Research Paper Physics

A Comparative Study of ECR Based Chemically Assisted Plasma Etching of GaAs and Si

* Ashutosh Bilves ** R K Bhardwaj

* Department of Applied Sciences, ICL Institute of Engineering and Technology, Sountli, Distt.- Ambala (Haryana) 134 202

** Department of Applied Sciences, ICL Institute of Engineering and Technology, Sountli, Distt.- Ambala (Haryana) 134 202

ABSTRACT

This paper is a comparative study of Etch rate of GaAs and Si when both are etched in the almost same conditions through Chemical Assisted Plasma Etching (CAPE) mode of Semiconductors. The etch rate is studied for GaAs and Si through comparison of graphs of outputs of experiments in which the etching was carried out for both the specimens through CAPE mode and it is investigated that in CAPE mode with CF4/Ar plasma, etch rate increase with increase in CF4 for GaAs and Si both and trend was reversed after increasing CF4 more than 50%.

Keywords : Plasma Etching, Chemical Assisted Plasma Etching, Etch Rate

Introduction

The effort to reduce the minimum feature size and access higher operating devices frequencies necessitates the use of high density plasma technology for high resolution, low damage etch processes in III-V device fabrication. 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]. The demand of high density plasma has been generated by the potential for achieving high etches rates and excellent anisotropy with low substrate damage [7-9].

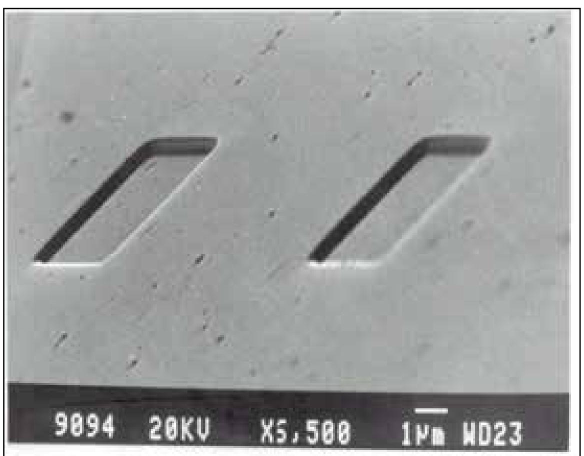

Figure1 *Micrograph showing etching of Si wafer using ECR Plasma*

The development of Reactive ion Etching (RIE) & Chemically Assisted Ion Beam Etching (CAIBE) both modes has achieved very good maturity for etching of silicon and silicon related materials but however some improvement in etching is always been carried out mainly by trial and error on the work front. RIE is the most used plasma based dry etching technique characterized by a combination of physical sputtering with the chemical reactive species. The physical sputtering mechanism is dominated by the acceleration of energetic ions formed in the plasma to the substrate at relative higher energies. However, it can result in significant damage, rough surface morphology, trenching, poor selectivity and non-stoichiometric surface, thus minimizing device performance [10]. A very attractive alternative is Chemically Assisted Ion Beam Etching (CAIBE), which is equally competitive dry etching technique with many advantageous factors than RIE like high etch rate [11], low energy for etching Si [12-14], SiO_2 [15,16], and semiconductor compound like InP & InSb [17].

In ECR plasma there is no self biasing of the wafer and therefore etching experiments are carried out in Chemically Assisted Plasma Etching (CAPE) mode. However, precise control of ion energy is carried out by additional biasing of the substrate either by RF or dc [18].

In this study we are comparing the etch rates of Si and GaAs when etched in CAPE mode.

Etching of Si and GaAs in CAPE Mode

In ECR illuminating a magnetized region with high-power microwave radiation creates the plasma. At a magnetic field of about 875 Gauss, the electron Larmor frequency is equal to the microwave frequency of 2.45 GHz. At low enough pressures, electrons gain energy on each circuit around the field lines; this field allows both confinement and efficient electron heating. ECR sources can achieve densities around $10^{12}/cm^{-3}$ ions at pressures of a few mTorr. The ECR has very low energy plasma potential and in order to achieve significant sputtering rates of wafer, it is necessary to apply a bias. The ECR plasma can be used in unconventional fashion, in which reactive gases are spread straight on the wafer to be etched while Ar is introduced into ECR cavity. The ionic species of Ar (electrons and positive ion) move along the line of force of magnetic field and shared their energy/momentum with reactive gases on the top of the wafer. The energy of the reactive gas after the collision is less than or equal to that of curable

Ar ions depending upon elastic or inelastic collision and therefore may not have the same energy assemble as in the case where reactive gas passed through resonance cavity. So in this case the energy damage impact will be lowered and etching rate will improve.

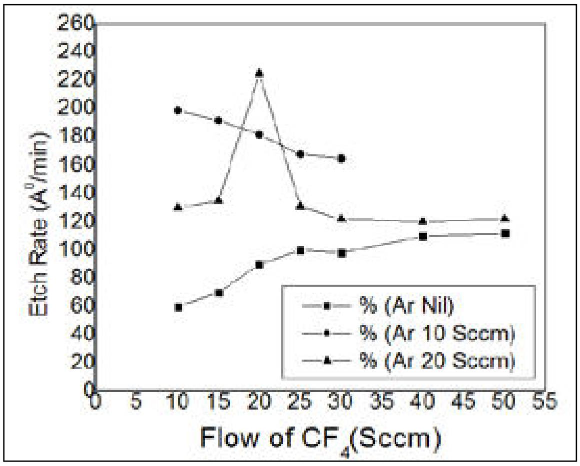

Figure 2 Plot between Etch Rate of GaAs and Flow of SF_4 at constant Ar 0,10,20 SCCM

In the ECR machine, plasma excited by a microwave field in the presence of a de-magnetic field of the correct magnitude to cause the electrons to gyrate at the microwave field frequencies thus increasing the probability of ionization. The potential advantage of the ECR in this separation of the fields, which is first create the plasma and then impart energy to the ions. In general, two main advantage of dry etching are (i) the use of highly directed ions results in the profile of the etched material, which can be anisotropic, (i.e. vertical walls can be formed) and (ii) it is possible to obtain better uniformity over the wafer. This investigation on the use of CF_4, O_2 and Ar as posses gases, where Ar was used aid in an isotropic and O_2 in reduction of residual surface polymers. The etch rate of GaAs at a pressure of 0.4 mTorr, 700 watt input power and negative 30 V bias as a function of flow of $CF_4 + O_2$ gases at different Ar flows (20,10 and 0 SCCM) [19]. In Figure 2 it has been observed that in last two cases, etch rate increases till the flow of CF_4 equals that of Ar flow and there after etch rate decreases.

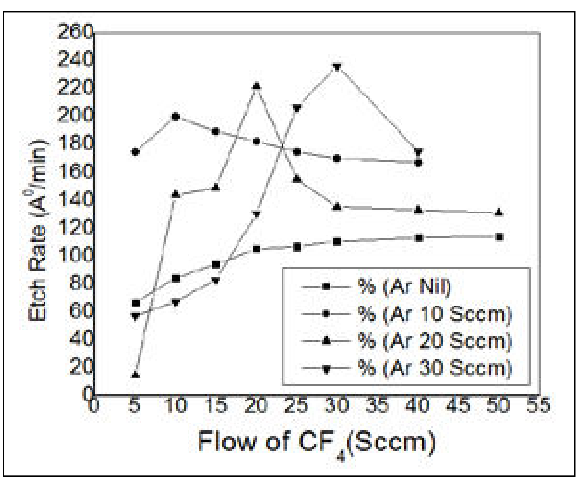

Figure 3 Plot between Etch Rate of Si and Flow of SF_4 at constant Ar 0,10,20,30 SCCM

The wafer of Si is similarly etched in almost same physical conditions in ECR machine and the etch rate for Si is studied. Figure 3 shows the etch rate variation of Si versus CF_4 flow on wafer for different constant Ar flows (30, 20, 10 and 0 SCCM) in ECR cavity at 0.4 mTorr pressure, 700 watts input power and negative 30 V bias [20]. It has been observed that in each case, etch rate increases till the flow of CF_4 equals that of Ar flow and thereafter etch rate decreases. 20 SCCM of Ar is made to flow into ECR cavity while CF_4 gas is varied from 0-50 SCCM

Discussion and Result

In the case of GaAs electrons and Argon ions move down the cavity towards the wafer where CF_4 molecules sprayed on the wafer. The ions are further accelerated near the wafer by the negative bias, these Ar ions and secondary electrons then ionize some of the CF_4 molecules and produces free atoms and CF_4 radicals. As the CF_4 increased further, the probability of secondary electrons and ions striking CF_4 molecules increases and increasing free F atoms. This increases F/Ar atoms ratio striking the wafer and this leads to increase in etch rate [21]. These trends continue, till the volume of CF_4 equals that of constant flow of Ar (i.e. 20 SCCM) in the cavity. This trend is reversed when flow of CF_4 is increased beyond 20 SCCM and etch rate of GaAs start decreasing. These characteristics may be due to the fact that probability of getting reaction on the GaAs surface producing non volatile products increases beyond 50% of CF_4 flow and leads to decrease in etch rate [22]. Abundance of CF_4 beyond 50% over wafer, decreases the ratio of active species (F atoms) to neutrals reaching the wafer and thereby decreasing the etch rate. Another reason may be that beyond 50% flow of CF_4 (i.e. > 20SCCM) the probability of getting CF_4 ionized decreases even for best efficiency of ionization in ECR cavity and thereby decreasing active species to neutral ratio. This leads to increase in amount of neutrals or molecules which are not useful in etching. These neutral and molecules get absorbed on surface and inhibit etching and decrease etching rate.

While in case of Si, an Ar^+ ion posses the removal of as many as 25 Si atoms and 100 F atoms from the surface. The total surface concentration of F in the SiF_x layer is reduced by a factor of 2 in the presence of ion bombardment. Further more, the etch product distribution changes and notably, a significant fraction of SiF_2 (gas) or SiF_4 etch product is formed, although the etch anisotropy can be as high as 5-10. When energetic ions collide with and penetrate the SiF_x layer, then a larger number of Si-Si and Si-F bond can be broken and reformed, leading to molecules such as SiF_4 and SiF_2 that are weekly bound to the surface. These molecules can be thermally dissolved during or after the collision cascade. This mechanism on the surface is similar to a reaction in the gas phase such as

$$\text{Ion} + 2SiF_x\ (x=3) \rightarrow SiF_4 + SiF_2 + \text{ion}$$

According to the above equation, therefore enhance the etch rate of Si due to the increases in volatile nature product SiF_4 and/or SiF_2

Conclusion

In ECR plasma source with a mirror type magnetic field configuration system, anisotropy & etch rate of GaAs in CAPE mode was evaluated with % of CF_4, flow of gases, and bias. In CAPE mode with CF_4/Ar plasma, etch rate increase with increase in CF_4 for GaAs and Si both and trend was reversed after increasing CF_4 more than 50%.

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