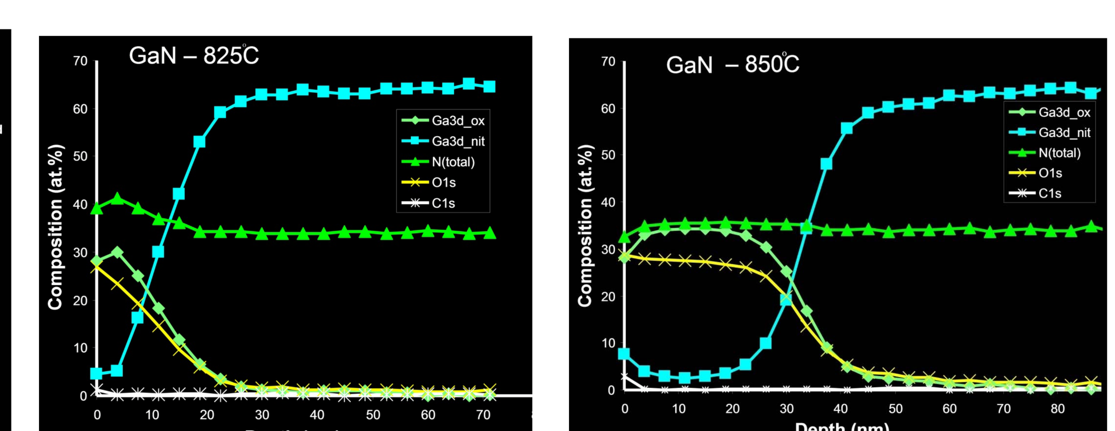




Figure 6. XPS survey and depth profile of GaN oxidation at different temperature.

The carbon concentration is higher on the GaN powder surface than that of the GaN wafer.

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 $Ga_2O_3$.

$I^n=k\times t$

Above 800̊C, the reaction was interfacial-controlled. At 1000̊C, 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 950̊C. This leads to a fast oxide growing rate and both smoother surface and oxide-semiconductor interface.

## Acknowledgements

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