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Low Temperature and Rapid Oxidation of GaN Surface by Saturated Water Vapor in High Pressure

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Abstract

A Gallium oxide layer was successfully formed on a GaN surface by the saturated water vapor oxidation in high pressure (350°C, 16.5MPa). The oxide layer of more than 1μm thickness can be grown in 15 minutes. The XPS analysis of the grown oxide layer showed the stoichiometric composition of Ga_2O_3. The rapid and low temperature process is applicable to a high performance device without thermal stress for GaN-FET.

Introduction

The field effect transistor (FET) devices on Gallium nitride (GaN), which have a wide bandgap, are promising for high power, high frequency operation. In order to improve the performance of FET, the formation of gate insulator film on semiconductor is a serious issue. High temperature (800-900°C) and long time are required to oxidize GaN surface by the conventional thermal oxidation.[1] Such high temperature oxidation shall introduce thermal stress, resulting in poor device performance. We have investigated the GaN oxidation process using high pressure water, so that GaN can be oxidized at low temperature

Experimental

Fig.1 shows temperature-pressure phase diagram of high pressure water. Around the critical point of water (374°C, 22MPa), water is a good medium for oxidation reaction. In this study, we evaluated GaN surface oxidation in supercritical water (SCW: 400°C, 25MPa), in high pressure hot water, and in hot saturated water vapor (350°C, 16.5MPa and 300°C, 8.5MPa).

Experiments were performed using a batch–type high pressure reactor, shown in Fig.2. Two GaN substrates were set in the reactor as shown in Fig. 2. One substrate was set in the bottom of the reactor and the other was set in the top. Appropriate volume of pure water was introduced and closed up tightly in the reactor. The reactor was heated up to the desired temperature, kept in the temperature in the desired time and cooled down naturally. By controlling the water volume in the reactor, the substrate in the top was always located beyond the gas/liquid interface. In other words, the top substrate went through the saturated water vapor to the desired temperature and the bottom substrate experienced the high pressure hot water environment as shown in Fig.3.

After the treatment, the X-ray photoelectron spectroscopy (XPS) analysis with Ar ion etching was carried out to obtain the depth profile of the atom composition ratio in the GaN film.

Results and discussion

Table 1 summarizes the experimental conditions and the results of GaN oxidation using high pressure water. Time 0(zero) minute represents that the reactor is cooled down immediately after the reactor is heated to the desired temperature. The SCW treatment (400°C, 25MPa) shows aggressive oxidation of GaN surface. However, too fast oxidation, which formed more than 1μm oxide layer at 0 minute, is not practically useful process. The high pressure hot water treatment and the saturated water vapor treatment at 300°C, 8.5MPa do not oxidize the GaN surface.

Fig.4 and Fig.5 show the depth profile of the atom composition in the GaN film after the saturated water vapor treatment at 350°C for 0 minute and 15 minutes, respectively. The 0 minute treatment forms the 5 nm Gallium oxide layer. The 15 minutes treatment forms more than 1μm oxide, which showed a stoichiometric composition of Ga_2O_3 (Ga:40%, O:60%). By controlling the time of the 350°C saturated water vapor treatment, the Ga_2O_3 layer of the desired thickness can be formed.

It is interesting that the high pressure hot water treatment at the same temperature 350°C does not form Gallium oxide. It is considerable that the high pressure hot water may dissolve the oxide. To investigate the mechanism, we applied the 350°C saturated water vapor treatment for 15 minutes and the 350°C high pressure hot water treatment for 15 minutes in a series. The result is shown in Fig.6. The Gallium oxide formed in the saturated water vapor is not etched by the high pressure hot water. It is thought that the saturated water vapor is the stronger oxidizer for the GaN than the high pressure water at 350°C.

Conclusion

We have achieved to form the stoichiometric Ga_2O_3 layer on GaN surface by the saturated water vapor oxidation at 350°C. The low temperature oxidation process will cotribute to improve the performance of future GaN-FET's.

References

[1] H. Kim et.al., J. Vac. Sci. Technol. B 19, 579 (2001).

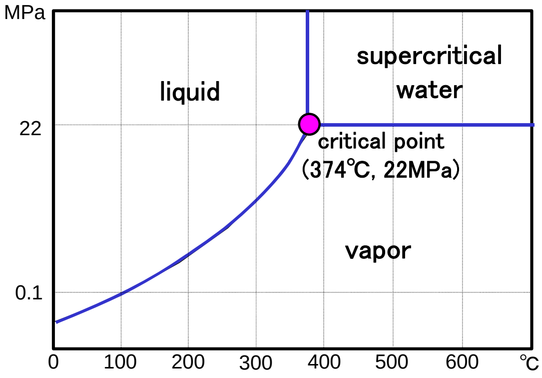

Fig.1 High pressure high temperature water

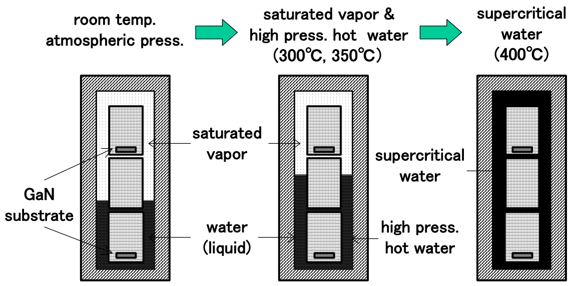

Fig.2 High pressure high temperature water reactor

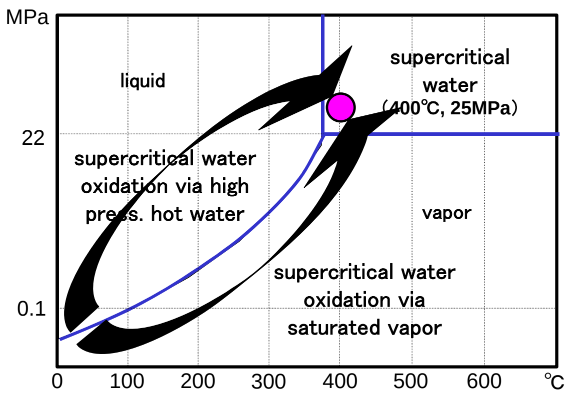

Fig.3 The trace of high pressure high temperature treatment in the experiment

Table 1 Sammary of the results

temp.	time	treatment environment	result
400℃	15 min	SCW via saturated water vapor	oxidation >1μm
		SCW via high press. hot water	oxidation >1μm
400℃	0 min	SCW via saturated water vapor	oxidation >1μm
		SCW via high press. hot water	oxidation >1μm
350℃	**15 min**	**saturated water vapor**	**oxidation >1μm**
		high press. hot water	no oxidation
350℃	**0 min**	**saturated water vapor**	**oxidation 5nm**
		high press. hot water	no oxidation
300℃	15 min	saturated water vapor	no oxidation
		high press. hot water	no oxidation
300℃	0 min	saturated water vapor	no oxidation
		high press. hot water	no oxidation

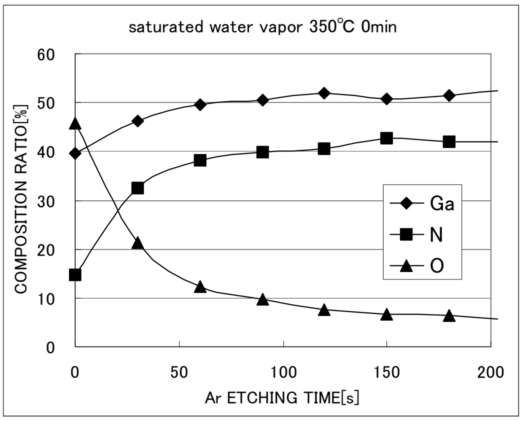

Fig.4 XPS atom composition profile of the sample treated in saturatede water vapor at 350°C 0min

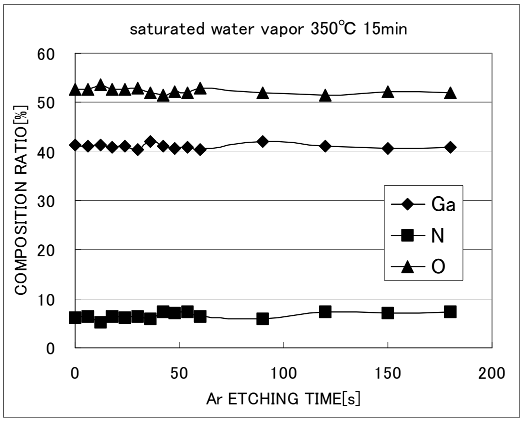

Fig.5 XPS atom composition profile of the sample treated in saturated water vapor at 350°C 15min

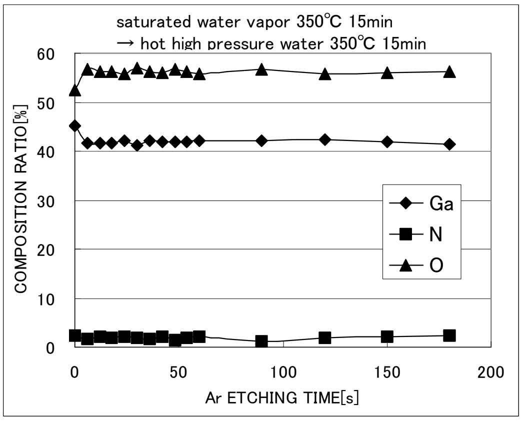

Fig.6 XPS atom composition profile of the sample treated in saturated water vapor and high pressure hot water treatment in a series.