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DRY ETCHING OF TITANIUM

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In this paper the application of a parallel plate reactive ion etcher (RIE) for Ti pattering is discussed. Two reactive gases, CF_4 + O_2 (7 %) and SF_6 were evaluated for the power densities in the range of 0.13 to 0.5 W/cm^2. The frequency of the rf-source was 13.56 MHz. The dependence of the etch rate on the Ti-layer thickness was significant in CF_4 + O_2-plasma. The optical end point detection was investigated based on either fluorine (704 nm) or carbonmonoxide (520 nm) emission.

INTRODUCTION

A thin Ti layer can be used to prevent spiking in Al based contact metallizations of integrated circuits. A Ti layer (100 nm) is deposited on the wafer before aluminium in the same sputtering chamber. In our case the aluminium is patterned by wet chemical etching. The Al pattern then serves as the mask for dry etching of Ti.

There is very little literature on the dry etching of Titanium or its alloys using fluorine based plasmas /1, 3/. Among the refractory metals Ti is known to be the most difficult material when etched with fluorinated chemistry. This is due to a low vapour pressure of the reaction product TiF_4 (e.g. 100 mtorr in 100 °C) /1/.

EXPERIMENTAL PROCEDURE

The etching experiments were performed in a commercially available reactive ion etcher (Plasmatechnology - RIE 80). In this system the rf-power (13.56 MHz) is applied to the lower electrode via a manual matching network. The area ratio of the electrodes is 3.1 and the distance between them is 6.5 cm. The electrodes are covered by oxidized aluminium and the chamber material is Pyrex-glass. The upper electrode has a shower-type gas inlet and the pumping port is located symmetrically around the lower electrode. The pumping unit consists of a Roots-blower backed by a rotary-vane pump. The temperature of the lower electrode is controlled by a water circulation system. Emission spectrometer (Bentham M300E) is connected to the chamber using an optical fiber bundle.

For the etching studies Ti films of various thicknesses were sputtered on 3 in. Silicon wafers covered by a thin (100 nm) thermally grown oxide. The oxidation of titanium surface in the atmosphere was prevented by sputtering a very thin (200 Å) α-Si layer on the titanium. The masking material was 1470 positive photoresist. In the actual structure a 100 nm thick Ti film was deposited before Al-sputtering to serve as the metallization layer in a 3 µm CMOS process. The Ti-layer was patterned by RIE after the wet etching of Al.

The etched step heights were measured using a Dektak profilometer.

RESULTS

$CF_4 + O_2$ The reactive gas mainly used in this study was a mixture of carbontetrafluoride with 7 percent of oxygen. The high selfbias voltage created between the substrate and the CF_4-plasma was expected to enchance the desorption of TiF_4-molecules from the surface. For the same reason a relatively high power density (0.45 W/cm^2) and substrate heating were used. The main problem during the first experiments was an unpredictable etch-rate between different types of samples. The reason for this phenomenon was discovered to be the dependence of the etch rate on the thickness of Ti-layer. In Fig 1 we can see that the etch rate of a 500 nm film is four times larger than that of a 100 nm layer. The etching conditions were identical. The same kind of observation was recently reported by Chem and Lee /4/for reactive ion etching of niobium. The explanation given by the authors was the heating effect caused by the eddy currents in the metallic film.

We studied the etch rate of titanium as a function of time keeping the etching parametres constant. The result is shown in Fig 2. It can be seen that the etch rate is very slow during the first 60...80 secounds. After this delay the etch rate starts to increase rapidly. This can be interpreted in two ways:

a) whether there is an initial period due to the etching mechanisms of Ti or
b) the conditions in the plasma phase are not constant during the etching. A similar delay that was found in the etchrate was also observed in the intensity of fluorine emission (704 nm) after switching on the CF_4-plasma.

The effect of the electrode temperature on the etch rate is shown in Fig. 3 for a 100 nm titanium layer etched with a power density of 0.45 W/cm^2. The dependence was not as strong expected though one should remember that the substrate temperature could not be measured. In addition to the influence on the etch rate the electrode temperature affected the etching uniformity and consequently the quality of the end point signal when F* emission was used.

The etch rate of titanium obtained with $CF_4 + O_2$ was acceptable for our application. The process time to pattern the 100 nm Ti layer was from 1.5 to 2 minutes. The main difficulty was a poor selectivity of the etching to the underlying SiO_2-film. With the power density of 0.45 W/cm^2 the etch rate of the oxide was equal or even slightly higher than that of the 100 nm Ti-layer.

SF_6 In addition to carbontetrafluoride, sulfurhexafluoride was evaluated as the reactive gas for RIE of titanium. The etching was found to take place with SF_6 but the etch rate was slightly lower compared to the results

with CF_4. The etch rate increased with increasing power density in the same manner as for the case of Freon 14. In contrast, the dependences of the etch rate on the chamber pressure seemed to be different for the two gases. While the Ti etch rate increased at higher pressures in CF_4-plasma, lowering the pressure (< 40 mtorrr) was found to enchance the etching in sulfurhexafluoride. This could be due to the rapid increase of the self bias voltage in SF_6-plasma when the pressure is lowered.

The temperature of the cathode was a more dominant process parameter for SF_6 than for CF_4-plasma. Practically no etching occured when the lower electrode was kept below 30 °C (0.45 W/cm^2, 100 mtorr, 5 sccm)

The selectivity R_{Ti}/R_{SiO_2} was about 2.3 at the power density of 0.45 W/cm^2, This value can not be considered to be high but it is clearly better than the selectivities obtained with CF_4.

The studies on the relationship of the relationship of the etch rate and film thickness and the linearity of the etching process as a function of time in SF_6 plasma are underway.

END POINT DETECTION

The most reliable method for the detection of the end point after the Ti etching was found to be the well known fluorine emission at the wavelenght of 704 nm. In Fig. 4a we can see a clear end point signal during the RIE of a 500 nm Ti-layer over silicondioxide on the $CF_4 + O_2$ plasma. In the beginning of the etching the F*-intensity stayed in a relatively low value as mentioned earlier. This phenomenon was typical for CF_4-O_2-plasma and its origin is not clear. A prolonged pumping cycle (1 hour) resulted in shortering of this initial delay. This suggests that the residual gases in the chamber increase the consumption of fluorine. The variation in the amount of fluorine can be the reason for the nonlinear behaviour of the etch rate as a function of the time (Fig. 2). On the other hand it can not explain the dependence of the etch rate on the Ti-film thickness. The end point detection for etching a thin (100 nm) Ti-film caused difficulties because the end point signal coincided with the rising slope of the F*-intensity curve.

When CF_4 was used as the reactive gas the emission of carbonmonoxide (520 nm) served to indicate the end point. The amount of CO in the gasphase increases when the erasion of the SiO_2 starts (Fig. 4b). The drawback of this method was a relatively low intensity level of the 520 nm line.

The self bias voltage on the cathode was recorded during all the experiments. A small change in the voltage was found at the transition between two layers but it was too weak to be used as an end point indicator.

CONCLUSION

The temperature control of the cathode is a significant process parameter in titanium dry etching using fluorine based chemistry. With $CF_4 + O_2$ a higher temperature results in improved etching uniformity. With SF_6 an elevated temperature is a necessity in order to statrt the etching reaction.

the etch rate of titanium in CF_4 plasma depends strongly on the thickness of the Ti-layer. One of the consequences is that the thinner the layer is the more difficult it is to selectively etch Ti on SiO_2.

ACKNOWLEDGEMENTS

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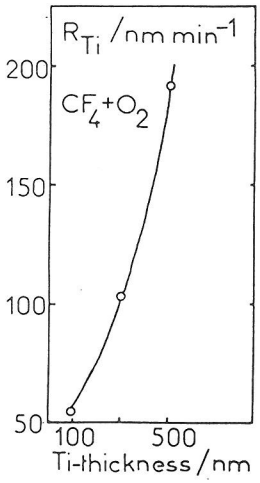

Fig 1: The etch rate of Ti as a function of the layer thickness (0.45 W/cm^2, 100 mtorr, 15 sccm CF_4 + O_2, 50 °C).

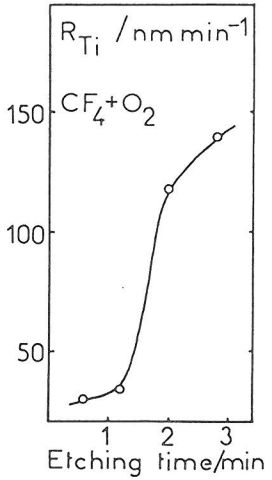

Fig 2: The etch rate of 300 nm thick Ti-film as a function of the time. (parameters: see Fig 1).

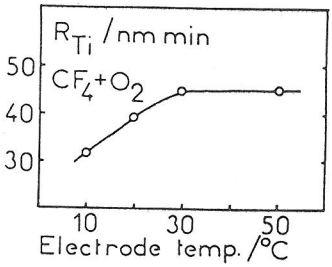

Fig 3: The etch rate of 100 nm thick Ti-film as a function of the electrode temperature (parameters: see Fig 1).

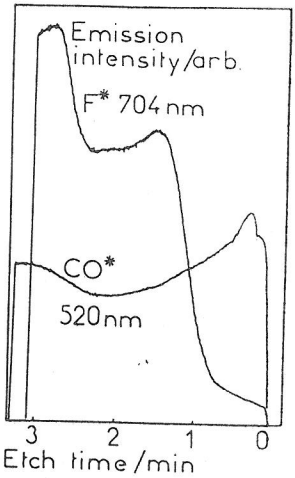

Fig 4: End point signals using emission line of a) F*, 704 nm b) CO*, 520 nm. The time scale is valid only for the curve a).