AN OPTICAL DETECTOR FOR MONITORING PLASMA ETCHING

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ABSTRACT

This paper describes an end-point detector for plasma etching that uses a photo-diode, a narrow band filter and a silica rod light-guide to extract the light from the reactor. The etching end-point is detected either by monitoring the intensity of light emitted by an excited species in the plasma or by changes in the intensity of light reflected from the substrate surface using the plasma emission instead of an external light source.

1. INTRODUCTION

It is desirable to be able to monitor the course of the plasma etching of semiconductor device structures since over etching can lead to distortion of the transferred pattern by undercutting of the material beneath the etch mask. Due to the loading effect (1), the time required to complete the etching of batches of wafers of different sizes usually varies and so end-point detection is a useful addition to any plasma etching system.

Optical reflection from the surface of the substrate is a well known technique used for monitoring the deposition of thin films (2). This method has been applied to the plasma etching of both opaque and transparent films in which changes in surface reflectivity or interference effects are utilized (3). Optical emission spectrometry has also been used, in which the light emitted from atomic/molecular transitions of reactant species or reaction products is monitored (4) (5) (6).

For production applications, the use of a spectrometer is less desirable and a simpler, more rugged system, which employs a solid-state optical detector in combination with a suitably selective filter, is to be preferred. A number of recent reports have described such units which are placed in front of a window in the reaction chamber (7)(8)(9)(10). This paper describes an optical detector which can be used either to monitor

a particular species in the plasma or to monitor the reflectivity of the substrate using light emitted by the plasma instead of the conventionally used external light source.

2. DESIGN

A novel feature of this detector is that light emitted by the plasma is extracted by means of a silica rod light-guide. This is easily attached to the reactor through a bored-out tube-fitting. Fig. 1 shows a schematic cross-section through the detector fitted to a reactor.

A silicon photo-diode combined with an operational amplifier (EG and G Inc. Type HUV-4000B) is mounted inside an aluminium housing with a readily interchangeable filter which has a suitable spectral transmission. A tube-fitting screwed into the front of the housing holds one end of a 6 mm silica rod, both ends of which are preferably plane polished although carefully broken ends will also work quite well. The other end of this rod passes into the reactor through a second, bored-out tube fitting tapped into the wall or top plate of the chamber. The photo-diode requires a 15v D.C. power supply, its spectral sensitivity extends from 200 nm to 1150 nm and its output, which is 15v at saturation, is displayed on a chart recorder.

3. THE DETECTOR USED AS AN EMISSION MONITOR

The device has been used on both parallel plate and barrel reactors. One advantage of the SiO_2 light-guide is illustrated in its use in conjunction with a commercial (International Plasma Corporation) barrel reactor. Under the conditions being used for photo-resist stripping i.e. 66 Pa (0.5 Torr) at 200 watts, there was insufficient light intensity emitted from the plasma to operate a detector placed in front of the SiO_2 door as is usually done. However, at the point where the vacuum line is connected to the silica reaction chamber, the plasma is constricted and the intensity of the emitted light is higher. By inserting the light-guide through a hole in the casing of the reactor so that it was close to the exit tube, sufficient intensity was obtained to provide a good signal.

The performance of the detector was checked by monitoring etching experiments simultaneously with it and with a spectrometer adjusted to the emission wavelength of a suitable transition. In this way, the detector has been used to monitor photo-resist stripping, the etching of SIPOS, Si and Si_3N_4 in CF_4/O_2 and the etching of Al in CCl_4. The Table shows the wavelengths of the emission peaks and characteristics of the filters used.

In the case of photo-resist stripping in O_2, the build-up and decay of the light emitted by the excited reaction products CO and OH is used. A filter with a transmission peak at 306 nm and a half-width of 19 nm accepts the CO peaks at 297.7 nm, 308.0 nm and 313.4 nm and the OH peak at 308.9 nm.

For Si and SIPOS etching in CF_4/O_2, the decay and subsequent increase in intensity of the emission at the end-point due to the atomic transitions of the reactant F at 703.7 nm and 712.8 nm is employed; a filter with a transmission peak at 707 nm and a half-width of 13 nm is used. The increase and decay of the emission peaks at 353.7 nm and 357.7 nm due to molecular N_2 transitions is used to monitor the etching of Si_3N_4 in CF_4/O_2 using a 362 nm filter with a half-width of 16 nm.

Although molecular transitions of AlCl emit quite strongly during Al etching in CCl_4 (6) it was not possible to monitor the reaction using a filter with a transmission peak at 258 nm and a half-width of 12 nm. This was because an intense, broad band centred at 258 nm due to the reactant CCl swamps the emission due to AlCl. The sum of the increase in intensity due to AlCl and the much larger decrease in intensity due to the consumption of CCl during etching, results in a total intensity decrease. For this reason the 306 nm filter used for monitoring resist stripping is used which monitors the intensity of the CCl reactant band at 305.5 nm.

In Fig. 2, recorder traces of intensity versus time obtained during the etching in CF_4/O_2 (13 Pa pressure and 0.3 watts cm^{-2}) of a 500 nm layer of Si_3N_4 on Si are shown. It can be seen that the etching end points given by the detector and by the spectrometer are in good agreement.

4. THE DETECTOR USED AS A REFLECTIVITY MONITOR

The optical reflection method makes use of either the difference in reflectivity between an opaque layer (e.g. a metal) and the underlying substrate or of interference effects in thin, transparent films. In the latter technique, the sample is usually illuminated by a laser and the measured reflected light intensity passes through a series of maxima and minima as the decreasing optical path length in the etched layer leads to varying conditions of constructive and destructive interference. The disappearance of the fringe pattern signifies the complete removal of the transparent layer.

In this application of the optical detector, a narrow band filter is used to isolate a selected emission peak from the plasma and this is used instead of an external light source for the reflectivity measurements. The experimental arrangement as applied to a parallel plate reactor is shown in Fig. 3. The SiO_2 light guide passes through a bored-out tube-fitting tapped into the top plate of the reactor and then through a small hole in the top electrode positioned just above a substrate. This hole does not affect the intensity distribution of the plasma. The etching of Cr in CCl_4/O_2, Al in CCl_4 and Si and Si_3N_4 in CF_4/O_2 have been monitored in this way.

At the end point of metal etching the intensity of the reflected light changes to a constant value determined by the substrate. The substrate usually has a lower reflectivity than the metal film so the reflected light intensity usually decreases as the end-point is approached. The

rapidity with which the intensity changes depends upon the refractive index and extinction coefficient of the metal and never occurs as a step function since the reflectivity is thickness dependent.

Fig. 4 shows the etching of a 500 nm thick Si_3N_4 layer on Si in CF_4/O_2. In this instance the filter with a transmission peak at 361 nm and a half-width of 16 nm was used. This filter accepts the 357.7 nm emission from a molecular transition in N_2 and gives a good sequence of interference fringes. The spacing d between fringes is given by

$$d = \frac{\lambda}{2n}$$

where λ is the wavelength of light (in this case 357.7 nm) and n is the refractive index (taken as 2 for Si_3N_4). Taking the number of fringes as 5.75 the thickness removed is calculated as 514 nm. This agrees well with the ellipsometric value of 500 nm measured before the etching experiment.

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Table 1

Emission Peaks and Filters used in the Optical Detector

Etching Reaction	Emission Peaks (nm)		Filter			
			Emission Monitor		Reflectivity Monitor	
	λ (nm)	Species	Peak λ (nm)	Half-width (nm)	Peak λ (nm)	Half-width (nm)
Photo-resist in O_2	297.7 308.0 308.9 313.4	CO CO OH CO	306	19		
Si_3N_4 in CF_4/O_2	353.7 357.7	N_2 N_2	362	16	362	16
Al in CCl_4	261.4	AlCl	-	-	258	12
	305.5	CCl	306	19	-	-
Si and SIPOS in CF_4/O_2	703.7 712.8	F F	707	13		
Cr in CCl_4/O_2	305.5	CCl	-	-	306	19

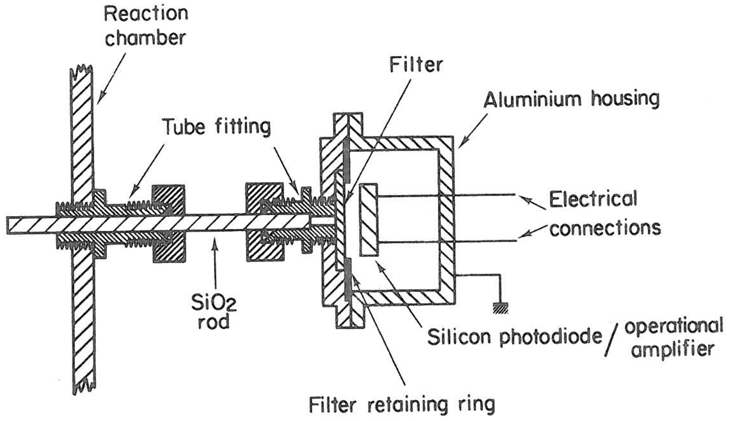

Fig. 1 Schematic of the detector

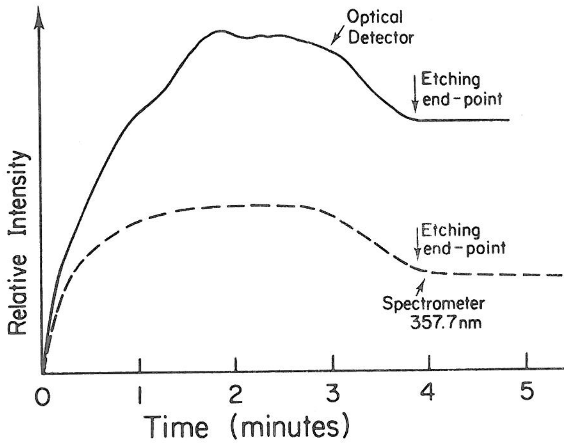

Fig. 2 Comparison of the detector output (upper curve) with spectrometer (lower curve) during Si_3N_4 etching in CF_4/O_2.

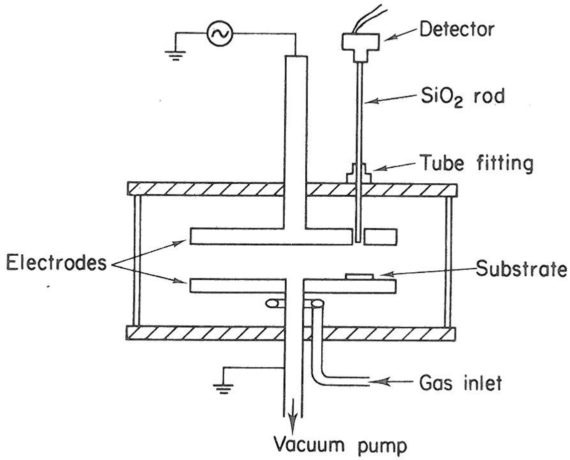

Fig. 3 The detector used as a reflectivity monitor.

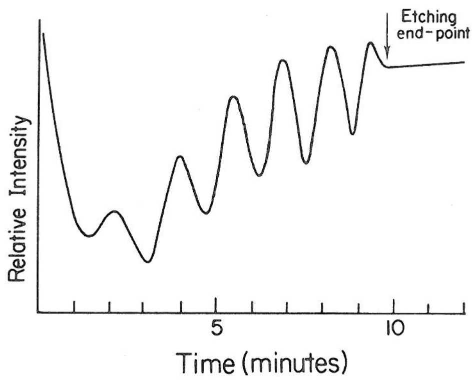

Fig. 4 Si_3N_4 etching in CF_4/O_2 monitored with the detector in the reflection mode.