REACTIVE ION ETCHING OF SILICON DIOXIDE USING BOTH OXYGEN AND CARBON DIOXIDE AS GAS ADDITIVES

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ABSTRACT

A study was performed on the etch characteristics of silicon dioxide and polysilicon for a reactive ion etch system, using CHF4 as the primary etchant gas and using either oxygen or carbon dioxide as an additive gas. Correlations were found between the amount and type of additive gas introduced to the system, the Rf power of the system, the pressure that the system is maintained at and the effects these parameters have on the etch rate and selectivity of SiO2 and polysilicon etches. It was found that adding CO2 in small amounts to the gas mixture instead of pure oxygen had the effect of making the etch process more predictable and easier to control.

BACKGROUND

One of the major trends taking place in the semiconductor industry today is the move away from wet etch systems and towards dry, plasma systems. This evolution is prompted by the many advantages inherent with using plasmas over wet etch techniques. Plasma systems allow better resolution at lower geometries, higher control of sidewall profiles, and lower processing and waste disposal costs than comparable wet etch systems. Then main drawbacks to using plasma systems are poorer etch selectivity and slower wafer throughput.

In the etching of either silicon or silicon oxide, fluorinated carbon reactant gases, with the general formula of CFn, are used. The reaction equasion can be represented as:

$$CFn + SiO2 \rightarrow SiF4m + CO, CO2$$

with all products being volitile.

Free fluorine atoms in the plasma will etch bare silicon, while the CF3 radical is responsible for oxide etching. The concentrations of one or the other is dependant on the

florine:carbon ratio of the etchant gas. When the ratio is three or less (as in the cases of CHF3 and C2F6), the concentration of CF3 radicals will increase relative to the concentration of free fluorine atoms, and oxide etching will be favored. When the F:C ratio is four or more, the opposite will occur [1,2]. Different additive gases can also affect the selectivity of the etch. Adding hydrogen to the mixture causes the fluorine concentration of the plasma to be reduced (forming HF, a volitile species), therefore promoting silicon dioxide etching. Oxygen added to the plasma has a similar effect of removing carbon from the system (in the form of CO and CO2), thus promoting silicon and polysilicon etching [3].

Plasma systems also have the added problem of excessive polymer formation occuring during silicon and silicon dioxide etching. This polymer forms when free carbon atoms in the plasma link with each other rather than with other atoms to form volitile species. Etchant gases with high carbon to fluorine ratios encounter this frequently due to the greater number of free carbon atoms they release to the plasma. Polymer formation on reactor surfaces can affect etch reproducibility and also acts as a source of particulate contamination. This polymer can be thoroughly removed at a later time by an oxygen plasma, but it is still desirable to reduce their initial formation. One means of accomplishing this is by altering the etch chemistry. The addition of oxygen or oxygen containing compounds to the plasma will serve to inhibit polymer formation, but will itself have an impact on the plasma's etch characteristics [4].

Reactive ion etching functions the same way as regular plasma etching except that, during etching, inert ions are directed at the wafer surface. When these ions impact with the wafer they damage the surface crystal lattice, free up bonds to enable the etchant gas to react with, and/or physically sputter the material to be etched. This results in faster etch times and more anisotropic etch profiles.

For this project, an optimization of the reactive ion etch process (RIE) will be performed for a silicon oxide etch. Such parameters as Rf power, gas composition, and chamber pressure (which in turn controls the degree of ion bombardment) will be examined for their individual and cumulative effects on both the speed and the selectivity of the etching process. The gas mixture used will be CHF3, using first oxygen and then carbon dioxide as the gas additive. The amount of additive gas will be altered from 0 to 20% of the total gas volume, and the effects that both additive gases have on the etch rate and etch selectivity will be determined.

PROCEDURE

For this project twenty-five three-inch, silicon wafers were prepared with a tri-layer selectivity pattern. This was accomplished by first growing approximately 5000 angstroms of

silicon dioxide on the wafers in a steam environment. Approximately 5000 angstroms of polysilicon was then deposited using a CVD system. The polysilicon was then patterned using KTI820 positive resist and a thick-striped test mask; once etched (in a wet, polysilicon etch bath) and stripped of resist, this resulted in test wafers with one centimeter wide, alternating polysilicon and silicon dioxide lines. The test mask was then rotated 90 degrees and a second exposure was made, resulting in a series of wide photoresist lines running perpendicular to the SiO2 and polysilicon lines. The resist was measured to be approximately 12000 angstroms thick.

The plasma system used was the PLASMATRAC single wafer reactive ion etcher. The primary etchant gas was CHF3, with either oxygen or carbon dioxide being used as the additice gas. The total gas flow through the etch chamber was maintained at 100sccm throughout the entire experiment. The etch parameters tested were Rf power, varied from 30 to 300 watts, chamber pressure, varied from 20 to 200 mTorr, and additive gas concentration, varied from 0 to 20% by volume of the gas mixture.

A total of twenty runs were made made for each gas additive. Etching of the silicon dioxide and the photoresist were measured using the Nanometrics Nanospec, while the Alpha-step was used to measure polysilicon thicknesses. This data was then correlated using the computer program RS/Discover.

RESULTS/DISCUSSION

The etch characteristics of both polysilicon and silicon dioxide were successfully plotted versus changes in the etch parameters of Rf power, chamber pressure, and additive gas concentration.

Etching performed without the addition of an oxygen containing gas encountered the problem of heavy polymer formation. Etching was only possible at the low end of the pressure scale where ion bombardment was the strongest; at this point the etch rate of SiO2 could be controlled by raising or lowering the Rf power, ranging from 100 to 500 angstroms/minute across the Rf scale. Etch selectivity favored SiO2 over poly, but the results fluctuated depending on polymer formation such that it is impossible to get an exact etch ratio.

The addition of oxygen to the system improves the problem of excessive polymer formation. Optimum etch occur at a point just below where polymer begins to form on the polysilicon. These etch "windows" are listed for the various concentrations of oxygen used:

Oxygen (%)	Rf power (watt)	Pressure (mTorr)
5.0	140-200	60-90
10.0	200-260	140-150
15.0	200-240	145-160
20.0	100-180	80-100

A drawback to using oxygen as an additive gas is the dramatic increase in the etch rate of photoresist that occurs. The following table is an example of the etch rate of KTI820 positive photoresist, etched at an Rf of 160 watts and a pressure of 110 mTorr:

Oxygen Conc. (%)	KTI820 Etch Rate (A/min)
0	-200.0
5	300.0
10	600.0
15	750.0
20	750.0

Carbon dioxide was also used as a gas additive to control polymer formation, and in this regard it worked almost as well as pure oxygen. In terms of etch rates and selectivities, it appeared that the carbon dioxide had a stabalizing effect on the polysilicon etch; the polysilicon etch with the addition of CO2 is much more linear than it was with the addition of pure oxygen. This effect makes it easier to locate a region of high etch selectivity during an etch process.

CO2 Conc. (%)	Rf Power (watts)	Pressure (mTorr)
5	140-220	85-95
10	220-240	130-140
15	220-260	165-180
20	240-300	190-200

It can be seen that a plasma etch using CO2 requires both a higher Rf and a higher chamber pressure to produce results similar to a plasma using pure oxygen as the additive gas. An advantage that CO2 has over oxygen is that it produces a lower photoresist etch rate. Etch rate taken at Rf of 160 watts and chamber pressure of 110 mTorr:

CO2 Conc. (%)	KTI820 Etch Rate (A/min)
0	-150.0
5	-25.0
10	50.0
15	125.0
20	225.0

CONCLUSIONS

It is possible to achieve silicon dioxide etch rates of 300 to 600 angstroms per minute with high selectivity over polysilicon by performing the etch at a point just below where polymer formation begins on the polysilicon. Control of this polymer formation can be achieved through careful additions of oxygen, or other oxygen containing gases, to the plasma. Both oxygen and carbon dioxide were tested for this reason, and it was found that although each has it's own drawbacks, both gases are effective in controlling the polymer formation, and therefore the etch characteristics of this dry etch process.

Copies of all plots can be found in the appendix section of this paper.

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REFERENCES

[1] S. Wolf and R. N. Tauber; Silicon Processing for the VLSI Era Sunset Beach California. Lattice Press. 1986

[2] Brian Chapman; Glow Discharge Processes New York. John Wiley and Sons. 1980

[3] Gianni O. Fior, Leslie N. Giffen, and Wendy W. Palmer Tegal Corp., Petaluma, California High-Selectivity, Silicon Dioxide Dry Etching Process Solid State Technology, April 1988; p.109-112

[4] Frank D.Egitto, David N. K. Wang, Dan Maydan, David Benzing Applied Materials, Inc., Santa Clara, CA; Signetics Corp. Sunnyvale, CA; Ion Assisted Plasma Etching os Silicon-Oxides in a Multifacet System; Solid State Technology, December 1981, p.71-75