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A study of GaN etching characteristics using HBr-based inductively coupled plasmas

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Abstract

In this study, HBr-based(Cl_2/HBr , BCl_3/HBr , and HCl/HBr) inductively coupled plasmas were used to etch GaN selectively over photoresist and its etch characteristics were investigated. The inductive power and dc bias voltage to the substrate were fixed at 1600 W and -150 V, respectively. Among the gas combinations used in this experiment, BCl_3/HBr showed the highest etch selectivity over photoresist and the etch selectivity of 1.5 with the etch rate of $6400 \text{ \AA}/\text{min}$ could be obtained with 40% $\text{BCl}_3/60\%$ HBr. Also, the most anisotropic GaN etch profiles could be observed with this gas mixture. The highest etch rate obtained was about $7700 \text{ \AA}/\text{min}$ for pure Cl_2 , however, the etch selectivity was lower than 0.6. Optical emission spectroscopy showed that the GaN etch rate and etch selectivity for BCl_3/HBr were related to the Cl_2^+ ions.

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1. Introduction

GaN-based semiconductors are very attractive materials for use in optoelectronic devices such as light emitting diodes and laser diodes and for developing high power devices. In order to fabricate GaN-based devices successfully, high etch rates, high etch selectivities, vertical etch profiles, and smooth sidewalls are required in the dry etching process. In general, chlorine-based plasmas have been used to obtain high etch rates and vertical etch profiles in the GaN etch processes [1–4]. To obtain high etch rates and highly vertical etch profiles in Cl-based gas mixtures, hard masks such as metal, SiO_2 , and a metal/photoresist etch mask have to be prepared instead of a conventional photoresist etch mask [2,3,5,6]. However, there are few reports on GaN etching selective to photoresist. If GaN etch processes selective to a

photoresist etch mask could be developed and optimized, then the etch process for the GaN device fabrication will be simpler and shorter.

In this study, HBr-based inductively coupled plasmas (ICPs) such as Cl_2/HBr , BCl_3/HBr , and HCl/HBr were used to etch GaN selectively over photoresist and the etch characteristics such as etch rates, etch selectivities over photoresist, and etch profiles were investigated as a function of these gas compositions. HBr was chosen as the base gas, because hydrogen containing halogen gases such as HBr have been used to obtain high selectivity over photoresist in the silicon etch process [7,8].

2. Experiment

In this study, an un-doped GaN film grown on (0001) sapphire wafers was used as the etch sample and $6 \mu\text{m}$ thick AZ9260 photoresist (PR) was used as the etch mask. GaN dry etching was performed in an ICP etcher using 13.56 MHz as the power supplies for both inductive plasma and bias voltage. The inductive power

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and dc bias voltage to the substrate were 1600 W and -150 V, respectively. HBr was used as the main gas and BCl_3 , HCl, and Cl_2 were used as additive gases. The total gas flow rate was maintained at 100 sccm and the working pressure was fixed at 1.27 Pa. The substrate temperature was kept at 3°C during the etching process to prevent photoresist from reticulating.

The etch rates of GaN and photoresist were measured using a depth profilometer (alpha-step 500, TENCO) and the GaN etch profiles were inspected using a scanning electron microscope (SEM, Hitachi Inc. S-2150). Optical emission spectroscopy (OES: SC Tech. PCM402) was used to monitor species such as Br, Cl, and Cl_2^+ to characterize GaN etch properties in BCl_3/HBr plasmas.

3. Result and discussion

Fig. 1 shows the etch rates of GaN and the etch selectivity over photoresist in HBr-based ICPs as a function of additive gases such as BCl_3 , Cl_2 , and HCl. As shown in the figure, in Cl_2/HBr gas combinations, the etch rates of GaN were increased almost linearly with increasing Cl_2 and the etch selectivities over photoresist were also increased from 0.15 up to 0.6 with increasing Cl_2 in the gas mixture. The highest GaN etch rate was about 7700 Å/min in 100% Cl_2 plasma. In the case of HCl/HBr gas combination, the change of GaN etch rates with increasing HCl in HCl/HBr was not significant. In fact, the GaN etch rates were slightly decreased with increasing HCl in the gas mixture and lower than

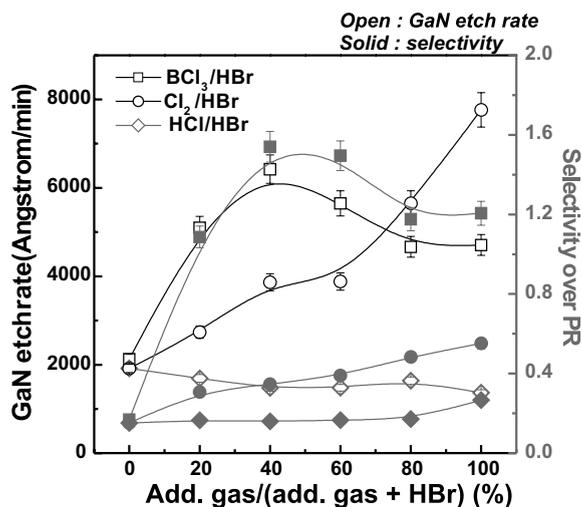


Fig. 1. Etch rates of GaN and etch selectivities over PR for various HBr-based etch gas combinations. (Etch conditions; inductive power: 1600 W, DC bias voltage: -150 V, pressure: 1.27 Pa, total gas flow rate: 100 sccm).

other gas combinations. This result may be due to the lower halogen atom density in HCl/HBr gas mixtures that is required to form volatile etch products compared to that in other gas mixtures, in addition to the recombination of hydrogen with halogen atoms. The etch selectivity over photoresist was slightly increased with the increase of HCl, however, the etch selectivity was generally lower than 0.3. In BCl_3/HBr gas mixtures, GaN etch rates were rapidly increased to 6400 Å/min with increasing BCl_3 up to 40%, however, the further increase of BCl_3 in the BCl_3/HBr decreased GaN etch rates monotonically. The etch selectivities over photoresist showed the same trend with GaN etch rates, and the highest etch selectivity of about 1.5 was obtained with 40% BCl_3 in BCl_3/HBr . To understand the effect of BCl_3 in BCl_3/HBr gas mixtures on the GaN etching, species in the BCl_3/HBr plasmas were investigated using optical emission spectroscopy.

Fig. 2 shows optical emission intensities of the species such as Br, Cl, and Cl_2^+ measured as a function of gas mixture in BCl_3/HBr . The monitored emission peaks for Cl, Br, and Cl_2^+ were 821.2, 700.5, and 430 nm, respectively. As shown in Fig. 2, the Cl atom intensity in the plasma was increased almost linearly with the increase of BCl_3 , while the Br atom intensity was decreased monotonically due to the increase of BCl_3 and the decrease of HBr in the gas mixture. Optical emission intensity from BCl radical also increased with the increase of BCl_3 (not shown). However, as shown in the figure, the optical emission intensity from Cl_2^+ ions was increased with increasing BCl_3 up to 40%, and the further increase of BCl_3 decreased the intensity similar to the trend of etch

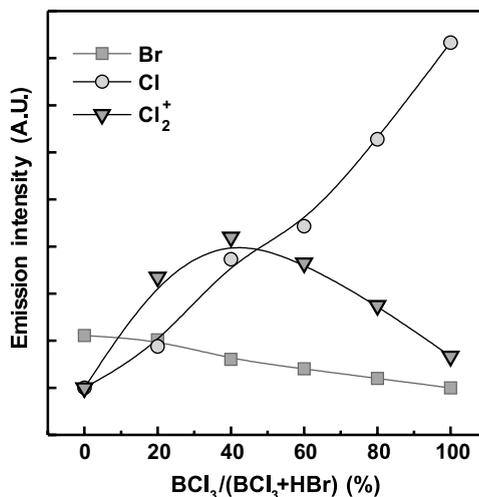


Fig. 2. Optical emission intensities of the species such as Br, Cl, and Cl_2^+ measured by OES as a function of BCl_3/HBr gas mixture. (Conditions; inductive power: 1600 W, pressure: 1.27 Pa, total gas flow rate: 100 sccm).

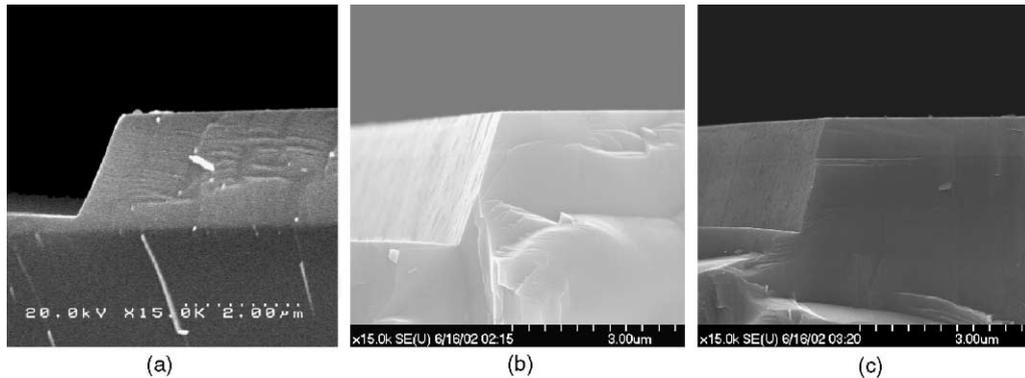


Fig. 3. SEM etch profiles of GaN masked with photoresist for various gas chemistries such as (a) 100% Cl_2 , (b) 100% BCl_3 , and (c) 40% BCl_3 /60% HBr . (Etch conditions; inductive power: 1600 W, DC bias voltage: -150 V, pressure: 1.27 Pa, total gas flow rate: 100 sccm).

rate shown in Fig. 1. Even though we did not investigate the ions and radicals for Cl_2/HBr and HCl/HBr plasmas by OES, the increase of Cl_2^+ ions with the increase of Cl_2 in Cl_2/HBr was also reported by other researchers [9], similar to the GaN etch rates observed in Fig. 1. From these results, it is believed that not only the chemical reaction of Cl atoms forming volatile etch products with GaN but also the surface bombardment by the energetic ions such as Cl_2^+ breaking the strong chemical bonding of GaN is important in the GaN etching. The similar trend of the etch selectivity over photoresist with that of etch rate for HBr-based gas combinations shown in Fig. 1 appears to be from the insensitivity of the photoresist etch rate for the etch gas combinations used in our experiment.

Fig. 3 shows SEM etch profiles of photoresist masked GaN for (a) 100% Cl_2 , (b) 100% BCl_3 , and (c) 40% BCl_3 /60% HBr plasma. The GaN etch depths were about 3 μm and SEM was taken after the photoresist stripping. As shown in Fig. 3, the most anisotropic and nearly vertical etch profile could be obtained in 40% BCl_3 /60% HBr plasma, and the lowest etch profile angle was obtained with 100% Cl_2 similar to the trend of etch selectivity over photoresist. Therefore, in our experiment, a nearly vertical etch profile with a very high etch rate close to 6400 $\text{\AA}/\text{min}$ could be obtained for photoresist masked GaN etching by using 40% BCl_3 /60% HBr .

4. Conclusion

In this study, HBr-based gas mixtures such as BCl_3/HBr , Cl_2/HBr , and HCl/HBr were applied to GaN etch processing using photoresist as the etch mask. The use of BCl_3/HBr showed the highest etch selectivity over photoresist while the use of 100% Cl_2 showed the highest GaN etch rate. The use of HCl/HBr showed the lowest GaN etch rate and etch selectivity possibly due to the

low halogen concentration in the plasma among the gas combinations used in the experiment. When 40% BCl_3 /60% HBr ICPs was used, the highest etch selectivity over photoresist close to 1.5 could be obtained with a high GaN etch rate of 6400 $\text{\AA}/\text{min}$. The GaN etch rate was strongly dependent on the energetic bombardment by the reactive ions such as Cl_2^+ as well as chlorine atoms to form volatile products in the GaN etch process. Nearly vertical GaN etch profiles could be obtained due to its high etch selectivity over photoresist and the high etch rate of GaN in 40% BCl_3 /60% HBr plasma.

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