SELECTIVE RIE IN BCl_3/SF_6 PLASMAS FOR GaAs HEMT GATE RECESS ETCHING

Y.-S. Lee, K. Upadhyaya, and K. J. Nordheden

Plasma Research Laboratory
Department of Chemical and Petroleum Engineering
University of Kansas
Lawrence, Kansas 66045

ABSTRACT

A selective reactive ion etch process for GaAs HEMTs has been developed using BCl_3/SF_6 gas mixtures. The influence of gas flow ratio, pressure, and rf power on the selectivity was examined. An optimum selective etching process using a Plasma Therm 790 reactive ion etching system was determined to be 50 W rf power, gas flow ratio of BCl_3/SF_6=2.5 sccm/7.5 sccm, and chamber pressure of 50 mTorr.

INTRODUCTION

One of the most crucial processes in the fabrication of gallium arsenide-based field effect transistors is the recessing of the gate region, which requires the selective removal of a thin layer (<50 nm) of GaAs. Reactive ion etching has become the most attractive method for selectively removing the GaAs cap layer over the underlying AlGaAs or AlAs layer. Historically, CCl_2F_2 was used to investigate the feasibility of a selective gate recess etch for HEMTs. Although this chemistry showed good selectivity for GaAs over AlGaAs, the inability to independently control the fluorine to chlorine ratio as well as the disadvantage of possible polymer formation led to the investigation of inorganic gas mixtures. Typical selective dry etch chemistries are currently based on the combination of a chlorine donor, like BCl_3 or $SiCl_4$ with a fluorine donor, like SF_6 or SiF_4. The selectivity of these etches depends on the formation of a non-volatile layer of aluminum fluoride [1,2].

High density plasmas, such as ICP and ECR, have recently been used for selective etching [3]. Although these plasmas are known to operate under high density and low ion energy, device damage resulting from the high ion flux has been shown in some instances to be greater than for reactive ion etching [4]. Furthermore, it has also been shown that the high ion flux may in fact result in lower etch selectivity due to the desorption of etch stop products [5]. In this work, a selective reactive ion etching process for GaAs/AlAs/AlGaAs HEMTs has been developed using BCl_3/SF_6 gas mixtures. The influence of gas flow ratio, pressure, and radio-frequency (rf) power on the selectivity was examined. An optimum selective etching process using a Plasma Therm 790 reactive ion etching system was determined to be 50 W rf power, a gas flow ratio of BCl_3/SF_6=2.5sccm/7.5sccm, and a chamber pressure of 50 mTorr.

EXPERIMENTAL

Two different HEMT structures were provided by TriQuint Semiconductor, Inc. Both of them were grown by molecular beam epitaxy (MBE) on semi-insulating GaAs substrates and had a 300 Å GaAs cap layer, a 15 Å AlAs etch-stop layer, and a 165 Å AlGaAs layer. The wafers were processed through the ohmic contact layer and then patterned with PMMA to define openings in the channel. The selective dry etching experiments described in this study were performed in a Plasma Therm 790 parallel plate RIE system. The 10 in. diameter powered electrode was operated at 13.56 MHz. Gases were introduced into the plasma chamber through a showerhead configuration in the top of the chamber. Prior to loading the samples into the etching chamber, an oxide etch was performed. Two wet oxide removal methods were examined in this study to investigate their effect on etch uniformity. For the first, the samples were dipped in 1:30 solution of ammonium hydroxide:DI water for 30 s and then blown dry with nitrogen. For the second, the samples were dipped for 30 s in a 1:10 ethanol:hydrochloric acid solution, rinsed for 1 min in ethanol, followed by a blow dry with nitrogen. After etching the HEMT saturated current (I_{dss}) between drain and source was measured, and each value stated was an average of five readings across the ½" by ½" sample. Each data point on the curves corresponds to a new sample, and all data on each curve was from the same wafer. In addition, a piece from each wafer was selectively etched in a succinic acid solution [6] to determine the expected value of I_{dss} at the etch stop.

GaAs etch rates were determined from ½" by ½" full thickness mechanical samples which were patterned with AZ 4210 photoresist. The samples were pretreated in a 1:30 solution of NH_4OH/H_2O for 15 s and then blown dry to remove native oxide prior to loading the samples into the RIE chamber. After etching, the photoresist mask was removed and the resultant depths were measured with a Dektak II surface profilometer. Optical emission from the discharge was focused with a fused silica lens onto the slits (100 μm) of a Jobin Yvon Spex Triax 550 spectrometer and detected with a Hamamatsu R928 photomultiplier. The 750 nm argon emission line was chosen as an actinometer since it has been shown to be excited directly from the ground state and does not have a significant contribution from the argon metastable state.

RESULTS AND DISCUSSION

The GaAs etch rate as a function of SF_6 percentage in the flow is shown in Fig. 1. The total flow rate was held constant at 20 sccm, and the addition of SF_6 corresponded to a reduction in the amount of BCl_3 in the flow. The addition of SF_6 results in an increase in the etch rate until the composition reaches 55% SF_6 after which it starts to decrease. The rf power was kept constant at 150 W. It should be mentioned that the etch rate was observed to increase when the dc bias was kept constant as well, although the peak in the etch rate occurred at a higher percentage of SF_6 (70%) [6].

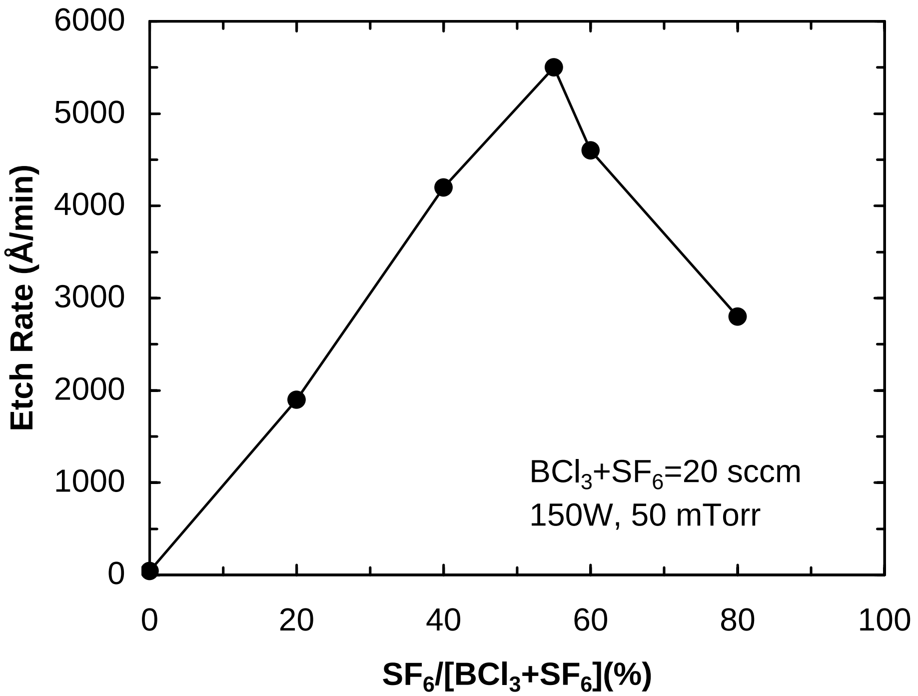

Fig. 1 Etch rate of GaAs as a function of SF_6 percentage in the flow.

In an attempt to explain the increase in the etch rate with the SF_6 addition, the normalized optical emission intensities for fluorine, chlorine, and argon as a function of SF_6 percentage in the flow were measured and the results are shown in Figure 2. The intensity of atomic chlorine increases with the addition of SF_6 and exhibits a maximum at approximately 70% SF_6. The excited state emission from argon also increases significantly with the addition of SF_6. These results combined with previous electron density measurements [6], indicate that an increase in the average electron temperature is responsible for an enhanced dissociation of BCl_3 [6], and hence an increase in the production of etch species. Optical emission from atomic fluorine increases slowly until about 70% SF_6 and then increases more rapidly thereafter.

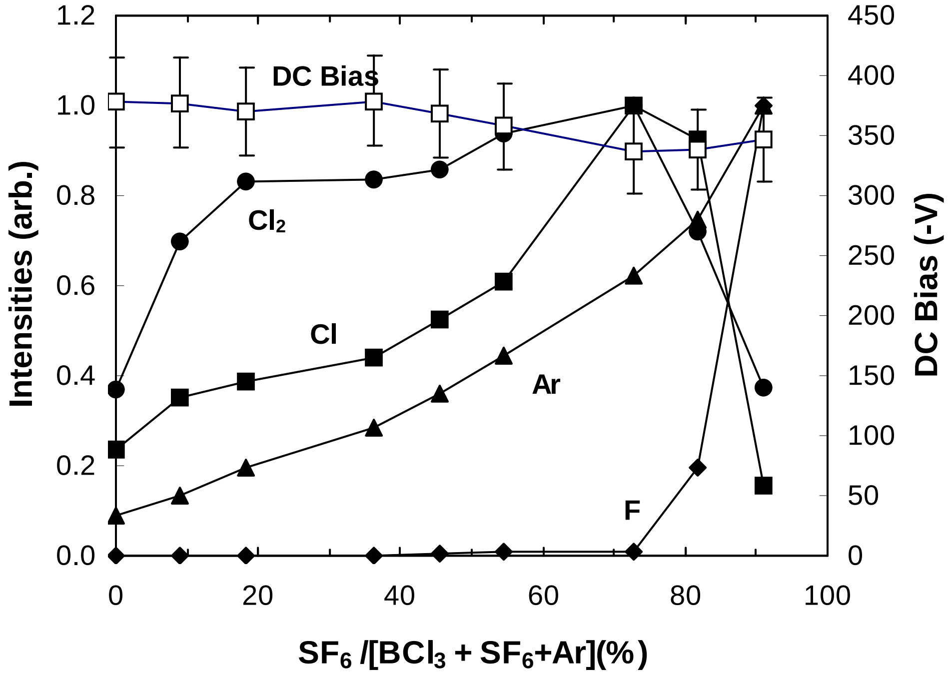

Fig. 2 Normalized optical emission intensities of Cl_2 (465.9 nm), Cl (725.3 nm), F (703.7 nm), and Ar (750.3 nm) as a function of SF_6 percentage in the flow. DC bias is also shown. (150W, 15 mTorr, 22 sccm)

Two different methods for removing native oxide were examined for the selective etch study. The first was a NH_4OH/H_2O (1:30) solution and the second was an ethanol/HCl (10:1) mixture. Non-uniform etching was observed on samples that were pretreated in the NH_4OH/H_2O solution. Previous work has shown that ammonium hydroxide solutions can cause etch initiation delays in BCl_3/SF_6 plasmas, presumably due to the formation of a gallium-rich oxide layer [8]. On the other hand, very uniform etching was observed on the samples which were pretreated with the ethanol/HCl mixture, indicating that this pretreatment may be a better choice for oxide removal prior to selective plasma etching.

The dependence of the selectivity on the gas composition was investigated. Fig. 3 shows the after etch I_{dss} as a function of etch time for different gas ratios (BCl_3/SF_6). The pressure, rf power, and total flow were held constant at 50 mTorr, 50 W, and 10 sccm, respectively. The percentage of SF_6 was varied from 50% to 80%. The two gas mixtures with 50% and 60% SF_6 (5/5 and 4/6 BCl_3/SF_6) show that the I_{dss} decreases with increasing etch time and then drops below the expected I_{dss} value (780 mA/mm) for longer etch times, indicating the etching process with these percentages is non-selective. When the SF_6 percentage was increased to 70% and 75% (3/7 and 2.5/7.5 BCl_3/SF_6), the I_{dss} decreases with increasing the etch time and then saturates at the expected etch stop value of 780 mA/mm, implying that the etches are selective. When the SF_6 percentage was increased to 80% (2/8 BCl_3/SF_6), the rate at which the I_{dss} decreases is much slower than for lower percentages of SF_6. This is consistent with the GaAs etch rate results in Fig. 1, which indicate that the peak etch rate occurs at 55% SF_6. The fact that the etch rate decreases at higher SF_6 percentages is most likely due to a combination of a decrease in the amount of chlorine available to etch the GaAs and an increase in gallium fluoride production (supported by the optical emission results in Fig. 2).

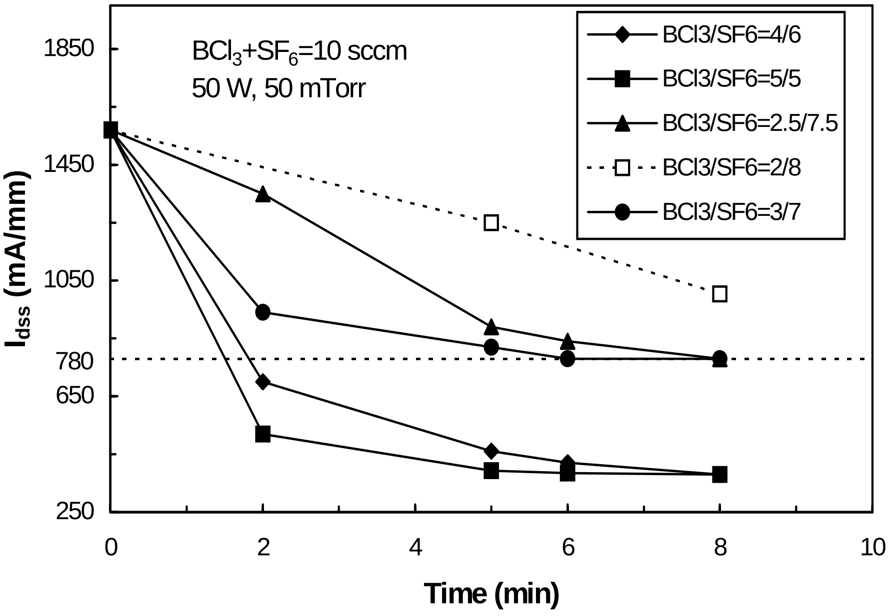

Fig. 3 I_{dss} as a function of etch time with BCl_3/SF_6 composition as a parameter.

The effect of rf power on the selective etching of GaAs/AlAs in BCl_3/SF_6 plasmas at a constant pressure of 15 mTorr was examined and the results are shown in Figure 4. The sample used for these data had lower doping which resulted in a lower expected etch stop current. The flow ratio of BCl_3/SF_6 and the total flow rate were also kept constant at 2.5/7.5 and 10 sccm, respectively, while the rf power was varied from 40W to 100W. For all rf power values studied, the I_{dss} initially decreased with increasing etch time and then either continued to decrease slowly or saturated, depending on the value of rf power. For an rf power of 100W, the I_{dss} drops to almost zero for an etch time of 8 min, indicating that the etch is not selective. This is probably due to high energy ion bombardment (higher bias voltage) which sputters away the AlF_3 etch stop layer. For both 50W and 60W cases, the I_{dss} saturates at etch times of 4 and 6 min, respectively. These results indicate that the ion energy corresponding to this rf power range is too weak to break through the stop layer AlF_3 and results in a selective etching process. For an rf power of 40W the I_{dss} decreases the most slowly and appears to begin to saturate at the expected I_{dss} etch stop value.

In Fig. 5, I_{dss} values are shown as a function of etch time while the pressure was varied from 15 to 100 mTorr. The rf power and gas ratio were held constant at 50 W and 2.5 sccm/7.5 sccm. At a pressure of 15 mTorr, the I_{dss} decreased sharply with etch time and did not show any sign of saturation. This non-selectivity is most likely due to the high bias voltage (-100 V), resulting in sputtering of any AlF_3 formation. At a pressure of

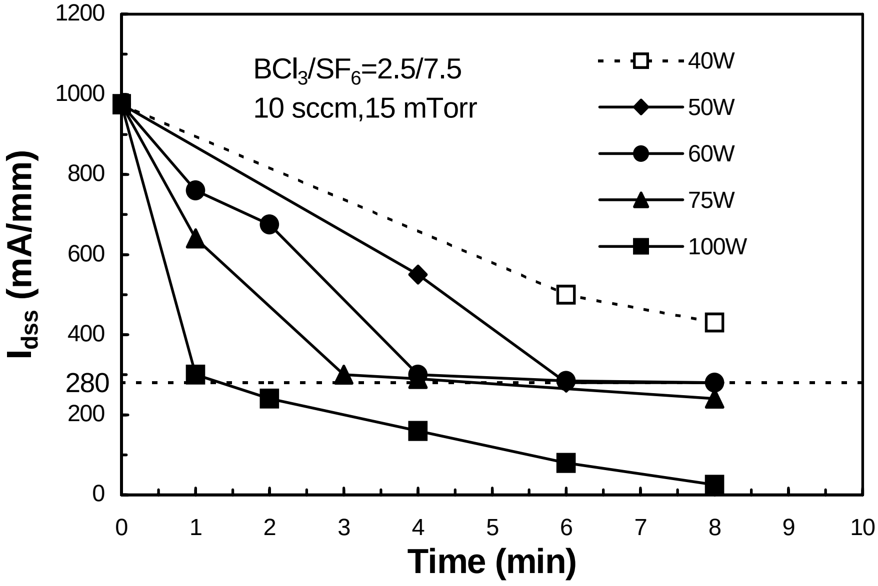

Fig. 4 I_{dss} as a function of etch time with rf power as a parameter.

30 mTorr the etch appears to slow down near the interface, and at a pressure of 50 mTorr the I_{dss} saturates at the expected etch stop value. Increasing the pressure further to 100 mTorr resulted in the loss of selectivity. It is possible that the high concentration of reactive species (Cl) at this pressure results in a fast etch which inhibits the formation of a AlF_3 stop layer.

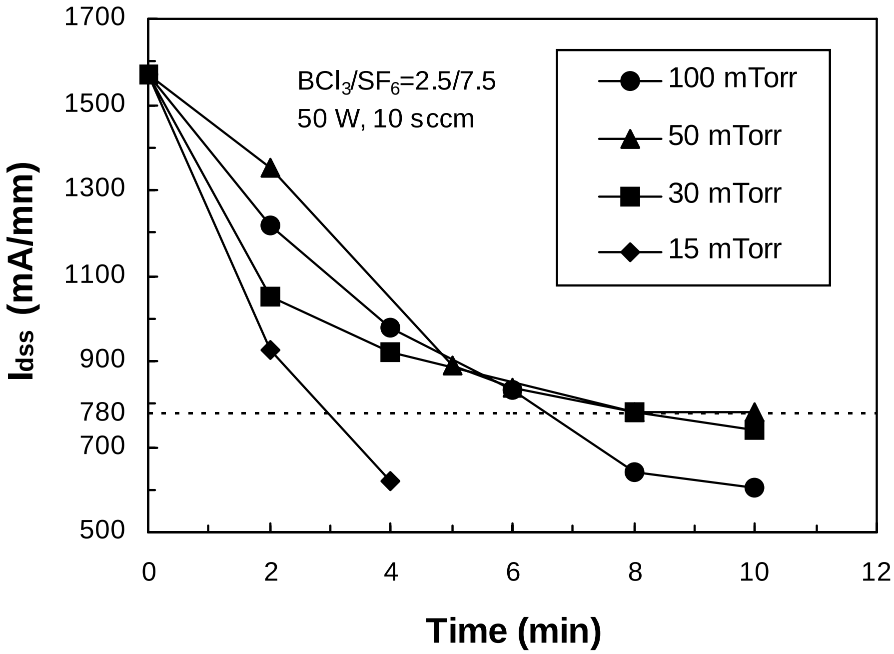

Fig. 5 I_{dss} as a function of etch time with pressure a parameter.

CONCLUSIONS

Plasmas in BCl_3/SF_6 show good selectivity for GaAs HEMT gate recess etching. The experimental results indicate that the selectivity has a strong dependence on operating parameters such as BCl_3/SF_6 composition, rf power, and pressure. Since an ideal selective etch process would minimize exposure to the plasma in order to preserve lithography profiles and minimize damage, an optimum selective etching process using a Plasma Therm 790 reactive ion etching system was determined to be 50 W rf power, gas flow ratio of BCl_3/SF_6=2.5 sccm/7.5 sccm, and chamber pressure of 50 mTorr. The addition of SF_6 to BCl_3 plasmas was also observed to dramatically increase GaAs etch rates due to enhanced BCl_3 dissociation.

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