Plasma-Therm I.P. ®

APPLICATION NOTES

PLASMA ETCHING OF SILICON NITRIDE AND SILICON DIOXIDE

Silicon nitride and silicon dioxide thin films find a variety of uses in both semiconductor and non-semiconductor applications where various properties of these materials are exploited (dielectric strength, mechanical strength, optical properties, plasma and chemical resistance). These applications include uses as inter-level dielectrics, implant anneal caps, anti-reflection coatings, masking materials and wear/chemical resistant coatings. Silicon oxynitride is also frequently employed in these applications, but its properties in many ways are intermediate between silicon oxide and nitride and here it is not treated separately, but rather as a hybrid between the two materials.

After the deposition of a thin film, many of these applications require the removal by etching of the film either completely or partially using a mask to define an etched pattern. Because of the large number of applications, there are many varying requirements imposed on the etch process, and consequently there are many possible etch processes. Fortunately, these fall into two rather broad categories: ion dominated etching and chemically dominated etching. These differ primarily in the range of materials that can be etched, resulting in the ability to select a process based on the etch selectivities required.

Ion Dominated Etch

CHF_3 will etch both silicon dioxide and silicon nitride by an ion dominated reaction. The species produced in the plasma and primarily responsible for etching are CF_3 and CF_2 radicals. As these are poor etchants for other materials, and because no other reactive species are generated, this type of process is frequently chosen where silicon dioxide or nitride must be etched selectively to materials such as Si, GaAs, Al, W, Ti etc. The "ionic" nature of the process means that the etch is exclusively anisotropic and etch rate uniformities are typically very good. Because of the degree of ion bombardment, precautions must be taken to prevent sputtering of unwanted materials (eg RF electrodes) by the use of appropriate electrode cover materials, such as carbon.

CHF_3 alone has a tendency to readily form fluorocarbon polymers, and consequently it is frequently used together with the addition of small amounts of O_2 to suppress this. This changes the nature of the process since the addition of O_2 generates reactive species such as atomic O and atomic F. This is a well understood reaction and is very similar to the reaction of CF_4 and O_2 reported in the infancy of plasma etching by Harschbarger et al. These species are good etchants for many materials such as Si, Si_3N_4, W and photo-resist, and consequently the selectivity of the process to these materials can be controlled by the addition of O_2. Typical results obtained for the etching of silicon dioxide and nitride using this type of process are listed below, and the response to the addition of O_2 is shown in FIG 1. As noted above, etch results for SiON will fall between those of Si_3N_4 and SiO_2, with the refractive index being a good indication of whether the etch will be more "oxide-like" or "nitride-like".

Process Gases.............. CHF_3/O_2
Etch Mode.............. RIE
Etch Rate - SiO_2.............. 300 - 400 Å/min
Etch Rate - Si_3N_4.............. 400+ Å/min *
Selectivity - Resist.............. 2 - 3 : 1
- Silicon, GaAs.............. > 10 : 1
- Ti,W,Al.............. > 10 : 1
Etch Rate Uniformity.............. < ±5%
Etch Profile.............. Anisotropic

9509 INTERNATIONAL CT. • ST. PETERSBURG, FL 33716 • PHONE (813) 577-4999 • FAX (813) 577-7035

* The etch rate of Si_3N_4 in this process is highly dependent on the method used for deposition. PECVD nitride will etch faster than CVD nitride and the etch rate increases as the deposition temperature decreases (more H incorporation in the film). Etch rates in excess of 1000 Å/min are not unusual.

Note that with this process, if the application requires pattern definition using a photo-resist mask, then the etch rate is limited by the maximum RF power that can be applied without degrading the photo-resist. However, for applications not having such a mask (eg. de-layering for failure analysis), significantly higher etch rates can be attained by operating at higher power levels.

Chemically Dominated Etch

While SiO_2 is only etched well using a process which has a high degree of ion bombardment, Si_3N_4 can be etched with little or no ion assistance in an environment containing atomic fluorine. The source of F atoms can be a variety of plasmas, such as CHF_3/O_2 noted above, but more commonly is CF_4/O_2 , SF_6 or SF_6/O_2.
The SF_6-based processes are particularly useful, because in the absence of C-containing species, the etch rates for SiO_2 are low, enabling Si_3N_4 to be etched with high selectivity to SiO_2. Because ion bombardment is not essential, processing at low power densities (low dc bias) and PE mode operation is possible, resulting in low damage processes for sensitive devices. Also, since the etch mechanism primarily involves atoms (not ions), the etch is isotropic, producing sloped and undercut etch profiles. This may be of little consequence for some thin film applications, or may be used to advantage in some applications (eg T-gate fabrication). Typical etch results are listed below:

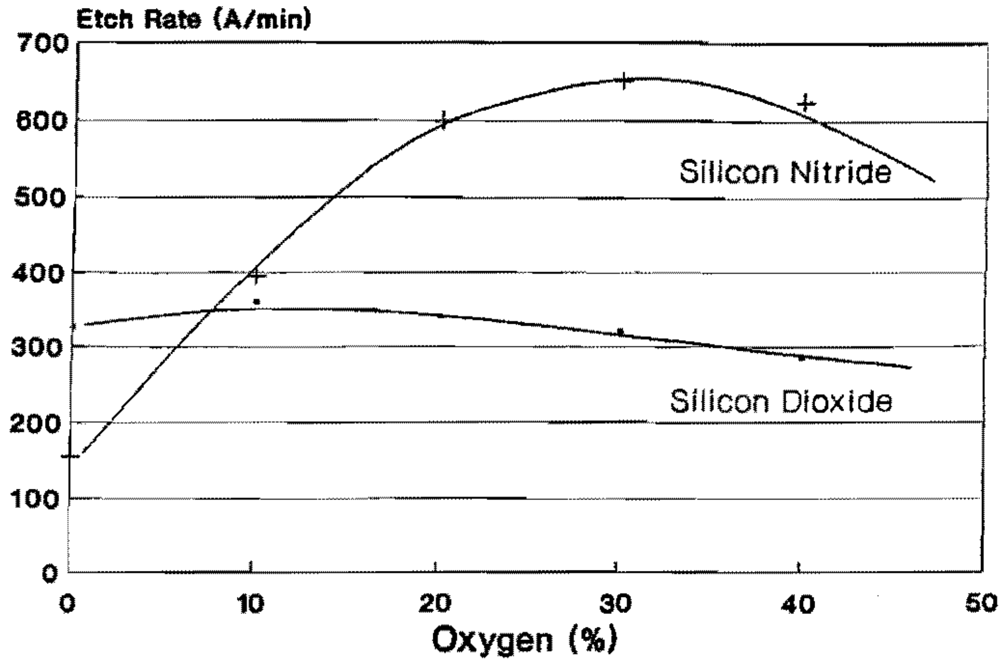
Process Gases.............. SF_6,O_2
Etch Mode.............. RIE or PE

Etch Rate - Si_3N_4 .... 1000+ Å/min
Selectivity - Resist.............. 2 - 3 : 1
- SiO_2.............. > 7 : 1
- GaAs, Al.............. > 20 : 1
- Si.............. 1 : 1

Etch Rate Uniformity.............. < ±10%
Etch Profile.............. Isotropic

09/24/92

Silicon Nitride / Silicon Dioxide Etch
Etch Rate vs Oxygen Addition



SiO_2/Si_3N_4 ETCH

Gas CHF_3		45 sccm
O_2		5-15 sccm
Temperature		35°C
Pressure		40-50mT
R. F.		150-200 watts
dc		450 ± 50 volts
Susceptor		Ardel
Endpoint Technique	SiO_2	laser
	Si_3N_4	laser or O.E. @ 337nm (N_2)
Gas Channels	0-200 N_2	(CHF_3)
	0-100 N_2	(O_2)
Etch Rate (thermal oxide)		300-400Å/min.
Etch Rate Si_3N_4		400 + Å/min.
Etch Rate LTO, PSG		400 + Å/min.
Selectivity SiO_2/Si		approx. 10:1
Selectivity SiO_2/photo-resist		approx. 3:1
Uniformity		< ± 5%
Profile		anisotropic

POWER

The etch rate of both SiO_2 and Si_3N_4 is influenced strongly by power. An increase in power can be used to increase etch rate, the limit being set by photo-resist stability. This can be improved by increasing the photo-resist post-bake temperature. In general higher power will reduce selectivity ratios.

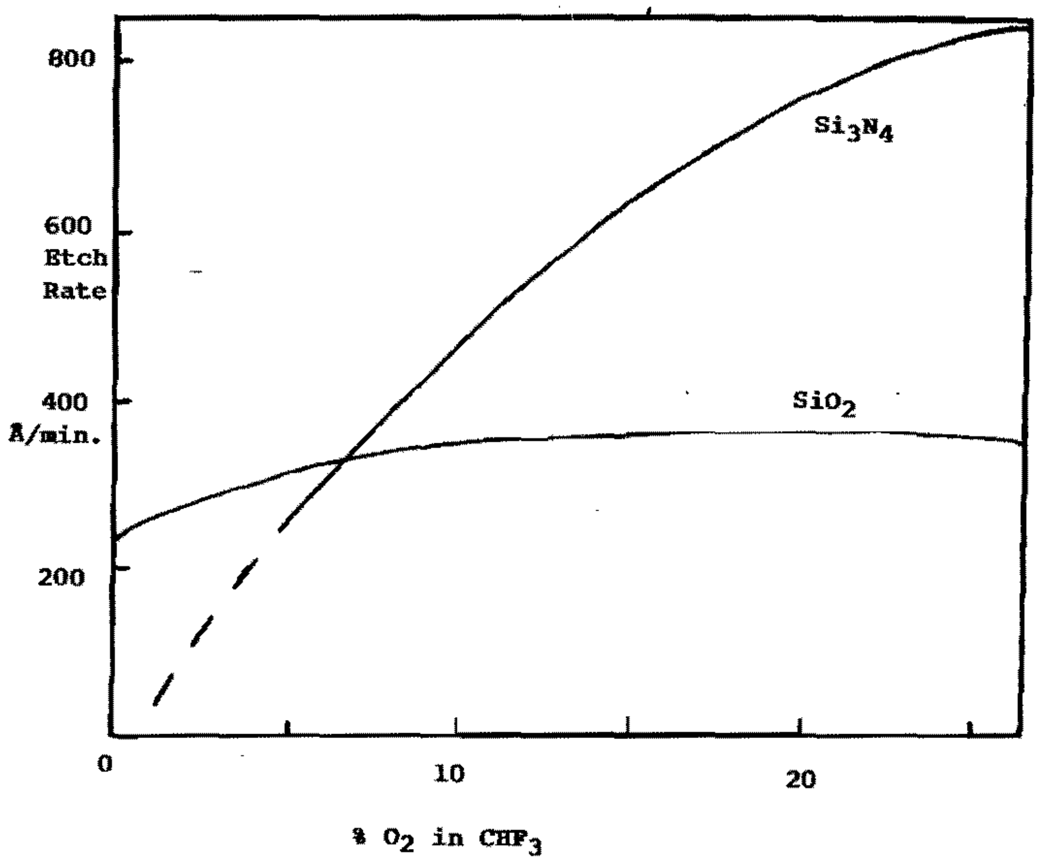
PRESSURE

Over a small range (30 - 60mt) the pressure has very little effect on the process. At higher pressures, polymerisation and poor etch uniformity may result: at lower pressures (higher d.c. bias) etch rates and selectivities are generally lower.

GAS FLOW

Total gas flow has little effect on the process. Increase in O_2 flow makes little change to SiO_2 etch rate but increases both Si and photo-resist O_2 etch rates. Some O_2 (approximately 5%) is necessary to the process to prevent excessive polymer formation. Si_3N_4 etch rate increases rapidly with increase in O_2 until a maximum value at 25-30% O_2 is reached.

At high O_2 flows the selectivity to photo-resist can be reduced to 1.5-1:1 so that the etched profile will reproduce the photo-resist profile. If this is initially sloped, then a sloped wall SiO_2/Si_3N_4 etch will result.



Variation of SiO_2 and Si_3N_4 etch rates with $[O_2]$

SLOPED WALL ETCH IN SiO_2