Etching of GaAs in RIE & CAPE Mode – Characterization of Surface Layer

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Abstract

The etching of GaAs materials under Electron Cyclotron Resonance conditions has been performed in Reactive Ion Etching (RIE) & Chemically Assisted Plasma Etching (CAPE) mode using the CF_4+O_2 and O_2 plasma chemistry. The surface morphology and etch depth were characterized by Scanning Electron Microscopy (SEM) and Dektek 3030ST from Veeco USA respectively. Etching experiments were carried out with change in flow rate, power and dc bias provided the good etching of the surface and fast etch rate. Hence, the surface of the GaAs material displays smooth and stoichiometric surfaces at higher ECR powers. Moreover the film with a complicated composition is grown on the surface during etching, but it does not stop the etching process. At a lower concentration of oxygen in the etching gas mixture, the oxide layer formed on the surface having a high concentration of impurities.

INTRODUCTION

In the fabrication of ultra large-scale integrated (ULSI) circuits, fluorocarbon plasma etching has been established as one of the most important processes [1-2]. High density plasma sources at low pressure operation such as electron cyclotron resonance (ECR) plasma have been proposed [3-6]**.** ECR plasma etching has been reported to achieve a high anisotropy with a high etching rate [3-4]**.**

In the etching process employing fluorocarbon plasmas, it has been recognized that polymer films are simultaneously deposited on the wafer surface during etching [7-8]. The etching and polymer deposition are mainly caused by surface reactions of fluorocarbon radicals, fluorine atoms and F/CFx (x=1-3) which depend on system parameters such as pressure, discharge power, gas flow rate, dc self bias in the plasma. Therefore, for further development of high precision etching process, it is necessary to understand the effect of these parameters.

Etching studies in RIE mode of GaAs, was carried out with CF_4/O_2 plasma in this system with the different ECR plasma system parameters like microwave power (600-1000W), pressure, substrate biasing, & off CF_4/O_2 ratio variation and the role of F atom in the fluorocarbon plasma. Etching studies in CAPE mode with CF_4/Ar plasma was also carried out. Detail investigation in this mode is in experimental stage. Results of etch profile in two mode RIE & CAPE mode were compared.

EXPERIMENTAL

A schematic diagram of ECR system for Reactive Ion Etching (RIE) and Chemically Assisted Plasma Etching (CAPE) are shown in figure 1.1 (a) & (b). The ECR plasma chamber is built from the stainless steel cylinder with a diameter 300 mm and length 325 mm. The vacuum system includes Varian mechanical pump, model SD-300 capacity 300 liters per minute and Varian cryo-pump model Cryostack-8 capacity 1500 lts/sec.

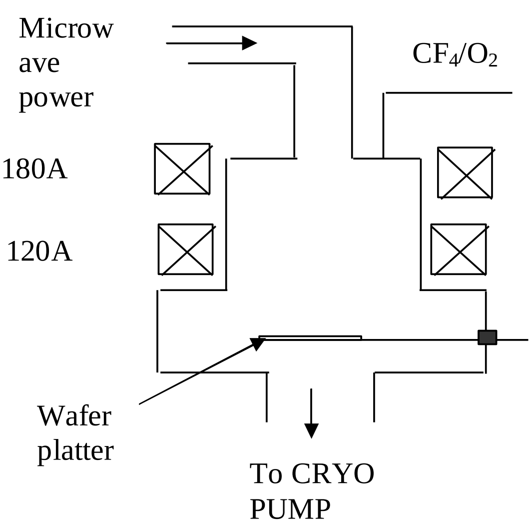

Figure 1.1 (a) Schematic of Reactive Ion Etching (RIE) mode.

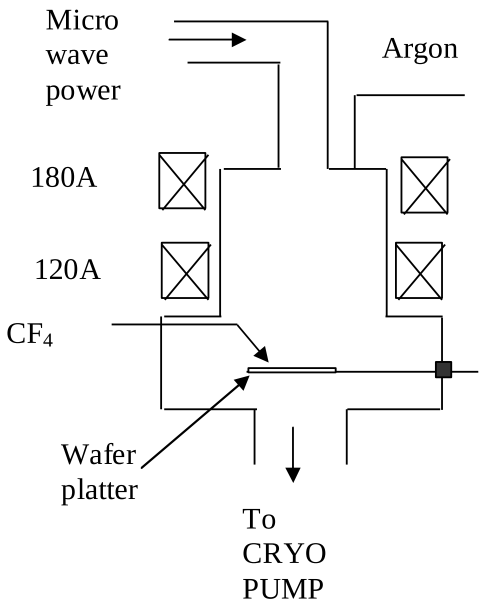

Figure 1.1 (b) Schematic of Chemically Assisted Plasma Etching (CAPE) mode.

The pressure of the gas is measured with two gauges, ionization gauge for measuring pressure in the range of 10^{-3} Torr and below, capacitance diaphragm gauge from Vacuum General Model CMH-01 for pressure range of 10^{-4} to 1 Torr Alphagaz mass flow controller, controlled gas flow.

The microwave power was generated by a continuously variable microwave power supply from M/s ASTeX, USA (50 to 1000 watts at frequency 2.45 GHz). Microwave in TM01 mode was launched in the source region through quartz window. A three-stub tuner is used to tune the reflected power to the minimum value. A set of two-solenoid coils surround's the cavity, where the plasma is produced. Each coil is powered by two EMS power supply model EMS 20-125-2D and EMS 27-185-2D. The entrance coil is powered by 180 Amp, 27 Volts supply while exit coil is powered by 120 Amp, 20V. The independent powered coils provide a static magnetic field of the order of 1.25 KGauss by entrance coil and 0.87 KGauss by exit coil. The two together create the resonance condition for efficient microwave absorption in the source.

Etching profile measurements were obtained by using the Dektek (model 3030ST from Veeco, USA). CF_4, O_2 and Ar gases were used in etching experiments [9].

RESULTS AND DISCUSSION

Figure 1.2(a) shows the dependence of different etch rates on CF_4/O_2 ratio in RIE mode. Experiment was carried out at microwave input power 800 watts, pressure 0.4 mTorr, current applied to coils are 180/120 amps bias –40 volts & for total flow of CF_4 & O_2 20 SCCM. It has been observed that there is continuous increase of etch rate with % increase in Oxygen flow for all GaAs,. This trend was reversed when O_2 was greater than 20% for all GaAs, wafer. The increase and decrease can be co-related to F/CFx (x =1-3) ratio in the fluorine containing plasma. In fluorocarbon plasma the main etching species are F atoms.

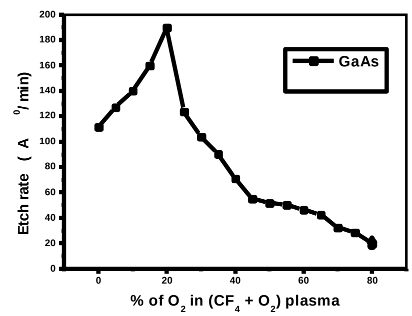

Figure 1.2(a) Plot between Etch rate (A^0/min) and % of O_2 in (CF_4 + O_2) plasma.

The enhanced etch rate by increasing percentage Oxygen atoms may be attributed to the facts that Oxygen atoms reacts with dissociated CF_4 plasma products and inhibit fluorine recombination reactions, efficient removal of adsorbed carbon by desorbing it as Carbon monoxide[10-11] and reducing polymerization [12] .The role of the oxygen is also to scavenge the CF_3 radicals and thus preventing recombination with F. It has been observed that presence of oxygen raises the F atom ten fold by preventing the recombination reaction [13]. Also C=F bond has a high formation energy and stable products such as COF_2 is formed. In the process of formation of COF_2 more F atom are released and all this enhances F/C ratio[14-17].

(i) $CF_3 + O \rightarrow COF_2 + F$

(ii) $CF_2 + O \rightarrow COF + F$

(iii) $CF + O \rightarrow CO + F$

Oxygen atoms do not react with CF_4 gas as the enthalpy of compound formation is insufficient [14]. The decrease in etching rate as oxygen percentage is increased beyond this limit is related to the fact that there is competition between F atom and O atom for chemisorptions on the Si surface [14]. Chemisorptions of O atom on the GaAs surface will reduce the etch rate because of polymerization. As the abundance of oxygen O increases the probability of O atom getting chemisorptions on the GaAs surface increases and thereby inhibiting further etching. This may not be the sole reason for fast decay of etch rate in all cases. There is also decrease in concentration of F atoms as oxygen percentage is increased beyond certain limit (20%). The addition of oxygen affects the ionization condition of the plasma. It has been found that in a given electric field to pressure ratio in plasma, electron energy is more in pure CF_4 plasma than in O_2 plasma[14]. The rate of CF_4 dissociation is a function of electron energy and will be maximum in pure CF_4 discharges and will decrease with addition of oxygen [18-19]. This will diminish the conversion of CF_4 into F atom and thereby decreasing F/C ratio and this reduces etching rate beyond certain limit of oxygen in CF_4. Etch rate of GaAs in CF_4/Ar plasma (50 % each, total flow 20 SCCM) was of the order of 247 A0/min in CAPE mode (Figure 1.2 [b]), which is greater than in RIE mode which is 140 A^0/min in similar condition with 20 % O_2. The etching rate in CAPE mode is greater than the RIE mode. Surface smoothness and etched profiles of processed wafer in two modes are different.

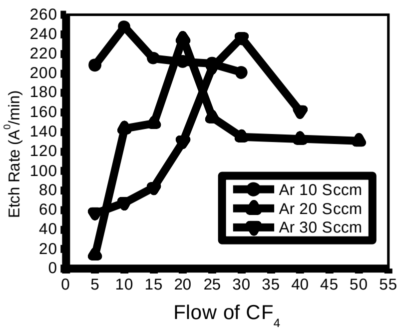

Figure 1.2 (b) Plot between Etch rate (A^0/min) and flow of CF_4 with different flow of Argon plasma

Surface smoothness studies were carried out over 1 mm length at different places of etched wafer in two modes (RIE & CAPE) with dektek (model 3030ST from Veeco, USA). It has been observed that average surface roughness (RA) after etching in RIE & CAPE mode is of the order of $165A^0$ (max) and $125A^0$ (max) respectively. Better Smoothness in CAPE mode may due to sharing of energy of ionized Argon atoms which collide with CF_4 atom over the wafer surface and there by reducing the impact energy of the reactive ions.

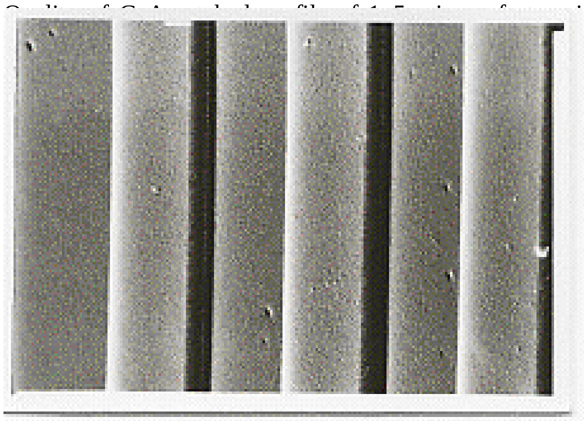

Figure 1.4 (a) Micrograph of GaAs etching profile of Reactive Ion Etching (RIE) mode at pressure $4x10^{-4}$ Torr, –40 V bias and input power 900 watts.

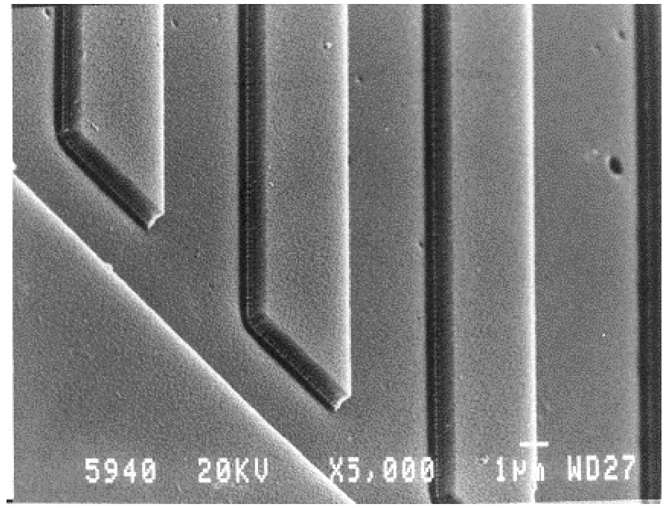

Figure 1.4 (b) Micrograph of GaAs etching profile of Chemically Assisted Plasma Etching (CAPE) mode at pressure $4x10^{-4}$ Torr, –40 V bias and input power 600 watts.

The etch rate dependence on microwave power (600-1000 Watts) in RIE mode has been studied and the results were shown in figure 1.5. The power region (100-600) watts in mirror type ECR source have not been included in the study because of unstable plasma characteristics in this power region [22]. In this region most of the enhanced input power gets reflected [19-22] and increase input power do not lead to increase in ion density. There is mode-hoping (under dense to over dense conditions) [17-18] in repeated experimentation, no increase in etching rate has been observed in this region [21]. The ratio CF_4/O_2 was kept at 4: 1(16 and 4 SCCM respectively) in RIE mode & 50% each ratio was for CF_4/Ar in CAPE mode, pressure 0.4 mTorr and wafer stage was kept at 17.5 mm below the exit magnet of the source. Beyond this region of input power (>600 watts) increase in power leads to increase in flux density [22-23] of ions and thereby increase in etch rate but after 900 watts there seem to be saturation in etching and increase in power does not etch to increase in etch rate.

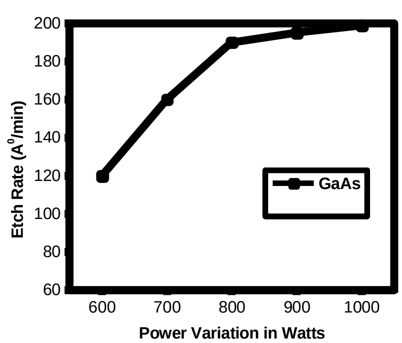

Figure 1.5 Plot between Etch rate (A^0/min) and input power variation in RIE mode.

Etch rate dependence on bias has been studied and is shown in figure 1.6. In our experiment DC bias $|V_{dc}|$ was varied –10 volt to –60 volts by varying power of DC supply connected to wafer holder. While other parameters like pressure, microwave input power; flow of gases was kept constant.

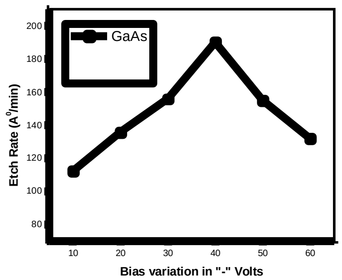

Figure 1.6 Variation of Etch rate (A^0/min) with bias in RIE mode

This had been observed that etch rate of GaAs, had increased from 112 to 190 A^0/min with increase in bias up to negative 40 Volts and beyond that there is again decrease in etch rate. It is clearly mention that polymer film is simultaneously deposited on the wafer surface during etching. This is because the enhance energy of ions leads to complete removal of fluorocarbon film being deposited during process and therefore fluorocarbon film is not there [24].

Beyond negative 40 volts, etch rate decrease with increase self bias because F/C ratio of poly carbon film on the wafer surface[24] decreases with increase bias and this will leads to an increasing fraction of energy of ions is dissipated in this film and can no longer break GaAs-O bonds and etching of GaAs decrease and/or stop. Apart from this there is decrease in etching rate this may be because of charge accumulation on the wafer, which leads to sparking on large diameter wafer.

CONCLUSION

In ECR plasma etch rate of GaAs in RIE mode was evaluated with % of O_2, variation of power, and bias. Smoothness of etched wafer surface and etched profile of silicon in two modes (RIE & CAPE) were compared. In RIE mode with CF_4/O_2 plasma, etch rate increase with increase O_2 for GaAs, and trend was reversed after increase O_2 greater than 20%.

(a) The etch rate increased with increase of microwave power beyond 600 watts and up to 900 watts. Beyond 900-Watts etching rate get saturated.

(b) The etch rate for GaAs increased from 112 to 190 A^0/min with negative bias it was maximum around – 40 volts.

(c) Surface smoothness, etched profile and etch rate are optimum in CAPE mode than in RIE mode.

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ACRONYMS

ECR: Electron Cyclotron Resonance