REACTIVE ION ETCHING OF ALUMINUM ON THE PLASMATRAC 2406

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ABSTRACT

A process for etching aluminum was developed for a Plasmatrac 2406 Reactive Ion Etcher. The etch gases used were a mixture of silicon tetrachloride ($SiCl_4$) and helium (He). A $SiCl_4$ flow of 35 sccm and He flow of 48 sccm at a chamber pressure of 100 mT and power of 150 watts resulted in an average aluminum etch rate of 1450 Angstroms per minute. Resulting selectivities ratios were 3.2:1 for aluminum to resist, and 30:1 for aluminum to the underlying oxide. The etch uniformity was approximately 27% and etching of aluminum lines less than 2 microns resulted in an anisotropic etch profile of approximately 75 degrees. This is a working process but further work is required to increase the aluminum etch rate and improve the selectivity to resist.

INTRODUCTION

Reactive Ion Etching (RIE) of aluminum is probably the only method used to etch aluminum in industry today because of the ever increasing demand to push semiconductor technology into the submicron region. One reason for using the RIE technique is that it is anisotropic while wet etching is isotropic, rendering it impractical for geometries below 2 um. Plasma etching of aluminum is currently done by chlorine and bromine containing gases. The reason for this is that halides of aluminum, for example $AlCl_3$ or AlBr, are volatile and are easily removed from the chamber. Fluorine containing gases form halides that are not volatile, thus they remain on the surface and retard the etching of the aluminum [1].

There are three basic challenges that must be met to achieve successful etching of aluminum. They are:

(1) Initiation: Aluminum Oxide break-thru and moisture removal.
(2) Aluminum etch
(3) Post-Etch treatment

Initiation refers to the removal of about 30 angstroms of native oxide (Al_2O_3) from the surface. This is very difficult to remove by plasma etching [1], but is easily removed by sputtering the wafer. Sputtering removes any other material exposed to the bombarding ions thus affecting all selectivities. Water vapor and oxygen removal is also essential in this initiation process because exposure of aluminum to moisture or oxygen after the Al_2O_3 removal results in the formation of the oxide, which creates an etch that is not repeatable. A water scavenging gas and/or low base pressure chamber is needed to minimize water vapor and oxygen.

After the sputter of the native oxide, the aluminum etching proceeds at a rate and with a profile, that is affected by the flow of the etch gas, power at the electrodes, and pressure of the chamber [1]. Selectivity to the oxide and resist is also controlled by these factors. The general chemical reaction leading to the principal etch product (chlorine based chemistry) is:

$$Al\ (s) + Cl^-\ (g) \dashrightarrow AlCl_3\ (g)$$

Aluminum chloride ($AlCl_3$) condenses at 27 degrees C and can cause buildup on the wafer or chamber. To ensure complete removal of the $AlCl_3$, the temperature of the reactor should be at 35 degrees C or higher [2].

The post etch treatment prevents corrosion of the aluminum. The aluminum chloride ($AlCl_3$), can condense on the wafer surface and chamber walls. Upon removal from the chamber any exposure to moisture will cause residual $AlCl_3$ to form hydrochloric acid (HCl), which quickly corrodes aluminum [3].

For this project, these challenges could have been met in a variety of etch chemistries. Gases currently used to plasma etch aluminum are BCl_3, $SiCl_4$, CCl_4, Cl_2, BBr_3, HBr, and Br_2 [1,4]. These gases are all either highly toxic or carcinogenic. Silicon tetrachloride is not considered a carcinogen but it is toxic. This was one of the main reasons for choosing $SiCl_4$ as the etch gas in this project. Another advantage of $SiCl_4$ is that it increases the selectivity of aluminum to photoresist. One drawback when using $SiCl_4$ as the only etch gas is that excessive arcing in the plasma may occur at relatively low power (<100 watts) and thus a diluent is needed to prevent this arcing. One such diluent that not only reduces the arcing in the plasma but also increases the photoresist selectivity is Helium [2]. The aluminum oxide break-thru is accomplished using a mixture of $SiCl_4$ and Argon at high power (300 watts). Argon was chosen because its ions are heavy and thus impart more damage to the surface during sputtering. $SiCl_4$ acts as a water scavenger by reducing moisture in the plasma atmosphere which prevents further growth of aluminum oxide [1].

EXPERIMENT

To obtain an optimum aluminum etch process, a design of experiments was done. This design determined a general operating area with respect to flow, pressure, and power. The responses for this design are selectivity to resist, selectivity to oxide, uniformity, and etch rate. A Nanospec was used to measure the resist and oxide and an Alpha-Step profilometer was used to measure the aluminum. Five points were measured per wafer. The SiCl4 was varied from 30 to 40 sccm, the pressure from 75 to 100 mTorr, and the power from 100 to 200 Watts. The helium was held constant at 48 sccm and the electrode temperature at 45 degrees C. For the initial aluminum oxide break-thru, the Argon flow was 20 sccm, the SiCl4 flow was 35 sccm, the pressure was 50 mT, the power was 300 watts, and the sputter time was 20 seconds.

A Plasmatrac 2406, which is a single wafer etcher was employed in this experiment. It minimizes water vapor and oxygen by using a load lock system. To get accurate etch data under true aluminum etch conditions, a wafer that had resist, oxide, and aluminum was used [2]. These wafers were patterned with thermal oxide, aluminum, and KTI-820 positive photoresist in a checker board pattern with 5 mm squares. The test wafers used were modelled to typical wafers processed at RIT that is, each wafer had approximately 3500 angstroms of thermal oxide, 3200 angstroms of aluminum, and 12000 angstroms of KTI-820 resist.

The general operating parameters from the design of experiments were then used to etch patterned resist on aluminum on oxide wafers. The patterned resist consist of lines and spaces that varied from 5 microns down to 0.2 microns. After etching, chloride ions and hydroscopic compounds from the surface of the wafer were removed by rinsing the wafer in deionized water [5]. The small geometries were then inspected using the Scanning Electron Microscope to determine the degree of anisotropy.

RESULTS/DISCUSSION

Table 1 shows the results from the design of experiments. From this design, at a flow of 35 sccm, pressure of 100 mT, and power of 150 watts, the maximum etch rate was 1457 angstroms per minute, with a 27% uniformity [(high - low)/ave etch]. The selectivities of aluminum to resist was 3.2 to 1, to oxide was 5.8 to 1, and the underlying oxide of 30 to 1. The manufacturer of the Plasmatrac 2406, Plasma Systems Inc., indicated that the machine can achieve an etch rate up to 10,000 angstroms per minute [6]. This could not be accomplished here because of the low chlorine concentration.

The comparison between the oxide and underlying oxide demonstrates the effects of sputtering. The underlying oxide did not see any sputtering thus resulting in such a large selectivity.

Since aluminum wafers processed at RIT has only aluminum and patterned photoresist exposed to the plasma, this high aluminum to oxide selectivity (30 to 1) will correct the uniformity problem. That is, the wafers can be over etch without doing any damage to the underlying oxide. The selectivity to photoresist (3.2 to 1) is not a major concern because the typical photoresist is four times thicker than the aluminum thus completion of aluminum etch will leave approximately 9000 angstroms of photoresist. The resist etch rate was 451 angstroms per minute.

FLOW SCCM)	PRESSURE (mT)	POWER (WATTS)	SELECT OXIDE	SELECT RESIST	UNIFORMITY (PERCENT)	ETCH_RATE (ANGS/MIN)
40.00	87.50	150.00	5.90	1.60	130.50	479.0
40.00	100.00	100.00	10.20	4.00	27.50	719.6
30.00	87.50	150.00	4.70	2.50	19.40	841.4
35.00	75.00	150.00	3.80	1.80	37.00	738.4
30.00	100.00	100.00	7.40	2.00	51.60	405.0
30.00	75.00	200.00	3.10	1.30	24.10	800.4
35.00	87.50	200.00	3.20	1.40	40.90	795.0
35.00	87.50	150.00	6.00	2.30	25.20	977.0
40.00	75.00	100.00	7.90	2.30	22.40	732.0
40.00	100.00	200.00	3.90	1.70	32.10	1238.4
35.00	100.00	150.00	5.80	3.20	27.00	1457.0
30.00	100.00	200.00	3.70	1.50	25.60	1173.0
35.00	87.50	100.00	6.30	2.50	30.50	1027.0

Table 1. Design of Experiment to determine the baseline for aluminum etching on the Plasmatrac 2406.

Figure 1 and Figure 2 show the patterned resist on aluminum on oxide wafers. They consist of 1.4 micron lines that were etched using the parameters determined above. These Scanning Electron Micrograph shows the anisotropic etching of the aluminum lines. The resist showed partial undercutting (fig 1) resulting in the rounding of the aluminum lines (fig 2.) The nonuniformity of the lines and spaces were due to improper exposure of the exposure tool (Kasper Contact Aligners).

Figure 1:
1.4 micron
resist on
aluminum lines.

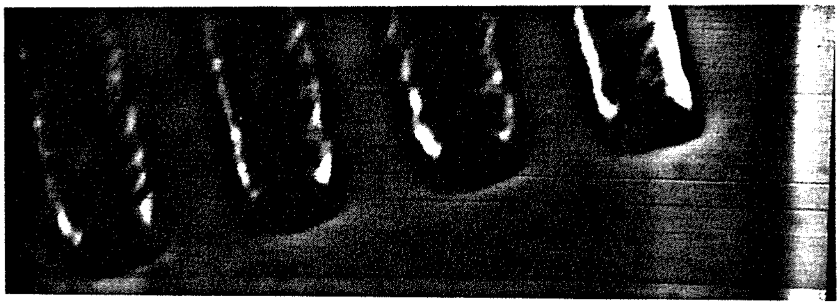

Figure 2:
1.4 micron
aluminum lines
with resist
stripped.

Wafers that were rinsed after etching in deionized water resulted in no visible corrosion while wafers that were not rinsed showed extensive corrosion. The time in which the corrosion took place could not be determined but it would be highly recommended that wafers should be rinsed as soon as possible after etching.

CONCLUSIONS

Reactive Ion Etching of aluminum was accomplished using a SiC14 flow of 35 sccm, Helium flow of 48 sccm, pressure of 100 mT, and power of 150 watts. These parameters resulted in an aluminum etch rate of 1457 angstroms per minute, uniformity of 27%, and selectivities of aluminum to resist of 3.20 to 1 and to the underlying oxide of 30 to 1. Etching of lines less than 2 microns resulted in an anisotropic etch with a resulting profile at approximately 75 degrees. Even though the aluminum etch rate is low, this is a working process which can be used to etch wafers. However, further work should be done to increase the aluminum etch rate and increase the selectivity to resist. This improvement can only take place, by using gases that are carcinogenic and toxic. Verification of the results and optimizing of the design should also done.

ACKNOWLEDGMENTS

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