SILICON DIOXIDE TO POLYSILICON SELECTIVITY OF A C2F6/CHF3 DRY ETCH PROCESS

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ABSTRACT

The etch rates and selectivity of thermally grown silicon dioxide and polysilicon were characterized on a 2406 PLASMATRAC with a C2F6/CHF3 gas mixture. At a gas flow, CHF3 concentration, chamber pressure, and power of 60 sccm, 65%, 150mtorr, and 255watts, respectively a 6.3:1 silicon dioxide to polysilicon selectivity occurred with an oxide etch rate 612 A/min.

THEORY

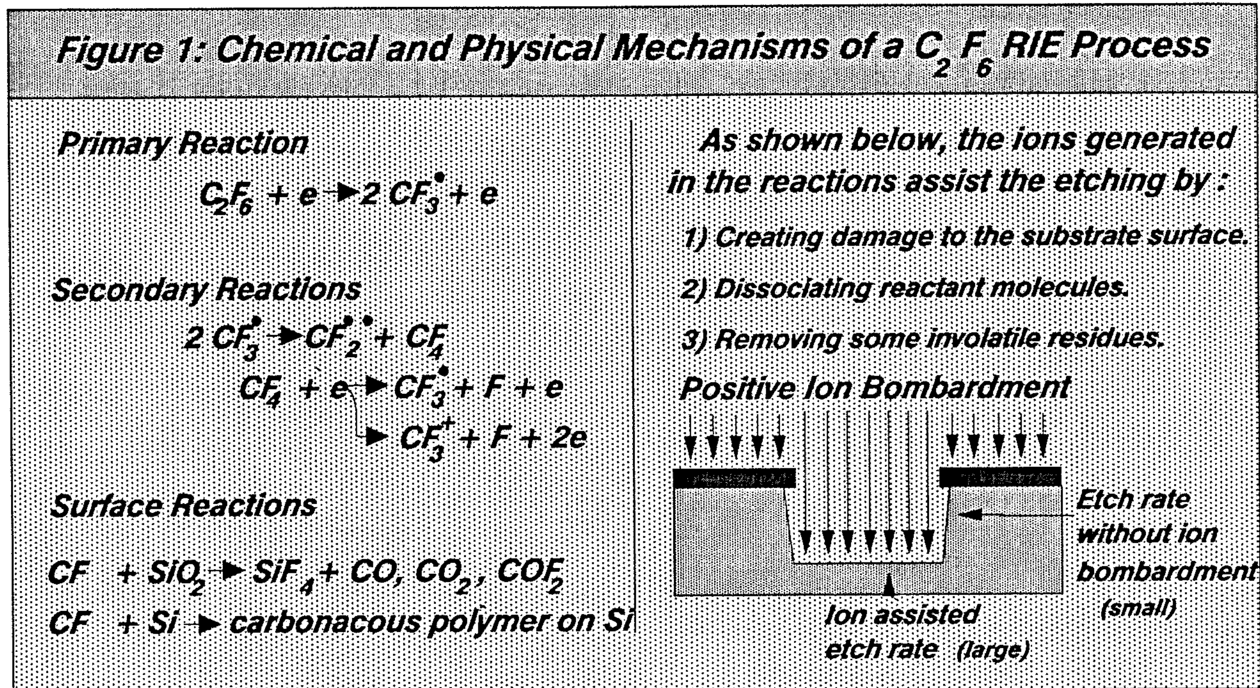
With the advent of smaller critical geometries isotropic wet etch processes have been largely replaced by anisotropic dry etch mechanisms. Unfortunately, the good selectivities that have been associated with wet etching are difficult to achieve with dry etch processes. This is particularly true in the case of silicon dioxide to polysilicon [1].

One way to increase the selectivity of silicon dioxide to polysilicon is to lower the fluorine to carbon ratio of the etch gas [1]. As shown in Figure 1, this can be explained by the reactions that occur between the etchant species and the two films. Silicon dioxide etching occurs when C2F6 molecules collide with electrons and rupture into CF3 radicals [2]. Subsequently, secondary reactions produce CFx radicals that dissociatively chemisorb on the silicon dioxide [3]. Once on the surface, the fluorine atoms reacts with the silicon and the carbon radicals react with the oxygen in the SiO2 to form volatile products that are pumped from the chamber [4]. This exposes the silicon dioxide surface to new radicals that can continue etching. Fortunately, the carbon radicals over polysilicon don't have any oxygen available which would result volatile products. This causes a nonvolatile carbonaceous polymer to build up the surface and inhibit etching [5]. Table 1 shows various gasses, their fluorine to carbon ratios, and the selectivities that have been reported[2].

Table 1: Reported Selectivities [3]		
Gas	F:C Ratio	SiO2:Si Selectivity
CF4	4:1	1:1
C2F6	3:1	3:1
C3F8	2.7:1	5:1
CHF3	2:1	10:1

The ion bombardment shown in Figure 1 reduces the selectivity, but is needed to produce an anisotropic etch. The balance between selectivity and anisotropy can be controlled by changing the power and pressure of the plasma. As the chamber pressure is decreased or the power is increased the amount of ion bombardment, and thus anisotropy, increases[5].

Figure 1: Chemical and Physical Mechanisms of a C_2F_6 RIE Process



A second method to increase the selectivity is to add hydrogen to the etchant gas. The added hydrogen reacts with fluorine atoms to form HF. Since HF is a stable compound, the fluorine to carbon ratio is decreased. This causes the etch rate of polysilicon to decrease monotonically to a value around zero [6] while the etch rate of silicon dioxide to remain relatively constant. Unfortunately, hydrogen is extremely explosive and presents a safety concern. To combat this, a self-supplying hydrogen gas, such as CHF3, can be used. In this experiment a combination of these methods were used to study the selectivity of silicon dioxide to polysilicon in a 2406 Plasmatrac. C2F6 was used as the primary source of fluorine and CHF3 was used to supply the hydrogen.

EXPERIMENT

The study utilized a central composite statistical design in RS1. With a 30sccm. gas flow, the CHF3 concentration, power, and pressure of the plasma were varied from 0 to 45%, 200 to 500watts, and 50 to 200mtorr respectively. The study included Taylor series regression models for the etch rate of silicon dioxide, the selectivity of silicon dioxide to polysilicon, and the uniformity of the silicon dioxide and polysilicon etch rates. The models were interpreted using contour plots. The curves on the plots are lines of equal response.

Eighteen wafers were prepared for the experiment. Sixteen were used to study the etch rate of silicon dioxide, the selectivity of silicon dioxide to polysilicon, and the etch rate uniformities of silicon dioxide and polysilicon. The other two were processed at the optimal conditions indicated by the RS1 response surface.

The substrates that were used are depicted in Figure 2. They were prepared by lithographically defining horizontal 1.2 um. thick KTI820 photoresist lines and vertical 6500A thick polysilicon lines on silicon wafers with 4500A of thermally grown oxide.

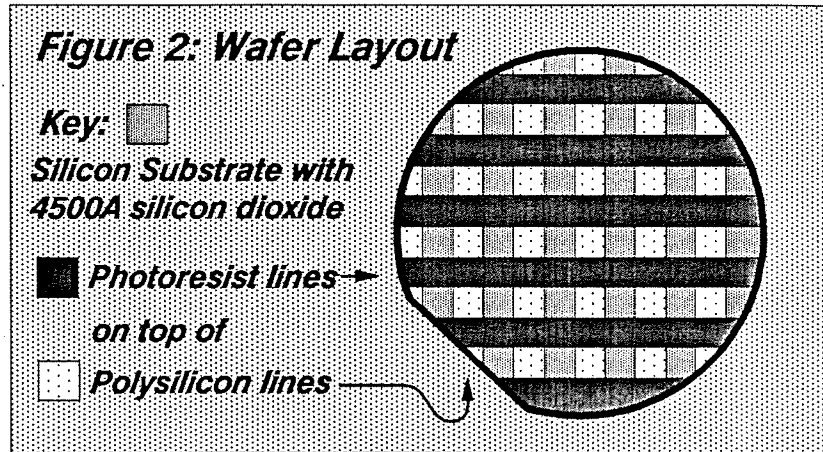


Figure 2: Wafer Layout

The film thicknesses were measured with a Nanospec and verified with a profilometer. The oxide and photoresist measurements were absolute and the polysilicon measurements were relative. This is due to the thickness of the oxide under the polysilicon. The etch rates were determined from the average of three best fit remaining thickness versus etch time plots, the percent uniformity was calculated from Equation 1, and the selectivities were found by dividing the appropriate etch rates.

RESULTS/DISCUSSIONS

A summary of the process conditions and results are shown in Table 2.

Table 2: Process Conditions and Results

	Controlled Factors			Etch Rate (A/min)		Selectivity	Uniformity	
	% CHF3	Power	Pressure	Oxide	Poly	Ox. to Po	Poly	Oxide
1	200	500	45.0	332.7	207.0	1.61	20.2	5.2
2	200	500	0.0	693.0	797.1	0.87	16.0	5.2
3	200	200	45.0	352.3	167.9	2.10	31.0	2.0
4	50	200	0.0	785.6	575.1	1.37	6.2	2.3
5	200	200	0.0	331.1	577.9	0.57	7.5	2.2
6	125	350	22.5	1098.2	836.6	1.31	15.7	0.9
7	50	350	22.5	1274.2	990.3	1.29	13.6	3.2
8	125	350	0.0	995.3	789.1	1.26	31.6	0.9
9	125	350	45.0	1328.2	544.6	2.44	8.4	3.5
10	125	500	22.5	1155.5	869.3	1.33	29.0	1.1
11	200	350	22.5	887.2	740.0	1.11	19.3	3.1
12	125	350	22.5	1132.3	909.0	1.25	8.4	1.1
13	50	500	45.0	1560.6	721.2	2.16	29.2	1.1
14	50	500	0.0	1320.0	1258.6	1.39	11.7	3.9
15	50	200	45.0	725.1	412.8	1.76	9.9	5.1
16	125	200	22.5	514.1	371.6	1.38	4.6	2.7

Figures 3-6 are computer generated contour plots of the Taylor series models for the responses. Figure 3 indicates that selectivity increases with CHF3 concentration and is a slight function of RF power. The etch rate of silicon dioxide increases with power, but is relatively unaffected by changes in CHF3 concentration. It also indicates that polysilicon etch rate uniformity decreases with RF power or CHF3 concentration. Figure 4 shows that the etch rate of silicon dioxide decreases with pressure and polysilicon uniformity decreases with pressure. A comparison of Figures 3 and 4 confirms the indications about silicon dioxide etch rate and selectivity.

Figure 5 predicts a maximum selectivity within the design space of 2.25 at a CHF3 concentration of 45%, a pressure of 112.7 mtorr, and an RF power of 365.8 watts with a 1207 A/min silicon dioxide etch rate. Figure 6 depicts the predicted uniformities with in the design space with a 45% CHF3 concentration. Both of these Figures indicate that a higher selectivity would be achieved at a higher CHF3 concentration.

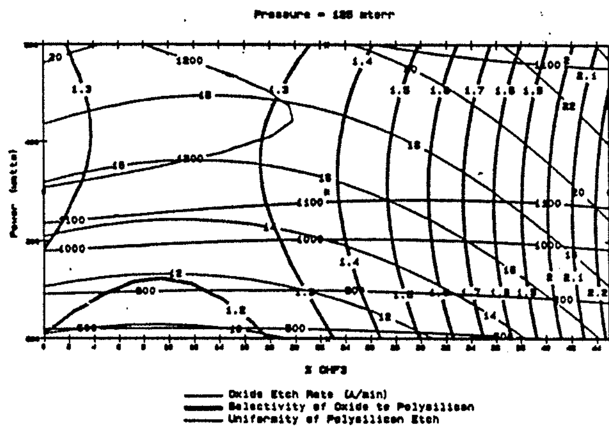


Figure 3: Oxide etch rate, selectivity, and polysilicon etch rate uniformity as a function of power and CHF3 concentration.

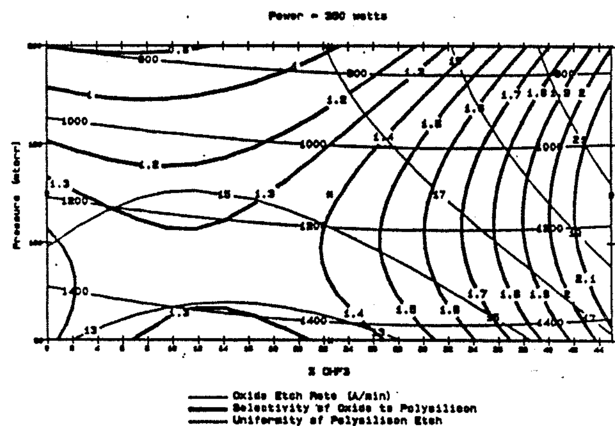


Figure 4: Selectivity, and oxide and polysilicon etch rate uniformities as a function of power and CHF3 concentration.

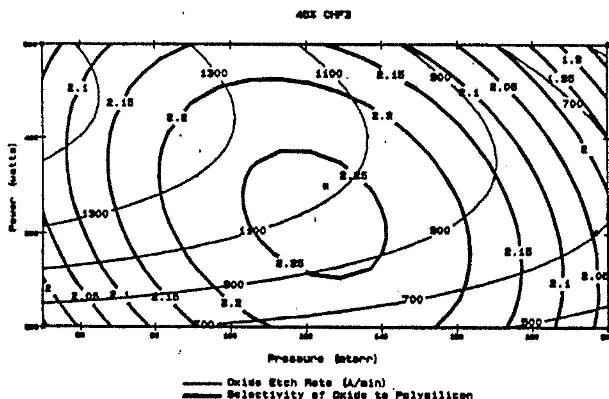


Figure 5: Oxide etch rate and selectivity as a function of power and pressure.

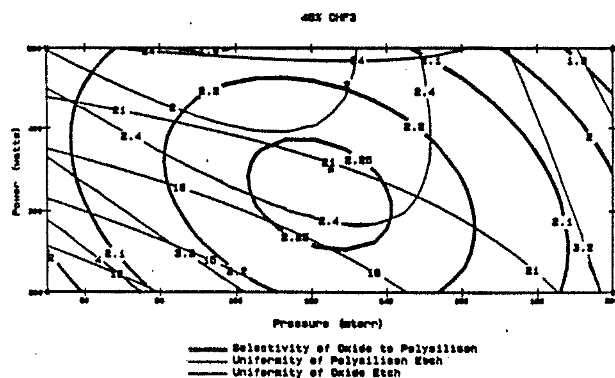


Figure 6: Same as Figure 5 with responses of selectivity, oxide and polysilicon

The Taylor series models for the maximum selectivity predicted that the power and pressure should be set at 255 watts and 150 mtorr with a 65% CHF3 concentration. At these settings a decrease in oxide etch rate was also predicted. To increase the predicted etch rate, a 60sccm. gas flow was used.The measured selectivity and silicon dioxide etch rate at these parameters were 6.3:1 and 612 A/min, respectively.

CONCLUSIONS

This experiment provided valuable information on the concentrations that should be used to maximize the silicon dioxide to polysilicon selectivity in a CHF3/C2F6 dry etch process. CHF3 should be used as the primary gas with a concentration between 45 and 85%. The exact concentration should be determined from the desired silicon dioxide etch rate and selectivity. The results from within the experimental design space resulted in a 2.44:1 oxide to polysilicon selectivity at an oxide etch rate of 1328 A/min. As indicated by the Taylor series response, an additional etch process was ran at a chamber power, pressure, CHF3 concentration, and gas flow of 255 watts, 150 mtorr, 65%, and 60 sccm, respectively. This resulted in a 6.3:1 selectivity at an oxide etch rate of 612 A/min.

ACKNOWLEDGEMENTS

I would like to thank Dr. Richard Lane for his supervision and guidance, Mike Jackson for his continual support of the project, and Gary Runkle for the maintenance he provided on the PLASMATRAC.

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