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Etch end-point detection of GaN-based devices using optical emission spectroscopy

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Abstract

In this study, optical emission spectroscopy (OES) was performed to detect etch end-point during the etching of GaN/AlGaN-based devices. In-situ OES experiments during the etching were carried out to measure the etch product signals of AlGaN/GaN heterostructures as well as single III-nitrides. A possibility of detecting etch end-point by OES was identified for both optoelectronic devices and electronic devices using etch product emissions such as Al (396.1 nm) and Ga (417.2 nm). © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Etch end point detection (EPD); OES; AlGaN/GaN

1. Introduction

The fabrication of GaN-based optoelectronic devices or high power electronic devices requires dry etching of multi layer thin films. Currently, the etch end-points of these devices are controlled by the etch time, therefore, the etch depth is dependent on the etch rates of the multi-layer materials. Due to the fluctuation of the machine conditions, the etch rates of materials could change, and the etch depth of the mesa structure also could vary from run to run. If a suitable method of etch end-point detection can be found for the etching of III-nitrides, a reliable and accurate etch depth can be maintained regardless of the change in the machine conditions.

To detect etch end-point between separate layers, several techniques have been reported in the III–V semiconductor fields including optical emission spectroscopy (OES), mass spectrometry (MS), and laser reflectometry [1–3]. However, in the case of III-nitrides, only the optical and mass detection of etch products for the etch mechanism have been reported [4–7] and the studies on the etch end-point detection of III-nitrides have not been reported yet.

In this study, in-situ optical emission spectroscopy (OES) was performed to investigate a possibility of etch end-point detection during the etching of GaN-based devices.

2. Experiment

At first, for the end-point detection, optimized etch conditions for some III-nitrides were etched using inductively coupled Cl_2/BCl_3 plasmas. The details of the ICP equipment used in the experiments and etch data are described elsewhere [4–7].

The two main etch recipes and their etch rates of GaN, AlGaN, and AlN used in this experiment are summarized in Table 1. The percentage of Al in AlGaN used in this experiment was in the range from 10 to 17 atomic%. From the previous work [7], selective etching of electronic devices could be obtained with 90% Cl_2/10% BCl_3, 600 W/−120 V, and 30 mTorr (etch I) and non-selective etching of optoelectronic devices with 70% Cl_2/30% BCl_3, 600 W/−200 V, and 15 mTorr (etch II).

After that, in-situ OES experiments (SC Tech 402) during the etching were performed to monitor etch product signals from AlGaN/GaN heterostructures as well as those from single layers such as GaN, AlGaN, and AlN. Optical emission from the plasma was collected by the optical fiber positioned at the quartz window near sidewall in ICP system.

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3. Results and discussion

In order to use a specific OES peak as the signal for process control, the signal must be correlated to the etch trend of the material being etched. Direct correlation between GaN etching and the specific OES peaks from the etch products has been already reported [4] and this correlation was also confirmed by mass spectrometry [6]. Fig. 1(a) shows the optical emission spectra from 250 to 500 nm obtained during the etching of AlN, AlGaN and GaN using the etch II recipe shown in Table 1. Among the many emission peaks observed, the major emission peaks related to etch products were Al lines at 309 and 396 nm, AlCl line at 406 nm, Ga lines at 286, 294, 403 and 417 nm, GaCl line at 337 nm, and N_2 line at 358 nm. The strongest Ga line at 417.2 nm and Al line at 396.1 nm were chosen for the process monitoring since they provided relatively high signal-to-background ratios. Fig. 1(b) shows the change of two emission intensities during the etching of a AlN(450 nm)/$Al_{0.1}Ga_{0.9}N$(400 nm)/*n*-GaN(1500 nm)/*u*-GaN(500 nm) layer on the Al_2O_3 substrate using the etch II recipe. The thickness of each layer was measured by SEM and the etch time of the layers estimated from the measured thickness and their etch rates was inserted in the figure (dotted line), too. As shown in the figure, the Al emission intensity showed a maximum value when AlN was etched and the intensity was decreased at the AlN/$Al_{0.1}Ga_{0.9}N$ interface. However, no noticeable change of Al emission intensity was observed at the $Al_{0.1}Ga_{0.9}N$/GaN interface. In the case of Ga emission intensity, sudden increase of the signal was also observed near the AlN/ $Al_{0.1}Ga_{0.9}N$ interface, and again no noticeable change of the Ga intensity was observed at the $Al_{0.1}Ga_{0.9}N$/GaN interface. The insignificant change at the $Al_{0.1}Ga_{0.9}N$ /GaN appears to be related to the small change of composition of both Al (10% decrease) and Ga (10% increase) at the interface. In fact, the OES used in our experiment is a non-intensified photodiode array type, therefore, if OES equipped with an intensified photodiode array (which has a better signal-to-noise ratio) is used, we may be able to observe the change in the signal intensities at the interface.

A different type of multi-layer structure consisted of GaN (700 nm)/$Al_{0.17}Ga_{0.83}N$(700 nm)/GaN (2000 nm) on the Al_2O_3 substrate was etched for 5 min using two etch recipes (etch I and etch II) and in-situ monitored using OES. The measured optical emission intensities from Ga at 417 nm and Al at 391.1 nm are shown in Fig. 2(a) for the etching with the non-selective etch recipe (etch II) and Fig. 2(b) for the etching with the selective etch recipe (etch I). As shown in Fig. 2(a), with the etch II recipe, Al emission intensity showed noticeable changes at the interfaces of both GaN/ $Al_{0.17}Ga_{0.83}N$ and $Al_{0.17}Ga_{0.83}N$/GaN even though there

Table 1
The etch recipes and their etch rates of GaN, AlGaN, and AlN

Etch recipe	Gas combination	Inductive power/bias voltage	Pressure (mTorr)	Etch rate (nm/min) GaN	AlGaN	AlN
Etch I	90% Cl_2/10% BCl_3	600 W/−120 V	30	850	13	7.5
Etch II	70% Cl_2/30% BCl_3	600 W/−200 V	15	550	540	380

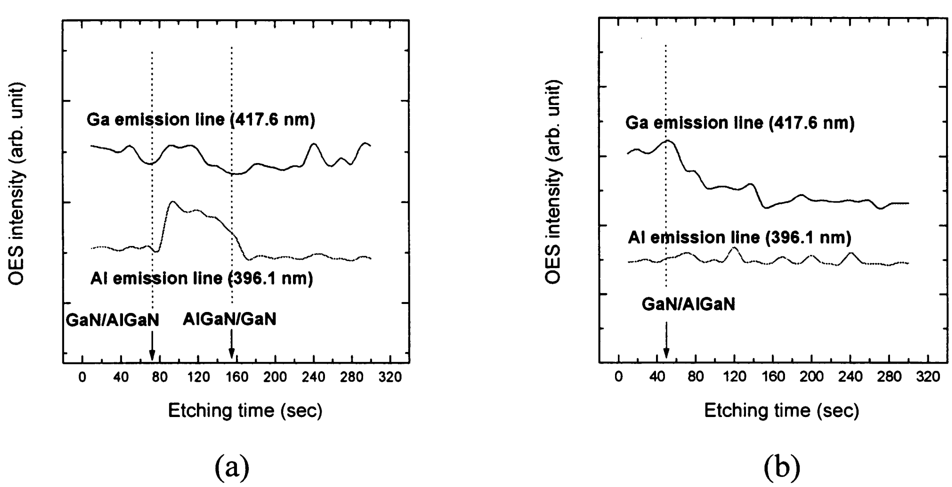
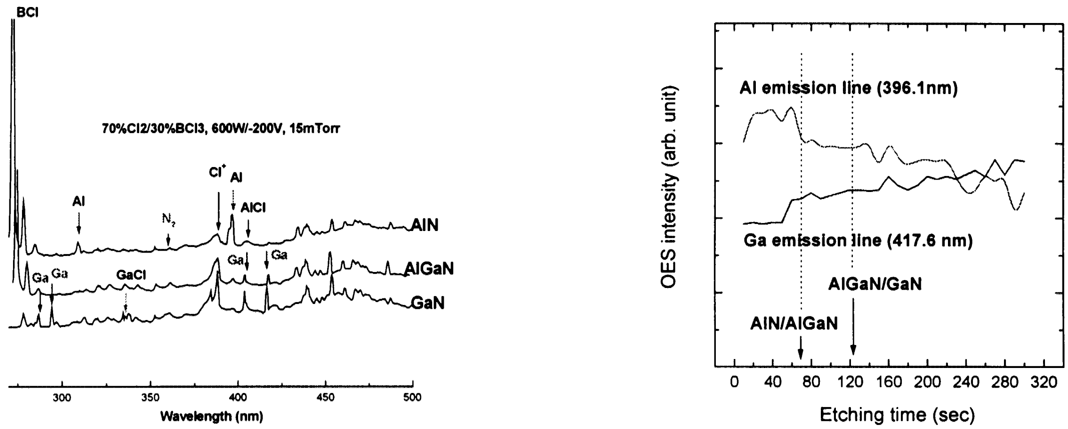


Fig. 1. (a) OES spectra during the etching of AlN, $Al_{0.1}Ga_{0.9}N$, and GaN and (b) the change of Ga and Al emission intensity during the etching of AlN (500nm)/$Al_{0.1}Ga_{0.9}N$ (400 nm)/*n*-GaN (1500 nm)/*u*-GaN (500 nm) layer on the Al_2O_3 substrate using etch II recipe shown in Table 1.



(a) (b)

Fig. 2. The change of Ga and Al emission intensities during the etching of the GaN(700 nm)/$Al_{0.17}Ga_{0.83}N$/GaN(700 nm)/*n*-GaN(2000 nm) layer on the Al_2O_3 substrate by (a) etch II recipe and (b) etch I recipe shown in Table 1.

is a tail at the interface of $Al_{0.17}Ga_{0.83}N$/GaN. However, in the case of Ga emission intensity, no noticeable change was observed at the both interfaces possibly due to the low signal change as observed in the $Al_{0.17}Ga_{0.83}N$/GaN interface in Fig. 1(b). When the etch I recipe was used to etch the same multilayer structure, Ga emission intensity showed a noticeable change with a tail at the GaN/$Al_{0.17}Ga_{0.83}N$ interface, however, no noticeable change of Al emission intensity was observed at the same interface.

No noticeable change of Al emission line and noticeable change of Ga emission line with the etch I recipe appear to be from the etch selectivity of the recipe. Because the etch rate of $Al_{0.17}Ga_{0.83}N$ is so slow that emission peaks from both Ga and Al can not be detected after the etch surface is reached at the GaN/$Al_{0.17}Ga_{0.83}N$ interface. Therefore, the apparent differences in the emission peaks is 50% for Ga and 0% for Al even though real composition changes at the interface are 17% for Ga and 17% for Al.

In GaN-based devices, the detection of the etch end-point at the interfaces such as AlGaN/GaN and GaN/AlGaN is very important in both various electronic devices and optoelectronic devices. GaN-based laser diodes are generally composed of *p*-GaN/AlGaN/active layer (InGaN/GaN multi quantum well)/AlGaN/*n*-GaN/buffer layer on the Al_2O_3 substrate. In this case, the multilayer film is non-selectively etched by time and stopped after it reached *n*-GaN layer which is used to form an *n*-contact [7]. If the etch rate varies, the remaining thickness of *n*-GaN layer and the damage to the *n*-GaN due to the etching can be also changed, and which results in the problem in the device reliability. The use of optical end point detection shown in Fig. 2(a) can help in detecting AlGaN/GaN interface, therefore, the thickness of remaining *n*-GaN layer and the damage to the wafer could be controlled.

In the case of certain GaN-based electronic devices such as GaN/AlGaN electronic device, precise control of etch end-point detection is more important due to the thin AlGaN layer exposed after GaN layer etching (called gate recess etching). The AlGaN layer is also very sensitive to etch damage in forming an ohmic contact. Therefore, not only highly selective GaN etching over underlayer (AlGaN) but also precise detection of etch end-point must be used to form a reliable and low resistance ohmic contact. The use of etch end-point detection with the selective etch recipe (etch I) shown in Fig. 2(b) will also improve the performance and reliability of the device.

Even though a possibility for the detection of the etch end-point of the interfaces such as AlGaN/GaN and GaN/AlGaN by OES was shown, to apply to the real devices, the following points should be addressed. As shown in Fig. 1(b), with the OES having a non-intensive type photodiode array, differences in the emission peaks from 10% compositional difference at the interface could not be detected. Therefore, to use the OES to detect the interface with low compositional differences, a more sensitive OES equipment or a recipe with higher etch rate should be used. At some interfaces, a tail of optical emission intensity was shown, therefore, the etch end-point was difficult to be determined. This tail can be from the non-uniform etching, residual etch products remaining in the chamber wall or on the sample as reported by other researchers for GaAs etching [3], or material itself due to the diffusion of the interface. In the case of tailing of the optical emission intensity due to the remaining etch product, careful determination of the etch end-point is required.

4. Summary

In this study, in-situ OES was performed to investigate a possibility of etch end-point detection during the etching of GaN-based devices. A possibility of detecting etch end-point was identified for both optoelectronic devices and electronic devices using Al emission at 396.1 nm and Ga emission at 417.2 nm.

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