DETERMINATION OF SIO2 PROFILES ACHIEVABLE WITH RIE USING C2F6 AND CHF3

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ABSTRACT

A dry etch SiO2 process was optimized using the Plasmatrac 2406 RIE etcher at RIT, while maintaining selectivity to polysilicon and photoresist. The optimized process had Power of 350 Watts, Pressure of 127 mTorr, C2F6 of 60 sccm, and CHF3 of 171 sccm. This provided an oxide to poly selectivity of 5.5:1 with an oxide slope of 60°.

INTRODUCTION

Etching is a process that transfers patterns to underlying layers and has traditionally relied on wet chemistry. Since wet etching is very isotropic, attention focuses on effectively clearing the layer of interest without pattern degradation. The resulting profile is such that uniform step coverage of subsequent layers is easy to obtain. However, the isotropic nature of wet etching allows a minimum feature size of 3 microns or larger to be accurately transferred. This resolution is unacceptable for current ULSI applications, which are below 1 micron.

Plasma etching, or dry etching, offers a solution. In addition to increased anisotropy, which allows transfer of smaller geometries, plasma etching lends itself to automation, helps increase uniformity across the wafer, involves lower chemical usage cost and increases the safety for operators by reducing operator exposure to toxic chemicals. Disadvantages include lower selectivity, higher equipment cost, radiation damage and increased process complexity.

However, increased anisotropy, while reducing the minimum feature size etched, may result in poor step coverage of subsequently deposited films. This requires plasma processing to obtain small geometries while maintaining an etch profile suitable for subsequent thin film deposition.

To help achieve good step coverage, a slight taper at the top of the profile would be required [1]. This profile is shown in Figure 1. Please note the profile is not dependant upon the physical spacing of the SiO2 edges.

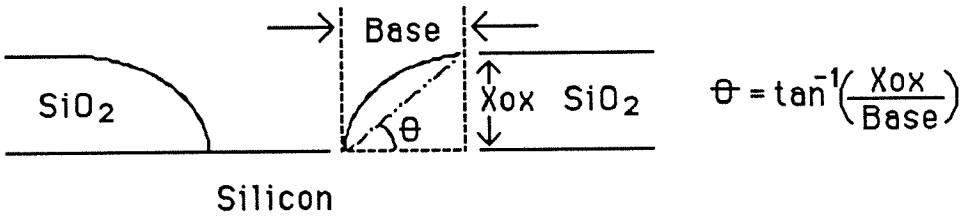


Figure 1: Oxide Profile and Measurement of Slope Angle.

Since the oxide profile has a slope, actual measurement of this slope is difficult. However, if the profile is approximated by a right triangle, as shown in Figure 1, then it becomes easier to refer to the angle, theta, as a measurement of the profile. Since the oxide thickness is easily measured, the only other parameter of interest is the base width. Taking the inverse tangent of the oxide thickness divided

by the base width, allows accurate measurement of theta. The measurement of the base width may be performed using a microscope with optical verniers.

While the profile in Figure 1 commonly occurs with wet processing, it is also possible to obtain through plasma etching. If a very low pressure is used for the etch process, the mean free path of the ions would be comparable to the interelectrode distance. This allows the ions to gain sufficient velocity causing a small amount of sputter etching [2].

The small sputter process would then cause the phenomenon of resist "facetting" [3]. The photoresist would be removed such that an angle of approximately 60 degrees results at the edge of resist profile. If continued for enough time, the resist erosion causes the substrate material to become exposed and start etching. This propagates the angle into the substrate topography. Figure 2, illustrates this phenomenon [4].

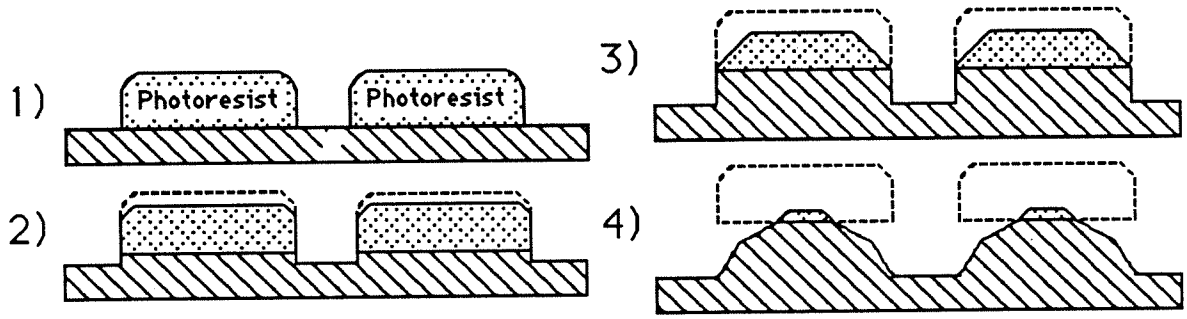


Figure 2: Oxide Etch Profile Creation [5].

A taper may also be created using an isotropic plasma etch. However this is inadequate since a very low etch rate of SiO2 would result and selectivity to silicon or polysilicon would be lost [6]. An anisotropic etch could be used, but would require two steps so that the taper could be induced. A disadvantage of this method is throughput reduction since a two step process requires more equipment time.

An anisotropic process could be used if the etch chemistry caused resist erosion. If the resist eroded fast enough, then the profile previously shown in Figure 3 would result. The slope of the etch feature depends on the removal rate of the resist. Increased resist removal causes shallow profile slopes while decreased resist removal causing steeper slopes [7].

The resist erosion may be increased through the addition of O2, but selectivity to silicon is lost. Another method is to use a chemistry such that products from the plasma etch photoresist as well as the desired film [8]. This method generally employs endpoint detection systems to monitor the intensity of CO emission from the plasma. An isotropic chemistry, such as CF4 and O2 would provide sufficient resist erosion to obtain a tapered profile, but would decrease the selectivity to poly to 3:1 or lower. This process would also be very nonuniform [9].

Other isotropic oxide etch chemistries would include NF3 or SF6, but both gases have low selectivity to silicon. Therefore, once the oxide etch reached a silicon or polysilicon surface, trenching would begin instead of the process stopping.

Another oxide etch chemistry is CHF3 with the addition of O2 or CO2. The selectivity of the process is controlled by the amount of oxidant used, but the etch rate would be low. CHF3 is a polymer

forming gas that reduces the effective etch rate [10]. C2F6 and C3F8 would be gases that could be mixed with the CHF3 to boost the etch rate, while maintaining selectivity. The selectivity of the etch chemistry is generally determined by the concentration of C2F6 in the plasma [11]. These gases also provide sufficient resist erosion to cause the formation of a taper at the top of the profile.

Previous work at RIT was performed using the C2F6/CHF3 etchant chemistry on the RIE etcher. The C2F6 was held constant at 30 sccm while the CHF3 gas concentration was varied from 0% to 45% of the C2F6 flow. The power was varied from 200 to 500 watts and the pressure was varied from 50 to 200 millitorr.

The results of this experimentation indicated the optimum process had power at 255 watts, pressure at 150 mtorr, a CHF3 concentration of 65% of the total gas flow, and 60 sccm of C2F6 gas. This resulted in a 6.3:1 oxide to poly selectivity with the oxide etch rate being 612 Å/min [12].

This project involved using statistical design of experiment methods to optimize the oxide sidewall profile. The desired profile was a 60° SiO2 slope so that adequate step coverage of subsequently deposited films may be achieved. The project involved first verifying or modifying the base process followed by the optimization of the SiO2 profile.

EXPERIMENT

The experimental work began with a small four run Taguchi matrix varying the pressure and power by +/-10% of the base process. The response variables were oxide selectivity to polysilicon and etch nonuniformity to verify previous results. Upon completion of the verification process, response variables including minimum feature size etched, the uniformity of the etch across the wafer and the sidewall slope angle were chosen to optimize the slope. The slope was evaluated by measuring the base of the right triangle, as stated earlier.

The experimental design used was a central composite design with 5 factors [13]. This design used 32 runs with the responses stated earlier. The software package Design Expert was used to create the design. The factors were RF power, main chamber pressure, C2F6 gas flow, CHF3 gas flow and the percentage of overetch used. The levels were +/- 10% of the base process, which is shown below.

Power = 255 Watts, Pressure = 150 mTorr, C2F6 = 60 sccm, CHF3 = 171 sccm.

The pattern used for the profile experiment would be the RIT Kodak ETM photoresist test mask. This mask has alternating patterns of lines and spaces with resolution targets, patterned geometries and alignment marks. For the purpose of this experiment, the alignment marks would not be needed. However the other geometries would be very useful in determining the minimum resolution and the etch profile slope by using both lines and spaces. SEM cross sections were then taken of representative slopes showing the optimized process.

RESULTS/DISCUSSION

The preliminary Taguchi results showed the base process was no longer valid. The best oxide to poly selectivity was 3.5:1, with an average selectivity of 3:1. Investigation into the selectivity difference revealed the etcher had several hardware modifications which included replacing the pump oil, sealing several leaks to the main chamber, and replacing pieces of the pump line.

A modified process was then created with the power increased to 350 Watts and the pressure decreased to 127 mTorr, keeping the gas flows constant. This produced a poly to oxide selectivity of 5.5:1. The oxide to photoresist selectivity was seen to be 3.8:1, which provided excellent resist erosion for profile control. SEM cross sections, shown below in Figures 3 and 4, indicate an oxide slope of 60° was achieved using this process.

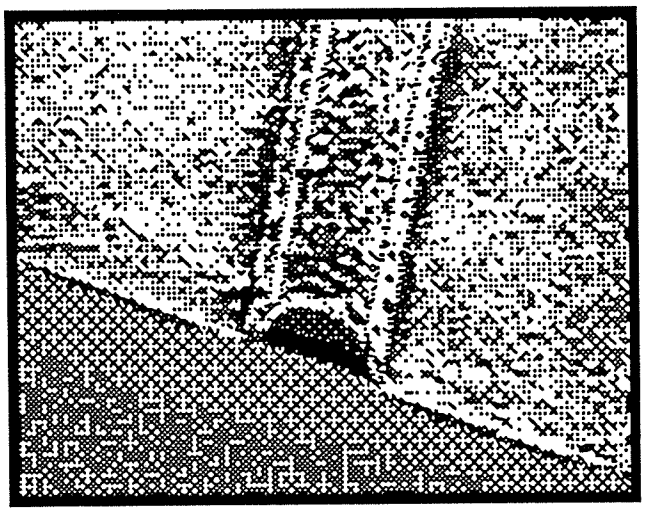
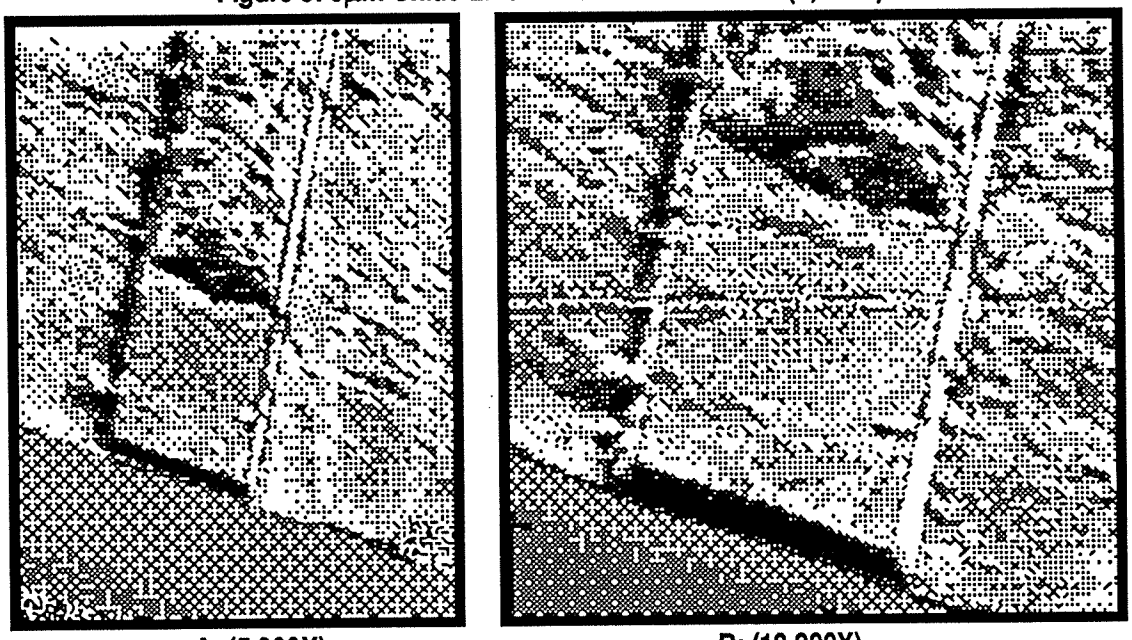


Figure 3: 6μm Oxide Line - Photoresist Present (5,000X).



A: (5,000X) **B: (10,000X)**

Figure 4: 6μm Oxide Line-Photoresist Flaked Off Exposing Oxide.

An attempt to run the central composite design was made, but arcing within the main chamber prevented reliable results from being found. Cleaning the main chamber with I.P.A. and Scotch Brite removed the conductive polymer and served to correct the problem temporarily, until more polymer built up. Eventually, polymer was present were the Scotch Brite could not remove it, and the chamber needed to be completely torn apart and cleaned.

Arcing was also seen between the four inch wafer holder and the main chamber. This was easily corrected by placing Teflon tape on the backside of the wafer holder covering the areas arcing.

CONCLUSIONS

As this report shows, a modified process was created using the Plasma Therm 2406 RIE etcher allowing an oxide slope of 60° to be achieved. The Plasma Therm etcher was also seen to be very sensitive to polymer build-up and required periodic cleaning with I.P.A. to prevent arcing within the main chamber by removing conductive polymer. Teflon tape on the backside of the four inch wafer holder was also seen to prevent arcing near the wafer through the holder.

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