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Monitoring of Plasma-Induced-Damage on GaN Cooled with Liquid Nitrogen

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We monitored the evolution of plasma-induced-damage on a gallium nitride (GaN) film with photoluminescence (PL) emission that was excited by an ultraviolet light. Our results showed that even argon plasma gives some changes on a GaN film, while the plasma gives only small changes on a GaN film by cooling GaN with liquid nitrogen. Here, the film temperature was kept below room temperature during the plasma exposure time. Our ex-situ X-ray photoelectron spectroscopy (XPS) measurements supported the small change as well so that the use of liquid nitrogen is likely effective to avoid the damage.

1. Introduction

Although the application to blue LEDs with GaN is successful, the application to high power devices is still on the way. The high-power devices made with semiconductors are attractive because high speed switching enables better electrical performances in a device such as an inverter. In order to achieve the application, it is necessary to use plasma processing in order to achieve anisotropic| etching/deposition or low-temperature processing. However, the use of plasma has a drawback in terms of the fact that the plasma could damage the surface of a substrate due to energetic ions, radicals, radiations, dusts, and charges etc. so that the semiconductor devices could be degraded. This drawback is generally called as plasma induced damage (PID).[1]

In this proceeding, we will show the effect to control the temperature of GaN films in processing plasma for the purpose of avoiding the damage. This idea came up because the processing temperature is sometimes controlled to let plasma affect differently to the surface.[2] The rate of chemical reactions exponentially increases according to Arrhenius equation, or the hardness of the material depends upon the temperature.[3]

2. Experimental Setup

In order to examine the temperature effect, we first created an inductively coupled plasma (ICP) with argon gas so as to expose n-GaN (that doped with 2×10^{18} cm^{-3} silicon). The GaN was made with metalorganic vapor phase epitaxy (MOCVD) method, and grown at 2 μm thickness on a 550 μm sapphire substrate. The plasma was operated at 200 watts so that the power achieved H-mode plasma in this experiment. The plasma here was made amplitude modulation at 500 Hz with 50 % duty cycle in order to realize in-situ measurement (discussed later). Here, the stage to locate the GaN was floating so that the stage should be negatively biased due to the asymmetric area of the electrodes. The pressure was maintained at 4 Pa with 15 sccm argon flow and fully pumped with a turbo molecular pump. (The base pressure of this reactor is 10^{-4} Pa).

The PL was obtained by exciting with a xenon-mercury lamp (Hamamatsu, L8858) filtered at 313 ± 5 nm. The emitting spectrum was collected through an optical fiber with 50-time software accumulations to increase signal-to-noise ratio. The PL spectrum was taken at 950 μsec. after the plasma turned off with 50 μsec. photon-collection time. Here, the PL spectrum indicates the GaN film condition. Argon plasma is supposed to make only physical damages so that the plasma exposure creates the crystal defects and dislocations. This means that the PL indicates the averaged degree of damages from the surface of the GaN down to the depth at 75 nm according to the calculation with the attenuation coefficient. [4]

We simultaneously monitored the surface temperature of GaN film with T-type thermocouple (Okazaki, GB087191) during PL measurement. This thermocouple is covered with a piece of aluminum plate in order to avoid additional temperature increase by ion bombardments from plasma.

3. Experimental Results

3.1 *In-situ measurements with PL from GaN*

Fig.1 shows PL spectrum from the surface of GaN for three different samples; a) pristine GaN, b) the sample exposed in argon plasma with liquid nitrogen (LN_2) cooing, and finally c) the sample exposed in argon plasma without LN_2. All samples were measured in low-pressure (4 Pa) chamber at approximately room temperature.

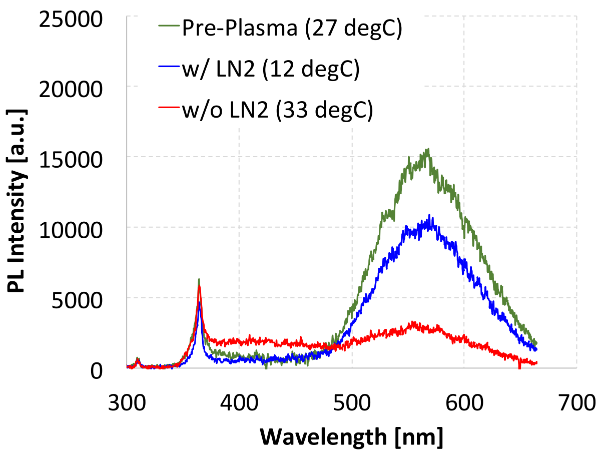


Fig.1. PL spectrum from the surface of GaN samples treated with three different experimental conditions.

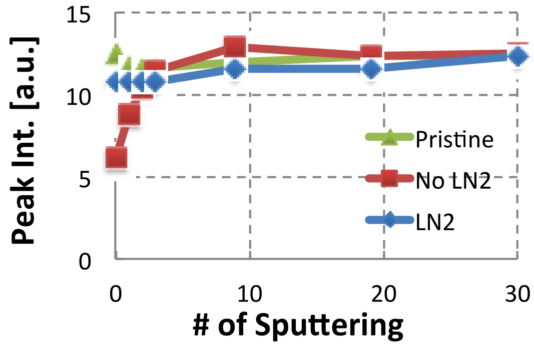
As seen in the figure, the total intensity of the PL decreased the most for the plasma exposure without LN_2. (The integration area decreased to 71 % with LN_2 cooling and 35 % without LN_2 cooling from the pristine sample.) This result indicates that the lowering temperature is effective to avoid PID in terms of PL emission.

Our in-situ temperature measurement of the GaN film showed that the temperature increased up to 25 °C with LN_2 cooling and 170 °C without LN_2 cooling after 15-minute plasma exposure. This indicates that the processing temperature should not exceed 170 °C and might as well keep the temperature as low as room temperature.

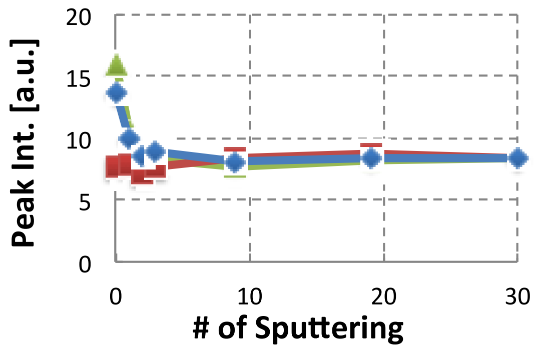
3.2 *Ex-situ measurement with XPS*

Fig. 2 shows the depth profile that was derived from XPS spectra. In order to find the depth profile, GaN film was sputtered with argon ion beam that was energized at 4 kV. Here, the sputtering time was set at 6 seconds so that each sputtering achieves 1 – 2 nm etching. In the figure, we focused on the two fundamental elements in GaN; (a) gallium (Ga) and (b) nitrogen (N).

As seen in the figure, the GaN that was exposed in argon plasma with and without LN_2 had fewer Ga and N atoms just below the surface than the pristine samples. This means that we likely had Ga and N desorption when GaN was exposed in plasma and the amount of desorption depends on the surface temperature. However, one might notice that the temperature looked too low to observe the desorption for both elements. For example, Ga should be desorbed at 450 °C and N should be done at 800 °C for GaN made with MOCVD method according to Ref. [5]. This result indicated that the plasma gives additional activation energy to make those kinds of desorption from the GaN.



(a) Ga3d Region



(b) N1s Region

Fig.2. XPS spectrum from GaN film for three different conditions.

4. Conclusion

From the experiments shown above, we can conclude that the regulation of the GaN temperature is important to reduce PID when exposed in plasma. In particular, plasma likely assists the desorption of Ga and N atoms from GaN with the surface temperature.

References

[1] K. Eriguchi, M. Kamei, K. Okada, H. Ohta, K. Ono: Emerging Technologies and Circuits **66** (2010) 97.

[2] S. Tachi, K. Tsujimoto and S. Okudaira: Appl. Phys. Lett. **52** (1968) 616.

[3] I. Yonegawa, T. Hoshi and A. Usui: Jpn. J. Appl. Phys. **39** (2000) L 200.

[4] J. Muth, J. Lee, I. Shmagin, R. Kolbas, H. Casey, B. Keller, U. Mishra and S. DenBaars: Appl. Phys. Lett. **71** (1997) 2572.

[5] A. Hattori, K. Endo, K. Hattori and H. Daimon: Appl. Surf. Sci. **256** (2010) 4745.