IMPLEMENTATION OF A CONTROLLABLE PROCESS FOR THE RIE ETCHING OF SiO2 AT RIT

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ABSTRACT

An Electrotech Plasmafab 425 reactor was brought on line to perform reactive ion etching (RIE). Samples of SiO_2 over Si were etched. Results show 400 angstroms/minute using a combination of freon 23 and oxygen as the etchant with good visual uniformity. A selectivity of 6:1 for SiO_2:Si was achieved.

INTRODUCTION

The reactive ion etching of SiO_2 maintains an important position in the microelectronics industry. As device features shrink in size it becomes increasingly important to perform etching with a high degree of anisotropy. Anisotropy is defined as preferential etching in the vertical rather than the horizontal direction and can be calculated as:

$$A=2D/(L-W)$$

Where A is the degree of anisotropy, d is the thickness of the film in nanometers, L is the width of the top etched image in nanometers and W is the width of the original photoresist image. [1] During wet processing a high degree of lateral undercutting is seen. RIE processing, however, yields a greater degree of anisotropy enabling the fabrication of smaller geometry devices. Table 1 shows a comparison of the bias achieved through wet and dry etching. Bias refers to the amount of lateral loss of sidewall material beyond the edge of the resist.

Table 1: Etch Bias During Pattern Transfer [2]

Thickness of Material	Wet Bias	Dry Bias
5000A	.4um	.1um
10000A	1.0um	.3um
17000A	5.0um	.4um

As can be seen, a dry etch process provides some very desirable results. In addition to this anisotropy, a dry process, with its small amount of gas disposal, provides a secondary advantage in that large quantities of dangerous acids and solvents do not have to disposed of.

When implementing a plasma etching process there are some very important parameters that need consideration, not the least of which is selectivity. This refers to the preferential etching of one film with respect to another and can be expressed as:

$$S = Ra/Rb$$

Where S is the selectivity, Ra is the etch rate of film 1 and Rb is the etch rate of film 2.[1] Maintaining a selectivity greater than 10 is usually desired to minimize damage to the underlying material.

A related parameter is the degree of resist mask erosion. The mask material most commonly used being photoresist, it is essential that the resist mask be extremely impervious to the effects of the etch. To insure that the resist mask maintains its integrity throughout the process the following steps can be taken:

a) increase resist thickness
b) optimize postbake time and temperature
c) use a plasma pretreatment process such as that in PRIST (Plasma Resist Image STabilization).

If the resist experiences severe degradation unwanted resist etching or liftoff can occur causing unreliable pattern transfer and failed devices.

For a process to be effective the etch rates of SiO_2 must be uniform across the entire wafer surface as well as from wafer to wafer. Uniformity refers to variations in the etch rate and can be quantified as follows:

$$U = (Rmax - Rmin)/(2Rav)$$

Where U is the uniformity and R is the etch rate measured at 5 equally spaced points across the wafer.[1]

When processing with a plasma a problem results from radiation damage. Deep level traps can be induced which can cause degradation of minority carrier generation time thus increasing junction leakage currents and decreasing capacitor charge retention times. Threshold voltage shifts can be caused by the increase in interfacial sites and also a degradation in transconductance occurs for MOS devices. The generation of ions by the plasma can form an additional trapping layer on the surface of the wafer. Reducing these effects is very important to device performance. With the use of CHF_3 as the etchant a polymer layer is formed during the etch which acts as a protective layer on the chamber walls and minimizes sputtered contamination yielding a lower concentration of interface states. Hydrogen in the discharge also ties up Si dangling bonds and reduces the number of defects. A 600°C anneal in forming gas can serve to reduce the threshold shifts and an HF dip after processing is useful in repairing the damaged wafer surface. [3]

PLASMA PROCESSING

The term plasma is used to describe a partially ionized gas containing electrons, both positive and negative ions, and various neutral specie. A glow discharge is a self sustaining plasma in the pressure range from 7.5 mtorr to 5.6 torr. For RIE etching the pressure is usually maintained under 100 mtorr. The electron density in a plasma used for etching is generally between 10e8 and 10e12 cm3 . Under a constant electric field the electrons present between the electrodes are accelerated toward the positive electrode (anode). During their travel these electrons can transfer energy to the various neutral specie present through collisions. Depending upon the magnitude of the energy transferred the collision can either fully ionize the neutral specie or just excite an electron to a higher energy state from which it subsequently relaxes giving the characteristic glow of the glow discharge. When full ionization occurs the products of the collision include another electron which can then be accelerated toward the anode with the possibility of gaining enough energy from the electric field to perform more energy transfer and a positive ion which is accelerated toward the negative electrode (cathode). This positive ion, upon impact with the cathode, can cause secondary electron emission which is required for the successful sustaining of the plasma. Secondary electrons generated in this manner can initiate a cascade effect thus helping to create a stable plasma where generation of electrons and ions is balanced by the loss to the electrodes and the diffusion out of the plasma. A major drawback of a DC system is the inability to etch insulators such as SiO2. The need for conducting electrodes negates the possibility of etching an insulator since the plasma cannot be sustained. As the secondary electrons are emitted from the insulator there can be no current flow through the insulator to replace the lost electrons so a positive charge builds up and the discharge is extinguished. A solution to this problem is to use an RF alternating field in place of the DC system.

With the change to alternating fields there is little difference in the plasma provided the frequency of the field remains low enough that the ions can be swept out of the discharge in a single cycle of the applied voltage. If this ion cutoff frequency (50KHz to 2MHz) is exceeded then the secondary ion emission is not the primary source of electrons anymore. The electrons are now generated by the ionizing collisions. For normal plasma operation an electron in the plasma oscillates with the field and undergoes collisions with the larger particles present. These collisions result in a random motion and the electric field does work on the electron in trying to restore it to ordered motion thus giving it a higher energy and a higher probability of undergoing ionizing collisions. The ions do not gain a high amount of energy due to their great mass and lower mobility. Therefore RF discharges require lower field strengths and they do not require conducting electrodes making the etching of insulators possible. To perform etching a gas is introduced

into the chamber and ionized to form reaction products which upon interaction with the film form volatile products which can be desorbed and swept out of the chamber. [4] [5]

EXPERIMENTAL

In order to begin process testing it was necessary to commission an Electrotech Plasmafab 425 reactor. After this was completed the etch tests were begun. A 4000 angstrom film of SiO_2 was grown in wet O_2 @ 1000 C for 80 min. An ellipsometer was used for thickness measurements. For a test of pattern transfer an RIT capacitor mask was used to pattern different size squares into 1.2 microns of Kodak 820 positive photoresist. This was postbaked at 140 C for 2 minutes. An Alpha Step surface profilometer was employed to determine etched step heights and, in conjunction with the ellipsometer data, etch rates and selectivity were calculated. An argon preclean was employed to degas the chamber and condition the resist. CHF_3 was used as the etch gas in conjunction with O_2 in a 16:1 ratio. An argon postclean was also utilized to clean the wafer and to remove any residual adsorbed halogens from the wafer surface. After much experimentation with flow rates and power the following process was arrived at.

Step	Gas	Flow Rate (sccm)	RF Power*	Time
1	Argon	24	2A	2 min
2	CHF_3 O_2	80 (16:1) 5	2A	var
3	Argon	24	2A	2 min

* RF power was measured in amps, not watts, on the Plasmafab

RESULTS/DISCUSSION

The etch rate of SiO_2 was determined to be approximately 400 angstroms/minute with a selectivity of greater than 6:1 for SiO_2:Si. Uniformity across the wafer was not measured but it was dramatically increased when the wafer table was stationary as opposed to rotating.

The reactions that are believed to occur with CHF_3 are as follows:

$CHF_3 + e^- \longrightarrow CHF_3 + H + e^-$ (most probable reaction)
$\longrightarrow CF_3^+ + H + 2e^-$
$\longrightarrow CF_2 + HF + e^-$
$\longrightarrow CF_2^+ + HF + 2e^-$

$CHF_3 + e^- \longrightarrow CHF_2 + F + e^-$ (not probable due to higher heat of reaction)

CHF3 plasmas produce CF3 and CF2 ions for etching but virtually no free flourine due to the scavenging effect of the free fluorine producing HF which does not contribute to the etch. The positive ion bombardment causes lattice damage creating active sites at which reactions can proceed at an accelerated rate. When SiO2 is etched in the presence of hydrogen the hydrogen promotes formation of a polymer layer which reduces the Si etch rate and thereby increases the selectivity. Polymer formation occurs both on the walls of the etched profile and the bottom. The impinging ions continually erode the layer at the bottom leaving sites open for etching. The sides however, are not subject to the ion bombardment and the polymer layer inhibits the etch.

CONCLUSION

The major thrust of the project was to bring the reactor up and to develop a process for utilizing RIE of SiO2 at RIT. This was accomplished in a very rudimentary manner due to time constraints. There can be much more experimentation done to further qualify the process and to develop processes for the etching of other films such as polysilicon, nitrides, and aluminum now that the reactor has been brought on line.

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