

# PLASMA ETCH OPTIMIZATION OF SILICON DIOXIDE WITH A RESIST MASK

Eric P. Meister  
Fifth Year Microelectronic Engineering Student  
Rochester Institute of Technology

## ABSTRACT

A dry etch process was developed and characterized to etch silicon dioxide ( $\text{SiO}_2$ ). Characterization included increasing the etch rate of  $\text{SiO}_2$  while decreasing the etch rate of a KT1820 positive photoresist mask, which is used in RIT's fabrication processes. Successful masking and etching of silicon dioxide occurred with 15 sccm  $\text{CHF}_3$  mixed with 6 sccm  $\text{O}_2$  at a chamber pressure of 750 - 800 mtorr and a power of 100 watts.

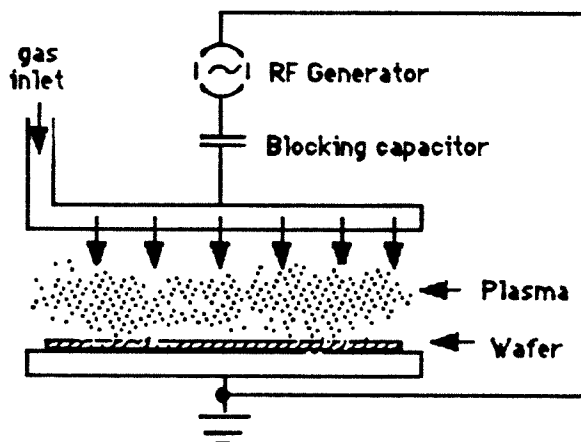
## THEORY

As VLSI geometries become smaller, the need arises for an etch process in which one can control the directionality of the etch. Wet etching systems are available which provide a high selectivity between the substrate and mask. However these systems usually etch isotropically. With linewidths on the order of one to two microns, isotropic etching undercuts the mask and the pattern may be lost, if not greatly altered.

An important advantage of dry etching is the ability to control the direction of etching. By lowering pressures in an rf plasma, processes can combine the chemical reactions found in wet etching with a physical bombardment of the substrate with ions. The sputtering mechanism provides the directionality.

Figure 1 represents a single wafer reactor setup. After a wafer is loaded, chamber pressure is reduced, etchant gases are introduced, and, once stabilized, an rf signal is applied. The primary frequency for this signal is 13.56 MHz. Molecular collisions between the gaseous species create electrons and radicals, and the higher mobility of the electrons with respect to the heavier radicals creates an electric field. The radicals, which are

electrically neutral, but in a state of incomplete chemical bonding, are highly reactive and responsible for the chemical etching which occurs.

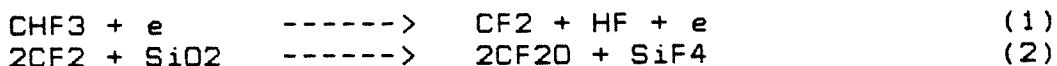


**Figure 1. Plasma reactor set-up**

Sequencing of the etch can be explained in the following manner. Molecular collisions create the reactive species. The rf induced electric field moves them towards the surface of the wafer where absorption can occur. Here the reaction occurs, products desorb and diffuse to the exhaust outlet.

As chamber pressure is reduced to the order of 100 millitorr, processing enters the regime of RIE, or reactive ion etching. Under these parameters, the radicals are still highly reactive. However, after absorbing and reacting, ions present in the plasma sputter off the products from the reaction sites, rather than having them desorb. It is this sputtering process which increases the control over the direction of etch. As pressure in the chamber rises above this value, the mean free path of the ion is reduced, as well as its velocity. Pressures of 400 mtorr or greater produce a completely chemical etch and results in an anisotropic profile similar to a wet chemical etch.

The primary chemistry for the etch of silicon dioxide when using CHF<sub>3</sub> (Freon 23) as an etchant can be seen in the following equations.



The CHF<sub>3</sub> molecule collides with an electron to create the CF<sub>2</sub> radical (eqn 1). The CF<sub>2</sub> radical is then available to absorb and react with the SiO<sub>2</sub> to create products which can desorb and outgas. Equation 1 also demonstrates that HF is a product. The hydrogen acts as a scavenger of fluorine radicals, and it is these radicals which are important to the etch of silicon. Utilizing CHF<sub>3</sub> rather than CF<sub>4</sub> lowers the concentration of fluorine and lowers the etch rate of silicon. The etch rate of silicon dioxide, however, is not greatly reduced.

## EXPERIMENT

Preparation for experimentation was essential. First the Tegal 700, the dry etch tool for all tests, was checked for leaks and these leaks were minimized with tube and clamp replacement where necessary. Secondly, mass flow controllers were connected to all gas lines in order to better regulate the flow of desired gases. Previous to this, gases were crudely mixed and flow rates were determined by the number of turns on a particular valve. The mass flow controllers provided more accurate data with respect to actual values.

With the etching tool in optimum order, experimentation began. Twenty 3 inch wafers were obtained, scribed, and subjected to a standard RCA clean. Approximately 4500 angstroms of silicon dioxide, using an 1100 C wet O<sub>2</sub> flow for 60 minutes, were grown. Following oxidation, wafers were coated with KT1820 positive photoresist on the GCA Wafertrac. They were then exposed using the contact aligner using a striped resist test mask. Following development, the pattern on the wafer was that of alternating stripes, approximately 1/2 inch wide, of resist and oxide. This allowed for selectivity analysis between oxide and resist, as well as uniformity analysis across the wafer.

Experimentation runs utilized these wafers to develop a process which would etch silicon dioxide. Plasmas of CHF<sub>3</sub>, CF<sub>4</sub>, and a mixture of these two were used to attempted. Pressures ranged from 460 millitorr to 1000 millitorr. Pressures below this could not be obtained because the mechanical pump with this tool was not large enough to do so. Varying the gas flow controlled this pressure with higher flows yielding higher pressures. With these runs, it was discovered that a polymer buildup was occurring across the entire surface of the wafer. To combat this problem, a plasma chemistry of CHF<sub>3</sub> and O<sub>2</sub> was implemented. The CHF<sub>3</sub> acted as the etchant of SiO<sub>2</sub> while the O<sub>2</sub> served as a polymerization inhibitor. Flows of CHF<sub>3</sub> ranged from 10 to 20 sccm while the O<sub>2</sub> flows ranged from 0 to 8 sccm. Optimization involved determining which flows determining which flows provided the best selectivity between the silicon dioxide and the resist mask.

## RESULTS/ANALYSIS

Successful etching of SiO<sub>2</sub> was the result of the addition of oxygen to the CHF<sub>3</sub> plasma. Without it a polymer formed across the entire wafer, and was the result of an excess of CF<sub>2</sub> radicals. These radicals were allowed to buildup on the surface of the wafer without reacting to form the polymer. The addition of oxygen in its molecular form (equation 3) or in its radical form (equation 4) prevented polymer buildup.



Table 1 illustrates the effect of oxygen addition to this process. Oxide thicknesses were measured before and after an etch. If a

polymer was formed, on the oxide, the nanospec would indicate this as an increase in the thickness of the oxide. After an oxygen ash however, the oxide thickness would return to its original value. The fact that this material could be removed in an ash was the key in determining that it was a polymer. As the O<sub>2</sub> flow increased the polymer buildup lessened until the flow was 6 sccm. At this point, polymerization was inhibited and the oxide etch occurred. Note that this flow yielded a negative value for (delta t ox).

TABLE 1: ETCH CHARACTERISTICS

CHF3 FLOW (sccm)	O2 FLOW (sccm)	ETCH TIME (minutes)	PRESSURE (mtorr)	DELTA t OX (angstroms)
15	0	3	590	+2867
15	2	3	638	+1000
15	4	3	690	+563
15	6	3	793	-826

The following is the process which was found to demonstrate the best results for an SiO<sub>2</sub> etch using a resist mask.

TABLE 2: RECOMMENDED CONDITIONS FOR ETCH OF SILICON DIOXIDE

CHF3 flow	15 sccm
O2 flow	6 sccm
pressure	750 - 800 mtorr
power	100 watts

There are several comments with respect to these parameters. First, selectivity, which equals the etch rate of SiO<sub>2</sub> divided by the etch rate of resist mask, ranged from 0.16 to greater than twenty. The major cause of this inconsistency may be the result of the mass flow controllers, which are designed to regulate up to 500 sccm. With such small flows actually being used, one must question the percent error of flow. Ideally, flows controllers in the range of 25 sccm should be implemented. Secondly, the pressure varied from 750 to 800 millitorr. This is too high to create an anisotropic profile. The present pump is too small to pump down to the 100 mtorr range and a larger pump could enable a RIE process.

## CONCLUSIONS

It is possible to achieve an oxide etch using the Tegal 700 plasma reactor. However, the present system has its limitations and a

more powerful pump may improve its capabilities dramatically. Maximum power for this tool is only 100 watts, which is relatively low compared to more recent models which are capable of 800 watt rf signals. Finally, obtaining more efficient mass flow controllers may improve the consistency of etching. Future investigation into these aspects is a definite possibility.

#### **ACKNOWLEDGMENTS**

I sincerely thank Dr. Richard Lane for his ideas behind the chemistry and experimentation of this research. As well, I would like to thank Scott Blondell and Gary Runkle for their assistance with the Tegal and its maintenance.

#### **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