SELECTIVE REACTIVE ION ETCHING OF SILICON OXIDE IN CF_4/H_2 MIXTURES AT 200-300 Pa PRESSURES

W. D. Partlow, C. B. Freidhoff, and P. J. Chantry

Westinghouse R&D Center
1310 Beulah Road
Pittsburgh, PA 15235 USA

Abstract

We have characterized the process for selective etching of silicon oxide over polysilicon in CF_4/H_2 mixtures in a planar reactor at pressures in the 200 to 300 Pa range. Process definition and characterization included measurement of polymer layer deposition and etch rates as well as etch rates of oxide and polysilicon layers. They were measured in-situ by reflectometry using a HeNe laser. Process power, pressure, flow rate, and feed gas composition were varied. Mass spectroscopy of the reactor exhaust gases was correlated with important characteristics of the process. We were able to show that the crucial scaling parameter for this process performance is the input electrical energy per hydrogen molecule in the feed gas. This parameter makes it possible to easily transfer the process to reactors with different geometries.

Introduction

Prior studies of the reactive ion etching (RIE) of silicon oxide in CF_4-H_2 mixtures have mainly been carried out at pressures in the 2 to 4 Pa pressure range/1/. Several modern commercial RIE reactors having cassette loaded, single wafer architectures operate at much higher pressures, in the 200 to 300 Pa range/2/. The purpose of this work was to characterize the process for selective etching of silicon oxide over polysilicon in the higher pressure range, to optimize and evaluate the process performance, and to provide experimental data for comparison to the model described in Ref. 3 in order to obtain a deeper understanding of the process.

Experimental Apparatus

A schematic of the experimental reactor is shown in Fig. 1. Parallel planar

electrodes 8.9 cm in diameter, with spacing of 1.5 cm are located in a vacuum system consisting of 10 cm Pyrex pipe with a LN2-trapped diffusion pump for base pressure pumping. A 100 CFM Roots blower with pressure control throttling, backed by a mechanical pump, is used for process gas pumping. Etch/deposition rates are measured with a laser reflectometer-interferometer, and downstream gas products are characterized with a quadrupole mass spectrometer which uses a turbo-pumped differential pumping system. 13.56 MHz RF was used to excite the plasma via the upper electrode. The excitation power was obtained by integrating the product of the voltage and current waveforms in order to separate the plasma excitation power from the RF losses in the matching network.

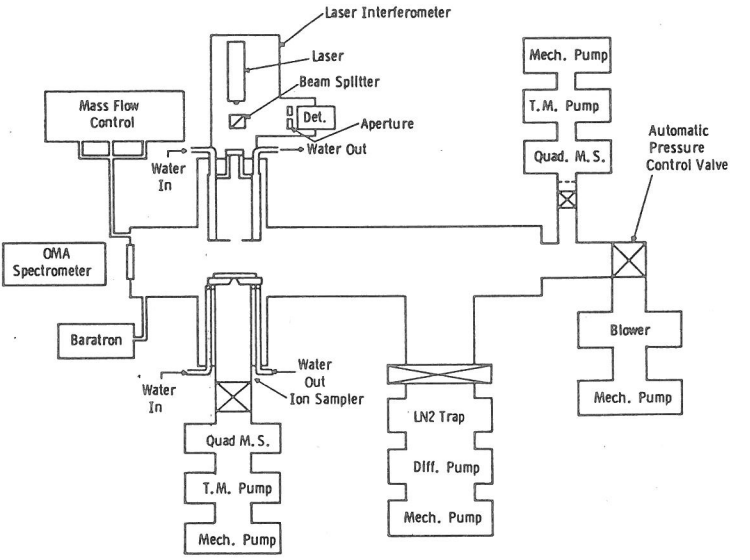

Figure 1. Schematic of the experimental apparatus used for performing and characterizing the etching process.

Location of the polymer point

The operating parameter space for CF_4/H_2 mixtures contains regions where etching of oxide occurs and other regions where deposition of polymer films occurs. These regions must be mapped in order to optimize a selective oxide etching process.

We made these determinations using the laser reflectometer to monitor both the deposition and etching of the polymer layers on silicon wafers. Fig. 2 illustrates that the polymer etching occurs only near the ends of the CF_4/H_2 composition ranges, and deposition occurs for compositions in between. The polymer points are defined as the point separating the etching from the deposition regions in parameter space. It can be seen in Fig. 2 that there are generally two polymer points, at high and low H_2 concentration. In this paper we will only be concerned with the one at low hydrogen concentrations.

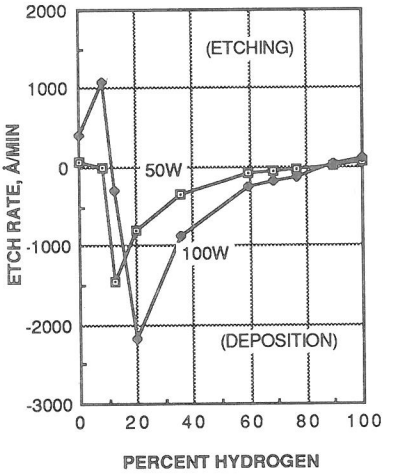

Figure 2. Etching and deposition rate of polymer formed from CF_4/H_2 gas mixtures, showing the two polymer points (PP).

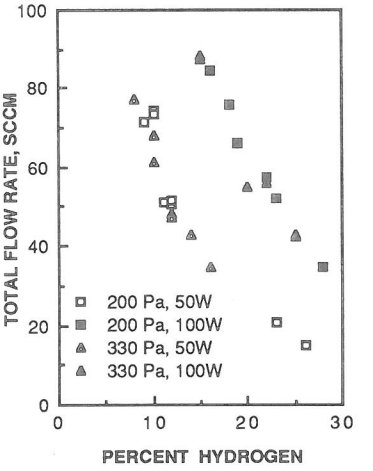

Figure 3. Location of the polymer point on silicon versus flow rate and hydrogen concentration at two pressures and RF power levels.

The dependence of the polymer point on our experimental variables is shown in Fig. 3. It is seen that the data fall on two contours corresponding to two values of RF excitation power. There is negligible dependence on operating pressure between 200 and 330 Pa. We made similar measurements of polymer point contours on silicon wafers coated with polysilicon (poly) and with CVD silicon oxide (silox) and got the same results, as shown in Fig. 4. We found no dependence of polymer point on substrate coating material or operating pressure. The composition-flow contours are the same as for silicon within experimental error, as determined from a multiple

regression analysis. These data can be collapsed into a very simple relationship by plotting the specific energy, energy per molecule entering the plasma, versus flow rate. This is done in two ways in Fig. 5 for all of our data points : energy per total feed gas molecules, and energy per H_2 molecule in the flow gas. The data all fall on a single line for this latter case, and it can be seen that the polymer point is located in all cases at the position where the specific energy is about 90 eV/H_2 molecule. Theoretical calculations on this process reported in Ref. 3 relate this specific energy value to the point in the flow where all the H_2 in the feed gases has been converted to HF.

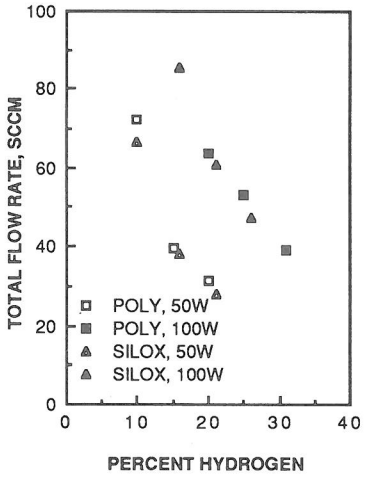

Figure 4. Comparison of the polymer points on polycrystalline silicon (poly) and CVD silicon oxide (silox).

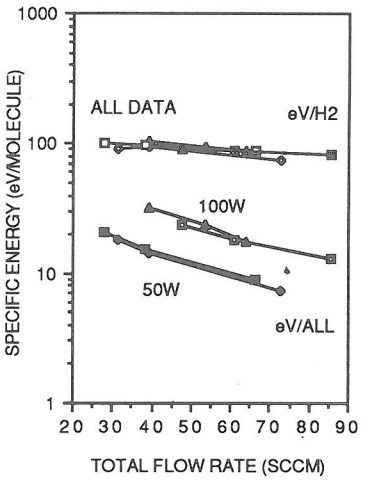

Figure 5. Specific energy per (total) molecule and specific energy per hydrogen molecule versus total flow rate.

Etch Rate And Selectivity

Etch rate measurements of poly and silox were made downstream of the polymer point by measuring the period of the laser reflectance oscillations. Gas compositions of 20% and 30% H_2 were used, and a typical dependence of the etch rates versus total flow is shown in Fig. 6 for the 30% H_2 mixture. Etch rate of the silox is seen to be independent of flow. The poly etch rate decreases at high total flow values, as the polymer point is approached, leading to higher selectivity of silox to poly. Selectivities

of as high as 15 were obtained for the 30% H_2 mixture, while no higher than 4 were obtained for the 20% mixture. For the 30% mixture, the etch rates were found to depend on the details of the material properties and previous process steps, for example the etch rate of doped polysilicon that was subsequently buried by silox was about twice as high as that of virgin (uncovered) doped poly on silicon, as seen in Fig. 7, where etch rates for these two types of poly are compared to silox as a function of specific energy per H_2 molecule. Silox etch rates were found to depend strongly on doping levels and process steps, undensified silox doped with 5% phosphorous was found to have an etch rate of 1900 Å/min for the 30% H_2 mixture. Steam densification of doped silox at 1000°C was found to reduce the etch rate to 800 Å/min.

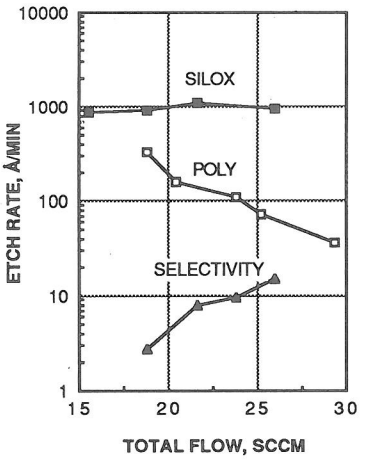

Fig. 6. Selectivity and etch rates for silox and poly for 30% CF4/H_2 mixtures at 100W RF power, 200 Pa. pressure.

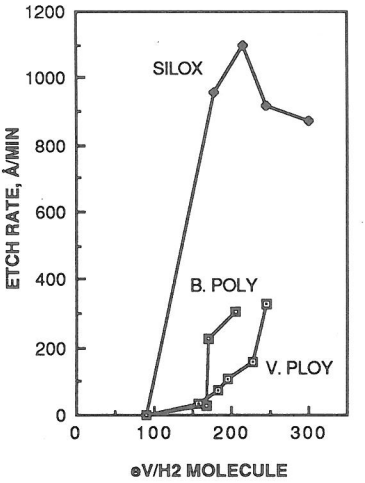

Fig. 7. Etch rates of virgin and buried poly versus specific energy per H_2 molecule compared to silox etch rates.

Discussion and Conclusions

We observed several process characteristics that give insight into this process. Firstly, the demarcation between polymer deposition and etching was quite sharp under our conditions. Interference fringes near the polymer point, dividing the downstream cleared area of an etched wafer and the polymer deposition region upstream, were restricted typically to about a centimeter. This indicates that there is not

much mixing by diffusion at these pressures and flows, and that the "plug flow" approximation/3/ is a good one. This is consistent with the sharp rate of rise of the silox etch rate seen in Fig. 7. The mass spectra of the gases sampled about 0.5 meter downstream of the plasma show evidence of depletion of H_2 and its conversion to HF, as well as identifying etching products to be both fluorides and oxyfluorides of Si.

We conclude that the specific energy is a useful parameter for controlling the polymer formation and thus the etching in this process. It condenses a large volume of parameter space into a single numerical quantity, and thus reduces the number of experiments needed to characterize the process. We have, in fact used this parameter to successfully transfer this etching process to a commercial etching reactor which has a significantly different size and geometry of the chamber. The specific energy parameter is also useful for helping to understand the process chemistry.

References

1. "Parameter and Reactor Dependence of Selective Oxide RIE in CF_4+H_2", L. M. Ephrath and E. J. Petrillo, J. Electrochem. Soc. Solid State Science and Technology, 129(10), 2282, (1982).
2. "Advancements in Plasma Etching of Silicon Dioxide", Arthur Zafiropoulo, Microelectronic Manufacturing and Technology, P. 10, August 1985.
3. L. E. Kline, W. D. Partlow, C. B. Freidhoff, and T. V. Congedo, "Modeling of selective reactive ion etching of silicon oxide in CF_4 + H_2 mixtures, to be presented at ISPC9.