A study of GaN-based LED structure etching using inductively coupled plasma

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Abstract. GaN as a wide band gap semiconductor has been employed to fabricate optoelectronic devices such as light-emitting diodes (LEDs) and laser diodes (LDs) [1, 2]. Etching is a required technique for patterning in the fabrication process of optoelectronic devices. Due to the chemical inertness and high thermal stabilities of GaN, a wet etching method without assistance is not suitable. Recently several different dry etching techniques for GaN-based materials have been developed [3-7]. Among these dry etching methods ICP etching is attractive because of its superior plasma uniformity and strong controllability. Most previous reports emphasized on the ICP etching characteristics of single GaN film. In this study dry etching of GaN-based LED structure was performed by inductively coupled plasmas (ICP) etching with Cl₂ as the base gas and BCl₃ as the additive gas. The effects of the key process parameters such as etching gases flow rate, ICP power, RF power and chamber pressure on the etching properties of GaN-based LED structure including etching rate, selectivity, etched surface morphology and sidewall was investigated. Etch depths were measured using a depth profilometer and used to calculate the etch rates. The etch profiles were observed with a scanning electron microscope (SEM).

1. Introduction

GaN as a wide band gap semiconductor has been employed to fabricate optoelectronic devices such as light-emitting diodes (LEDs) and laser diodes (LDs) [1, 2]. Etching is a required technique for patterning in the fabrication process of optoelectronic devices. Due to the chemical inertness and high thermal stabilities of GaN, a wet etching method without assistance is not suitable. Recently several different dry etching techniques for GaN-based materials including reactive ion etching (RIE), electron cyclotron resonance (ECR) etching and inductively coupled plasma (ICP) etching have been developed [3-7]. Among these dry etching methods ICP etching is attractive because of its superior plasma uniformity and strong controllability. Yeom et al. investigated the effects of process parameters on the plasma characteristics and GaN etch properties of inductively coupled Cl₂/Ar and Cl₂/BCl₃ plasmas [8, 9]. Im et al. presented a parametric study of ICP dry etching of undoped, n-type and p-type GaN films with Cl₂-based plasmas [10]. Lin et al. compared the etching characteristics and etching induced damages of n-type GaN films using Cl₂/He and Cl₂/Ar [11]. Kim et al. studied the GaN etching properties with HBr-based inductively coupled plasmas such as Cl₂/HBr, BCl₃/HBr and HCl/HBr [12]. Kao et al. applied the etching results of undoped, n-type and p-type GaN using Ni mask to fabricate highly smooth and anisotropic facets on InGaN laser structure and create the GaN-based
material nanorods [13]. Most reports emphasized on the ICP etching characteristics of single GaN film. In this work, we focused on the etching properties of GaN-based LED structure including etching rate, selectivity, etched surface morphology and sidewall related to the key process parameters such as etching gases flow rate, ICP power, RF power and chamber pressure with Cl₂ as the base gas and BCl₃ as the additive gas. A detailed study was presented as below.

2. Experiment
In this work, GaN-based multiple quantum wells (MQWs) LEDs wafers were grown by metalorganic chemical vapor deposition (MOCVD). The LED structure comprised a 1.5μm thick undoped GaN layer, a 3μm thick n-GaN layer, a 0.15μm thick InGaN-GaN MQWs active layer, a 30nm thick p-AlGaN layer, and a 0.3μm thick p-GaN layer. A 480nm thick SiO₂ layer as etching mask was deposited on the surface of the GaN by plasma enhanced chemical vapor deposition (PECVD). A standard lithography process and wet etching were performed to form the patterns on the SiO₂ film as mask. Dry etching process was performed in an ICP system (Oxford Plasmalab System 100). Cl₂ was used as the base gas and BCl₃ was used as additive gases. The total gas flow rate was held at 50 standard cubic centimeters per minute (sccm). The ICP power was varied between 0 and 1200W, the RF power between 100 and 500W and the working pressure between 5 and 15mTorr. The temperature of the backside cooled sample chuck was kept at 23 °C during the etching process. Etch depths were measured using a depth profilometer after removing the SiO₂ layer in a buffered oxide etchant and used to calculate the etch rates. The etch profiles were observed with a scanning electron microscope (SEM).

3. Results and discussion
Figure 1 shows the etch rates of sample and the etch selectivity over SiO₂ with different gas combination at ICP power of 1000W, RF power of 100W and chamber pressure of 7mtorr. It can be seen from Figure 1 that the etch rate decreased with increased BCl₃ and the etch selectivity also decreased with increased BCl₃ percent in the gas mixture. The highest etch rate obtained was about 262 nm/min in pure Cl₂ gas. The etch selectivity decreased rapidly when BCl₃ was added into the pure Cl₂ gas and the selectivity was as high as about 66 in 100% Cl₂.

![Figure 1. Etch rate and selectivity as a function of Cl₂/BCl₃ gas ratio at 1000W ICP power, 100W RF power and 7mtorr chamber pressure.](image)

The effect of ICP power on the etch rate and selectivity is shown in Figure 2. During the etching processes the gas ratio, RF power and chamber pressure were held at 20%BCl₃/80%Cl₂ and 7mtorr, respectively. The etch rate increased as the ICP power increased from 300W to 500W. The etch rate decreased when the ICP power increased further. The initial increase of etch rate could be resulted...
from the increase of ion density as the ICP power increased. The decrease of etch rate may be due to the lower ion energy. The etch selectivity decreased with increased ICP power.

![Figure 2. Etch rate and selectivity as a function of ICP power at 20% BCl3, 100W RF power and 7mtorr chamber pressure.](image)

It is shown in Figure 3 that the etch rate and selectivity as function of RF power at ICP power of 1000W, gas combination of 20%BCl3/80%Cl2 and chamber pressure of 7mtorr. It can be seen from Fig. 3 that the etch rate increased monotonically as the RF power increased. This result is consistent with some previous studies. The etch rate increase due to increase of ion energy which is controlled by RF power. The highest etch rate was 717 nm/min when the RF power was 500W. The etch selectivity decreased first and then increased when the RF power increased from 150W to 500W.

![Figure 3. Etch rate and selectivity as a function of RF power at 20% BCl3, 1000W ICP power and 7mtorr chamber pressure.](image)

Figure 4 shows that effect of chamber pressure on the etch rate and selectivity at ICP power of 1000W, gas combination of 20%BCl3/80%Cl2 and RF power of 100W. The etch rate increased as the pressure increased and reached a maximum value, and then decreased with further increased chamber pressure. The highest etch rate obtained at chamber pressure of 10mtorr was about 253 nm/min. The etch selectivity increased monotonically as the chamber pressure increased.

![Figure 4. Etch rate and selectivity as a function of RF power at 20% BCl3, 1000W ICP power and 7mtorr chamber pressure.](image)
Figure 4. Etch rate and selectivity as a function of chamber pressure at 20% BCl₃, 1000W ICP power and 100W RF power.

Some etch profiles are shown in Figure 5. It can be seen that different etching parameters influenced the sidewall morphology. The increased BCl₃ percent in gas mixture reduced the etch anisotropy. The effect of ICP power on etch anisotropy is not obvious. Higher RF power could result in more perpendicular sidewall.

Figure 5. SEM photograph of some etch profiles with different etching parameters.

4. Conclusion
In summary, ICP etching of GaN-based LED structure was performed with Cl₂ as the base gas and BCl₃ as the additive gas. The effects of the key process parameters such as etching gas ratio, ICP power, RF power and chamber pressure on the etching properties of GaN-based LED structure was investigated. The highest etch rate was 717 nm/min at ICP power of 1000W, gas combination of
20%BCl3/80%Cl2, RF power of 500W and chamber pressure of 7mtorr. The etched sidewall morphology with different etching parameters was also investigated in this paper. It can be seen that the gas combination effect the etch anisotropy greatly.

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