REACTIVE ION ETCHING OF GaN THIN FILMS

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ABSTRACT

Reactive ion etching of GaN grown by electron-cyclotron-resonance, microwave plasma-assisted molecular beam epitaxy on (0001) sapphire substrates was investigated. A variety of reactive and inert gases such as CCl_2F_2, SF_6, CF_4, H_2/CH_4 mixtures, CF_3Br, CF_3Br/Argon mixtures and Ar were investigated. From these studies we conclude that of the halogen radicals investigated, Cl and Br etch GaN more effectively than F. The etching rate was found to increase with decreasing pressure at a constant cathode voltage, a result attributed to larger mean free path of the reactive species.

INTRODUCTION

The family of refractory nitrides (InN, GaN, AlN), their solid solutions and heterojunctions are one of the most promising families of electronic materials. All three binary compounds are direct bandgap semiconductors with energy gaps covering the region from 1.95eV (InN) and 3.4eV (GaN) to 6.28eV (AlN). These materials should find applications in optical devices (LED's lasers, detectors) operating in the green-blue-UV parts of the electromagnetic spectrum. Due to their unique physical properties, the materials are also expected to find applications in high temperature, high power, and high frequency electronic devices. However, the fabrication of such devices requires the development of a number of device processing techniques, including reactive ion etching.

There are limited reports in the literature regarding etching of GaN [1-4]. Pankove [1] reported that GaN dissolves in hot alkali solutions at very slow rates, and thus, wet etching is not practical for this strongly bonded material. Foresi [2] reported the reactive ion etching of GaN grown on the R-plane of sapphire using CCl_2F_2, and Adesida [3] reported the etching of GaN using $SiCl_4$. Pearton [4] investigated ECR microwave discharges for the etching of GaN, InN and AlN.

In this paper we report on reactive ion etching studies of GaN grown on (0001) sapphire substrates using a variety of reactive and inert gases. The effect of plasma parameters on etch rate, morphology and selectivity were investigated.

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EXPERIMENTAL METHODS

The GaN films were grown onto (0001) sapphire substrates by the method of electron-cyclotron-resonance microwave plasma-assisted molecular beam epitaxy (ECR-MBE) using a two temperature step growth process [5,6]. In this method a GaN buffer is grown first at low temperature (500°C) and the rest of the film is grown at higher temperatures. This process was shown [5,6] to lead to high lateral growth rate resulting in a layer by layer growth. The films have the wurtzite structure with the c-axis perpendicular to the substrate. Although the films were not intentionally doped they were found to be n-type with carrier concentrations in the order of $10^{18}cm^{-3}$, due presumably to nitrogen vacancies.

The ion etching of the GaN films was carried out in a parallel plate reactor supplied with 13.5 MHz RF power. Various patterns were formed on the top of the GaN films with AZ 1350 J photoresist. Various reactive and inert gases were employed. The depth of the profile of the etches was determined by a profilometer or by directly measuring the thickness by a cross-sectional SEM image. The quality of the etch morphology was also assessed by SEM imaging.

EXPERIMENTAL RESULTS AND DISCUSSION

First the etching rate from different reactive and inert gases was investigated. To compare the results the etching was carried out at the same gas pressure (11mT) and the same cathode voltage (600V). The results are listed in Table I.

Table I. Etching rates of GaN (11mT and 600V cathode voltage.)

Gas	Etching Rate (Å/min)
CCl_2F_2	185
CF_3Br	150
CF_3Br/Ar (3:1)	200
CF_4	120
SF_6	100
H_2/CH_4 (2:1)	30
Ar	65

From these results it is apparent that F is a less efficient etchant of GaN than the other halogen radicals Cl and Br. Etching by hydrogen radicals and physical sputtering are even less efficient processes. Nevertheless, the mixture of a certain percentage of Ar in CF_3Br improves the etching rate of the reactive gas.

The effect of gas pressure on the etching rate of GaN was investigated by using CF_3Br/Ar (3:1) and a constant cathode voltage of 600V. The results are shown in Figure 1.

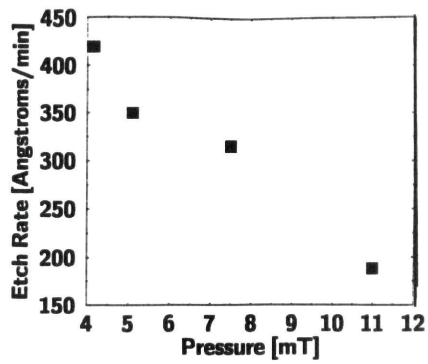

Fig. 1 Etch rate of GaN vs. the pressure of CF_3Br/Ar (3:1) at a constant cathode bias of 600V.

The higher etching rate at lower pressures suggests that the limiting step in the etching process is the mean free path of the halogen radicals. A typical etching profile obtained at 11mT of CF_3Br/Ar (3:1) and 600V of cathode voltage is shown in Figure 2.

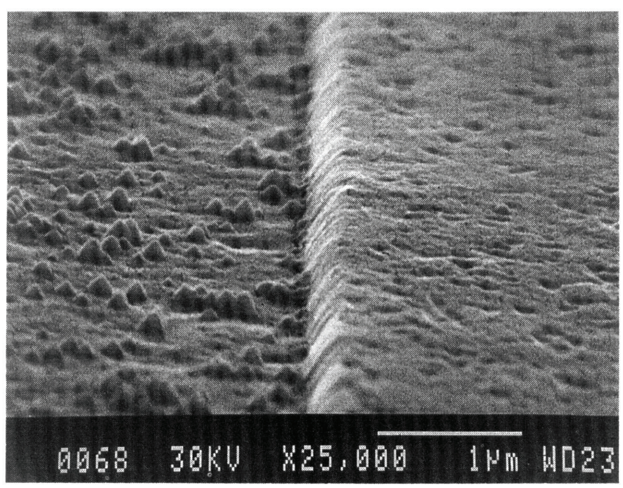

Fig. 2 A typical etch profile of GaN using CF_3Br/Ar (3:1) made under conditions described in the text.

We observed that the pyramidal features in the etching pattern are not present when etching was carried out at 5mT. By measuring the thickness of the photoresist prior to and after etching the selectivity at 5mT was found to be greater than 3:1 GaN to photoresist.

CONCLUSIONS

We report on reactive ion etching of GaN grown onto (0001) sapphire. Various reactive and inert gases were employed from which it was found that Cl and Br etch GaN more effectively than F. The effects of plasma parameters on etch rate and surface morphology were investigated using a CF_3Br/Ar mixture in a 3:1 ratio. Etch rate and surface morphology were found to improve at lower plasma pressure, resulting in an etch rate in excess of 400 Å/min at 4.2 mT.

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REFERENCES

1. J.I. Pankove, Electrochem. Soc. Vol **119**, 1110 (1972)

2. J. Foresi, M.S. Thesis (Boston University, 1991)

3. I. Adesida, A. Mahajan, E. Andideh, M. Asif Khan, D.T. Olsen and J.N. Kuzna Appl. Phy. Lett. **63**, 2777 (1993)

4. S.J. Pearton, C.P. Abernathy, F. Ren, J.R. Lothian, P.W. Wisk, A. Katz, and C. Constantine, Semicond. Sci. Technol. Vol **8** pg 310 (1993)

5. T.D. Moustakas, T. Lei and R. Molnar, Physica B 185 pg 36-49 (1993)

6. T.D. Moustakas and R. Molnar Mat. Res. Soc. Symp. Proc. Vol **281** (1993)