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Surface roughness when etching SiO_2 in fluorine type plasma

1. Introduction

Dry etching of SiO_2 layers is often done using a fluorine type plasma. Common gases are CF_4, CHF_3, NF_3, and SF_6. It is also common that aluminium is present during the etching. The electrode in the etch chamber can be made of aluminium or Al_2O_3 and often aluminium is present on the sample as an etch mask or as a conducting layer.

A problem with aluminium in a fluorine type plasma is that since Al is not etched by flourine plasmas, any Al sputter-deposited on the sample will act as a micromask. Added to the problem is the risk of Al forming aluminium fluorides which are not volatile and can deposit on the sample. The Al-fluorides will also create surface roughness by acting as a micromask. The investigation reported here shows some of the things that should be considered if you want to reduce the risk of surface roughness.

2. Etch tests

The samples used were silicon wafers with 400 nm thermal SiO_2. Most of the tests were done using 2-inch wafers split into four quarters. Some tests were done on whole 2-inch or 3-inch wafers.

Etching was done in three different etch systems, tool #404 (Oxford RIE/ICP), tool #418 (Plasma-Therm BatchTop), and tool #419 (Plasma-Therm BatchTop). Various conditions were investigated such as with or without carrier wafer, different pressures and different RF-power.

Measurement of the SiO_2 thickness was done in the Woollam M2000 ellipsometer (tool #112) before and after the etching. The ellipsometer is quite sensitive to surface roughness and the amount of roughness can be quantified.

3. Results

The first tests were done in the two BatchTop systems using CF_4 gas at 100 mTorr and an RF-power of 250W. It was immediately observed that if a 150 mm diameter Si wafer was used as carrier, very little surface roughness appeared after etching. However, if the sample was placed directly on the electrode, large surface roughness was detected by the ellipsometer. The amount of surface roughness was verified by some AFM measurements. It was interesting to note that an electrode with Al_2O_3 surface (tool #418), gave the same amount of roughness as an electrode consisting of pure aluminium (tool #419).

By etching a few samples with different etch times, it was concluded that the thickness of the "rough" layer (as determined by the ellipsometer) increased linearly with etch time, see Figure 1.
A good indicator for the roughness is therefore to calculate the percentage of roughness, defined as

%Roughness = 100 x Thickness of rough layer / (SiO_2 before etch - SiO_2 after etch)

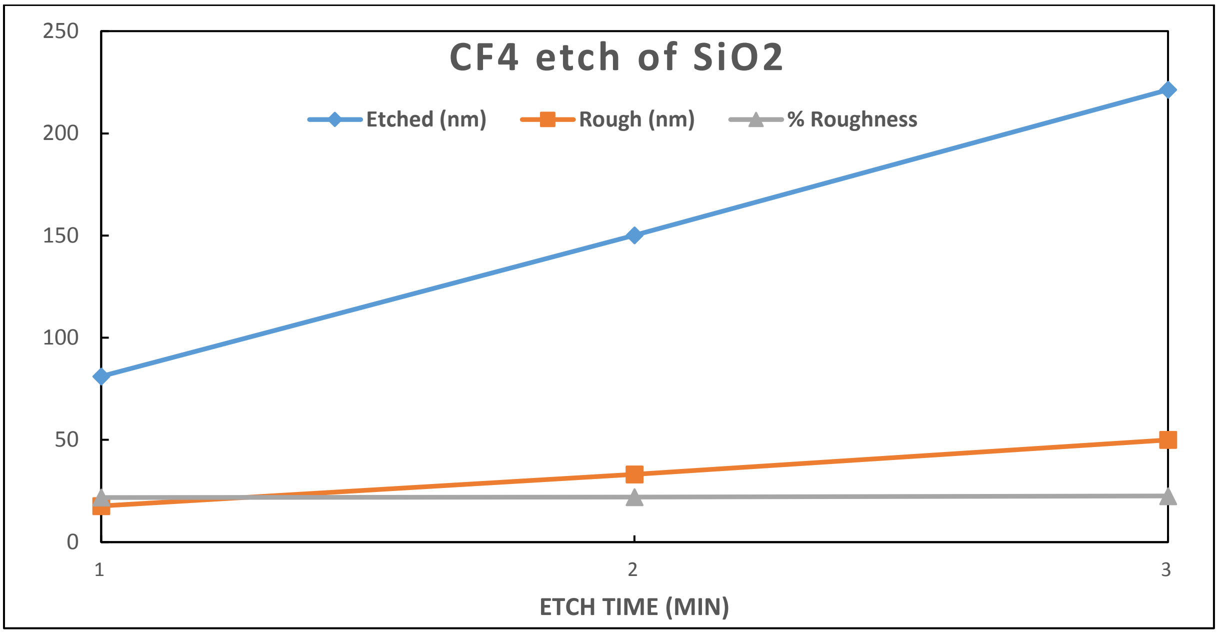

Figure 1. Thickness of the etched layer, thickness of the rough layer, and % roughness for different etch times. Conditions were RF= 250W, CF4= 40 sccm, and p= 100 mTorr. Etching was done in tool #418 without carrier wafer.

Next it was investigated how the RF power influences the surface roughness. The result can be seen in Figure 2 and it is obvious that higher RF power creates more surface roughness. This is probably because a higher ion energy will sputter more aluminium.

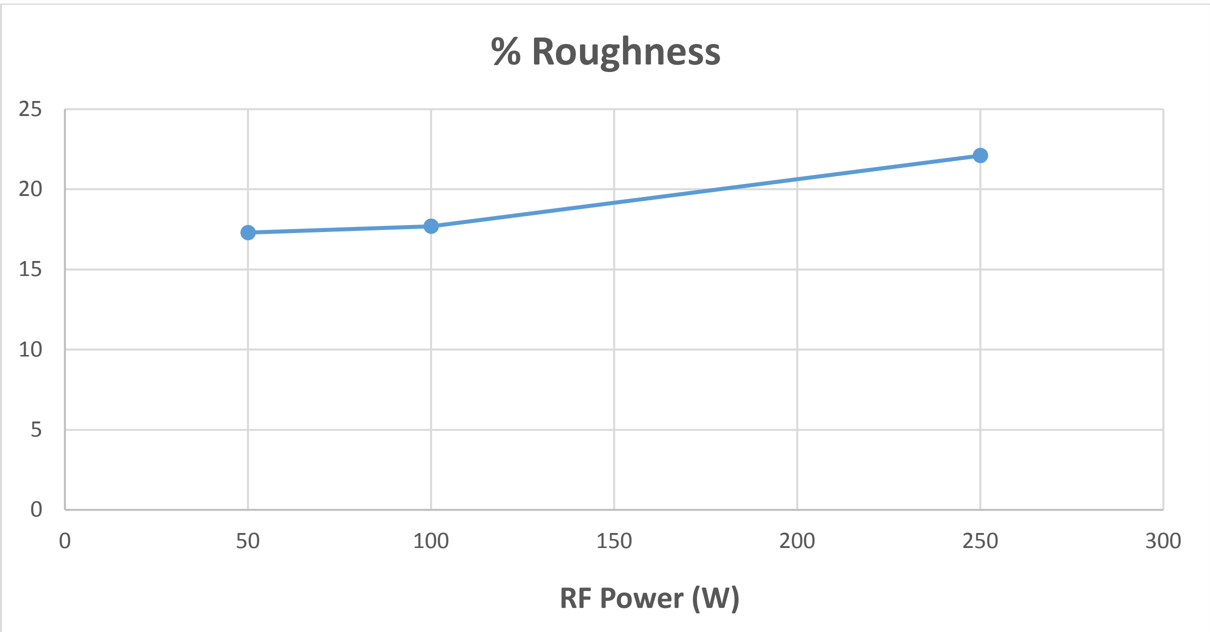

Figure 2. Roughness of etched SiO2 as a function of RF power. Etching was done in tool #418 without carrier wafer, CF4= 40 sccm, and p= 100 mTorr.

Another parameter that might influence the roughness is the pressure during etching. Measurements were done for 30 mTorr and 100 mTorr. The results are in Figure 3 and shows that a higher pressure leads to more roughness. It is likely that a low pressure more effectively removes Al and Al-fluorides and reduces the micromasking.

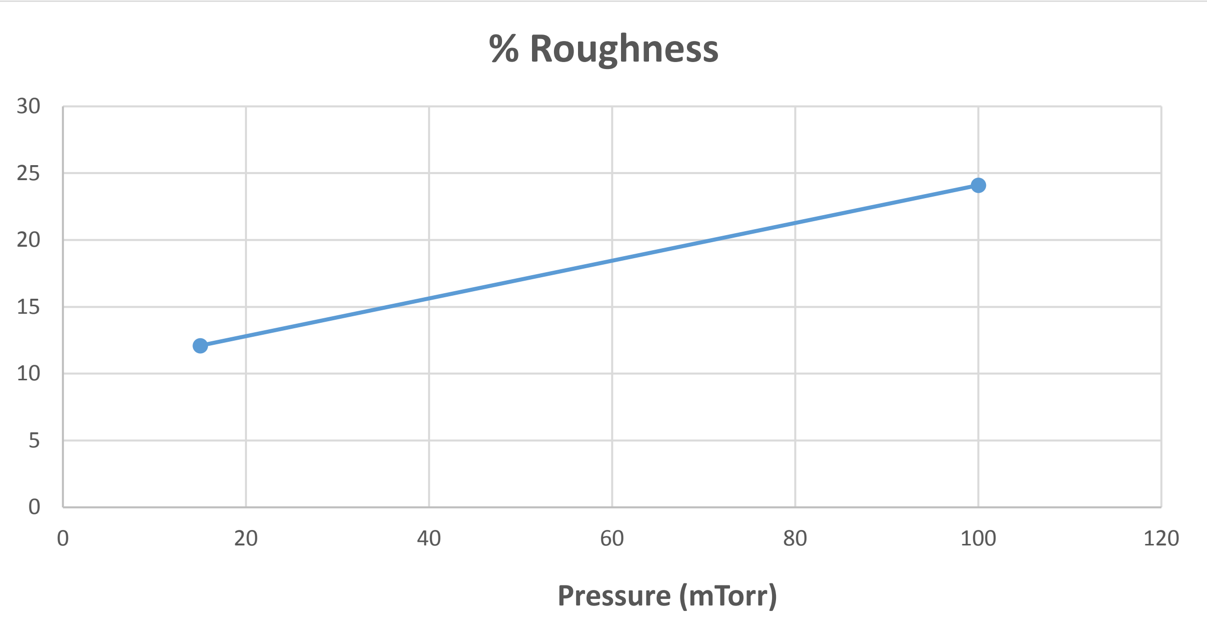

Figure 3. Roughness of etched SiO2 as a function of chamber pressure. Etching was done in tool #418 without carrier wafer, CF4= 40 sccm, and RF power= 250W.

To investigate the edge-to-centre variation of the roughness, a few 3-inch, oxidized Si-wafers were etched. The results are in Figure 4 (without Si-carrier) and Figure 5 (with Si carrier). The wafer etched without a carrier shows large surface roughness near the edge and a reduced roughness for the inner part. However, when comparing to the wafer in Figure 5, it can be seen that roughness in the centre is larger when etching without a carrier then when using an Si carrier.

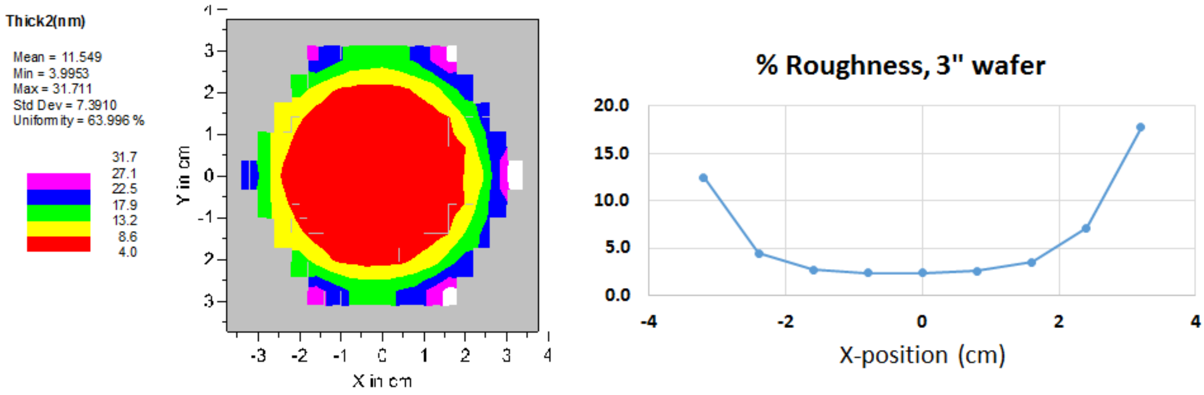

Figure 4. Roughness of etched 3-inch wafer. The left side shows a 2D-plot of the roughness and the right side shows roughness across the wafer (position y= 0). Etching was done in tool #418 without carrier wafer, p= 100 mTorr, CF4= 40 sccm, and RF power= 250W.

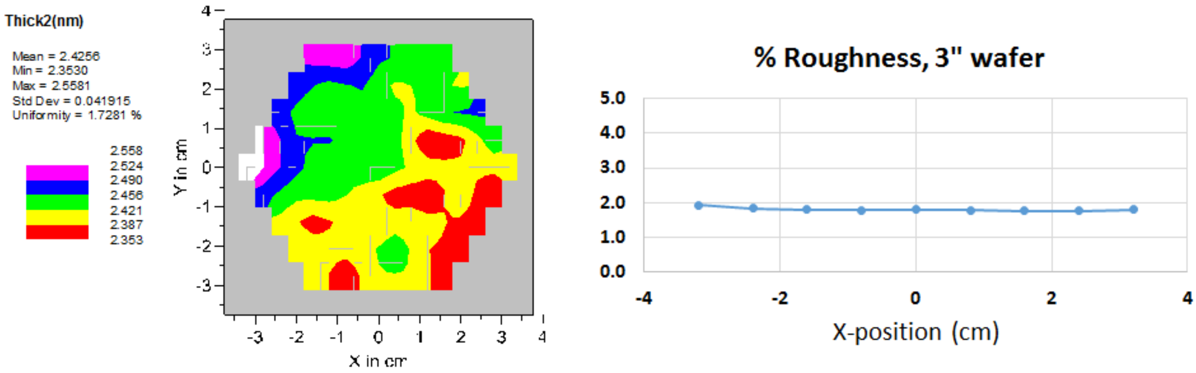

Figure 5. Roughness of etched 3-inch wafer. The left side shows a 2D-plot of the roughness and the right side shows roughness across the wafer (position y= 0). Etching was done in tool #418 with a 150 mm diameter Si carrier wafer, p= 100 mTorr, CF4= 40 sccm, and RF power= 250W.

Some further tests were done to investigate conditions that create surface roughness. Some of the results are:

- Use of a carrier wafer covered with photoresist give the same result as an Si-carrier, i.e. very little surface roughness.
- Use of an Al2O3 wafer as carrier give the same result as putting the sample directly on the Al-electrode, i.e. a large surface roughness.
- Etching of a Si3N4 layer in CF4-plasma without a carrier gave the same result as for SiO2-etching, i.e. a large surface roughness.
- Etching in tool 404 (Oxford RIE/ICP) using CF4 at 100 mTorr and an Al2O3 carrier gave the same result as etching in the BatchTop systems, i.e. a large surface roughness.

5. Conclusions

When etching in a fluorine type plasma, surface roughness created by micromasking from Al and Al-fluorides can be a problem. The aluminium can come from the electrode in the chamber or from an Al_2O_3 carrier wafer. Things to consider are:

- Roughness gets worse at high process pressure (> 50 mTorr)
- Roughness gets worse at high RF power
- Roughness gets worse near sample edge
- Very little roughness if an Si carrier wafer is used