

Application of Optical Emission Diagnostics and Control Related  
to Semiconductor Processing

Greg C. Vilorio

Richard N. Savage, Ph.D.

SC Technology Inc, 368 Earhart Way, Livermore, CA 94550

Abstract

This paper will discuss and show applications of optical emission spectroscopy techniques and methods to monitor plasma emissions during semiconductor processing. A brief discussion of the instrumentation that was used and the software to control the instrumentation will also be presented. Optical emission spectroscopy techniques that will be discussed include chemical species identification in plasma etching, process fingerprinting, contamination detection, endpoint analysis/control and sputter/deposition plasma monitoring.

1. INTRODUCTION

Increasing feature densities in semiconductor processing have placed higher and higher demands on both the equipment manufacturer and process developer/designer. Significantly, optical emission provides a direct method of measuring the good correlation to the concentration of chemical species inside the plasma which are controlled indirectly through process parameters such as applied power, gas flow and temperature<sup>1</sup>. The intensity of the emission of chemical species within the plasma can be related to the number of excited species contained within the plasma through the familiar Boltzmann expression<sup>A</sup> where:

$$I_{\text{chem. specie}} = E_{\text{chem. specie}} = A_{\text{chem. specie}} * N_{\text{chem. specie}}$$

Intensity	#Excited Atoms	Ground State Atoms	Excitation Efficiency
-----------	----------------	-----------------------	--------------------------

Unfortunately, excitation efficiencies are very dependent on the nature of the plasma and are not well quantified; therefore emission spectroscopy remains a relative measurement proportional to the abundance of excited atoms and/or molecules contained within a reactive plasma.

Process diagnostics and process monitoring have been key terms used in the area of optical emission spectroscopy for semiconductor fabrication<sup>2,3</sup>. Process diagnostics provides the ability to detect changes in important reactive chemical species

along with process problems such as impurities or air leaks. Process monitoring/control is a term that has been traditionally associated with the word "endpoint" but has expanded into more sophisticated closed-loop control schemes<sup>4</sup>.

By utilizing a photodiode array based spectrometer for wide spectral range monitoring with fast acquisition speed we will demonstrate how process diagnostics together with process monitoring provide good control of the critical dimensions during etching and can identify process deviations from machine to machine.

## 2.OVERVIEW OF INSTRUMENTATION USED

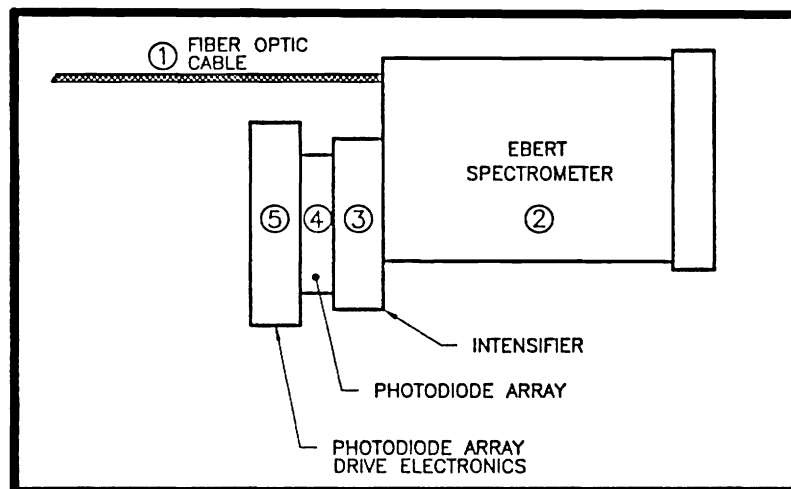


Figure 1. Detector Block Diagram

Figure 1 shows the basic spectrometer system used for the data presented herein. Plasma emission is collected through fiber-optics 1 and sent into a 160mm Ebert spectrometer 2 where light is dispersed onto a 512 element photodiode array 4. An optional image intensifier 3 can be used to gain more sensitivity for low light applications. The data is sent to a PC based acquisition system which manipulates the data into useable form.

The software for this instrumentation allows the basic acquisition and display of data and provides two key data manipulation features for analysis and one feature for monitoring/control. One of the spectral analysis features is the ability to automatically determine the chemical composition of the plasma through the use of a library containing emission lines emanating from chemical species excited within reactive plasmas

( Figure 2. ). By utilizing a cross-correlation algorithm, the spectral pattern of the chemical species in the library can be matched to a process spectrum yielding a correlation value for each library spectral pattern. In turn, the correlation values indicate that chemical species ( atoms, molecules and ions ) are most likely present in the plasma<sup>5</sup>. The second key spectra analysis feature in the software is provided through an overlay operation. Individual chemical optical emission spectra can be overlaid with a process spectrum to see similarities or differences between the two for fingerprinting and diagnostics ( Figure 3. ). Once process species are identified the monitoring and control feature provides the ability to mathematically manipulate selected process spectral lines and correlate these results with process endpoint and/or transition controls ( Figure 4. ).

### 3. RESULTS

Examples of process diagnostic and endpoint control spectra are shown in Figures 5 - 14. The first spectra shows a spectrum of a non-commercial etcher using SF<sub>6</sub> and O<sub>2</sub> gasses. This spectrum clearly shows an air leak ( Figure 5. ). The following spectra, shows an aluminum etch process using CO, BCl<sub>3</sub>, Cl<sub>2</sub> and He gasses ( Figure 6 a,b. ). This is a good example of the library overlay feature. Figure 7 is an example of "spectral model building", whereby combinations of chemical optical emission spectra are added together to model the process spectrum. In Figure 8 , a PECVD SiO<sub>2</sub> process utilizing Silane (SiH<sub>4</sub>) and Nitrous Oxide (N<sub>2</sub>O) is being monitored. Deposition of SiO<sub>2</sub> occurs in the first step of this PECVD process followed by a clean-up CF<sub>4</sub> etch. Typically, plasma product species remain constant during deposition however, in this example, a trace of Fluorine emission at 690 and 704nm is detected. Fluorine should only be present during the CF<sub>4</sub> etch. It was later found that there was a leakage of CF<sub>4</sub> from the mass flow controller.

The next set of spectra is a good example of contamination detection coupled with endpoint monitoring and etcher control ( Figure 9a,b. ). The process being monitored is a polysilicon etch which was performed through a multi-step process. Step 1 was an initialization etch with SF<sub>6</sub>, He and CCl<sub>4</sub>, followed up by the main CCl<sub>4</sub> poly etch step. The presence of SF<sub>6</sub> in the main etch step is detrimental to the process. To ensure that there is no SF<sub>6</sub> contamination during the main etch the instrument must measure 1-2 sccm of SF<sub>6</sub> per 180 sccm of total gas flow. To characterize the process, spectra of the plasma emission without SF<sub>6</sub> and with a fixed flow ( 5 sccm ) of SF<sub>6</sub> were measured. A ratio of the largest changing optical emission lines was determined to be the method to monitor the contamination and provide repeatable process endpoint. To determine the two wavelengths that changed the most, a spectral subtraction was performed between the spectrum of "no SF<sub>6</sub>" and "SF<sub>6</sub>" ( Figure 10. ). The spectral lines at 568nm and 479nm were determined to

be the best lines to be ratioed. The percent change of the ratio of 568nm/479nm from no SF<sub>6</sub> to 5 sccm of SF<sub>6</sub> was

	<u>No SF<sub>6</sub></u>	<u>5sccm SF<sub>6</sub></u>	<u>%change</u>
568nm/479nm ratio	1.36	1.12	17.64

( See Figure 11. )

If it is assumed that the intensity change is linear with respect to added SF<sub>6</sub>, then a 7.0% change would be expected using this ratio for 2 sccm of SF<sub>6</sub>.

For "endpoint" monitoring and control a similar technique was applied. The spectra for pre-endpoint conditions and endpoint conditions were measured ( Figures 12a,b). When a spectral subtraction was performed on both spectra to determine which spectral lines had the greatest signal change, the 575nm and 487nm lines were chosen( Figure 12c. ). Again a ratio was applied to these spectral lines ( Figure 13. ) and endpoint was determined on the basis of a percent change of this ratio.

	<u>Beginning Value</u>	<u>End Value</u>	<u>%change</u>
575nm/487nm ratio =	1.17	0.94	19.7

By detecting the RF ON signal from the etcher, the endpoint control loop is closed and the detection algorithms for both SF<sub>6</sub> contamination and endpoint are initiated. Etch step termination will occur when either the SF<sub>6</sub> level reaches 2.0 sccm or when the ratio of endpoint lines reach a 19.7% change ( Figure 14. ).

#### 4. CONCLUSION

This paper touches briefly on applications of optical emission spectroscopy in semiconductor processing. Optical Emission Spectroscopy is being considered for more developments in the areas of etch and deposition rate enhancements, stoichiometric control during sputtering, characterization of photolithography exposure systems and multi-step endpoint control algorithms. Given the previous examples, applied optical emission spectroscopy techniques provide methods for examining and determining contaminants in processes, insights in process correlation between machines, and versatile multi-wavelength endpoint monitoring and control through the use of spectral mathematical functions.

#### 5. Acknowledgments

The authors would like to thank the staff at SC Technology for their help and work in putting this paper together.

## 6. References

1. Harshbarger, W.R. , Porter, R.A. , Miller, T.A. and Norton, P. , "A Study of the Optical Emission from an RF Plasma During Semiconductor Etching", Applied Spectroscopy, Vol. 31, No. 3, 1977, p. 201.
  2. Savage, R.N., "Applications of Optical Emission Spectroscopy to Semiconductor Processing" Spectroscopy, Vol. 2, No. 8 , 1987, p. 40.
  3. Mautz, Karl , Parsons, Michael and Moore, Carleton  
" The Application of ICP Spectroscopy to Model the Chemistry Occuring in Plasma-Etch Reactors" Applied Spectroscopy, Vol. 43, No. 8, 1989, p. 1414.
  4. Bergeron, S.F. , Bergendaho, A.S. , Duncan, B.F. and Herman, D.L., "Plasma-Etch Endpoint Detection", MM&T, August 1983, Pg 35.
  5. Patent No. 5,014,217 U.S. Patent, Issued May, 1991, R.N. Savage.
- A. Peters, D.G., Hayes, J.M., and Hieftje, G.M., *Chemical Separation and Measurements- Theory and Practice of Analytical Chemistry*, W.B. Saunders & Co., 1974.

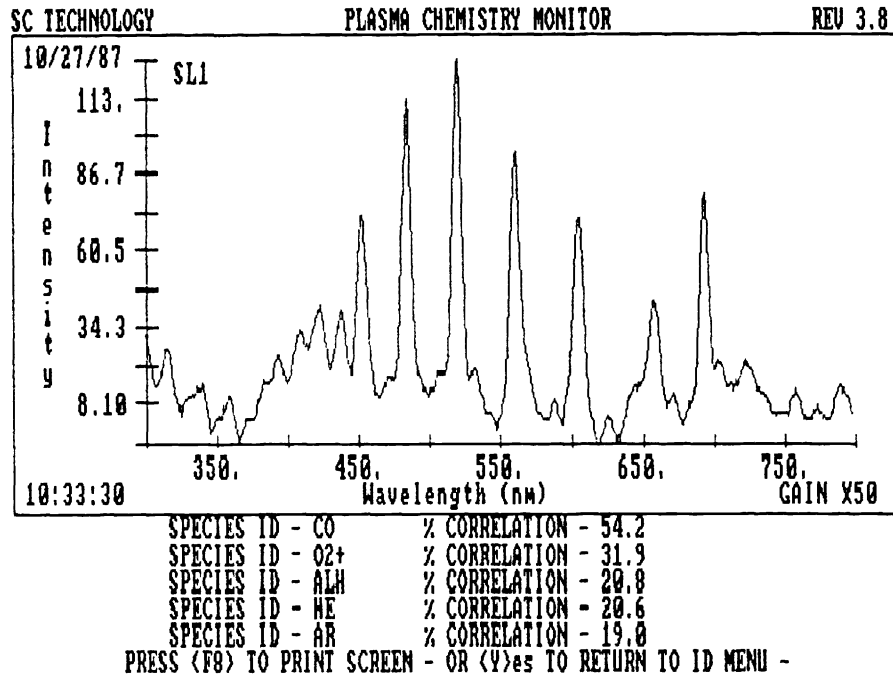


Figure 2. Automatic Species Correlation Feature

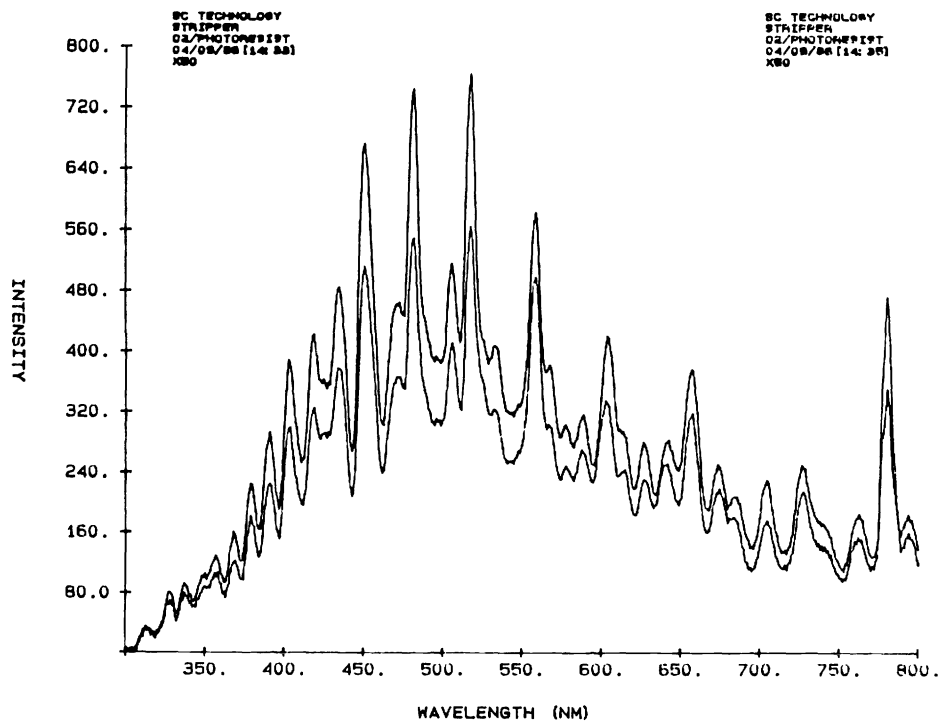


Figure 3. Spectral Overlay Analysis

Integration ( $\lambda_{a1}$  . . .  $\lambda_n$ )

Subtraction ( $\lambda_{a1}$  . . .  $\lambda_{an}$  -  $\lambda_{b1}$  . . .  $\lambda_{bn}$ )

A  
%A  
A+B+C  
A & Slope  
%A & Slope  
%A/B  
A/B+1  
A-B

where A,B, and C are intensities of a given wavelength.

Figure 4. Wavelength Line Maths

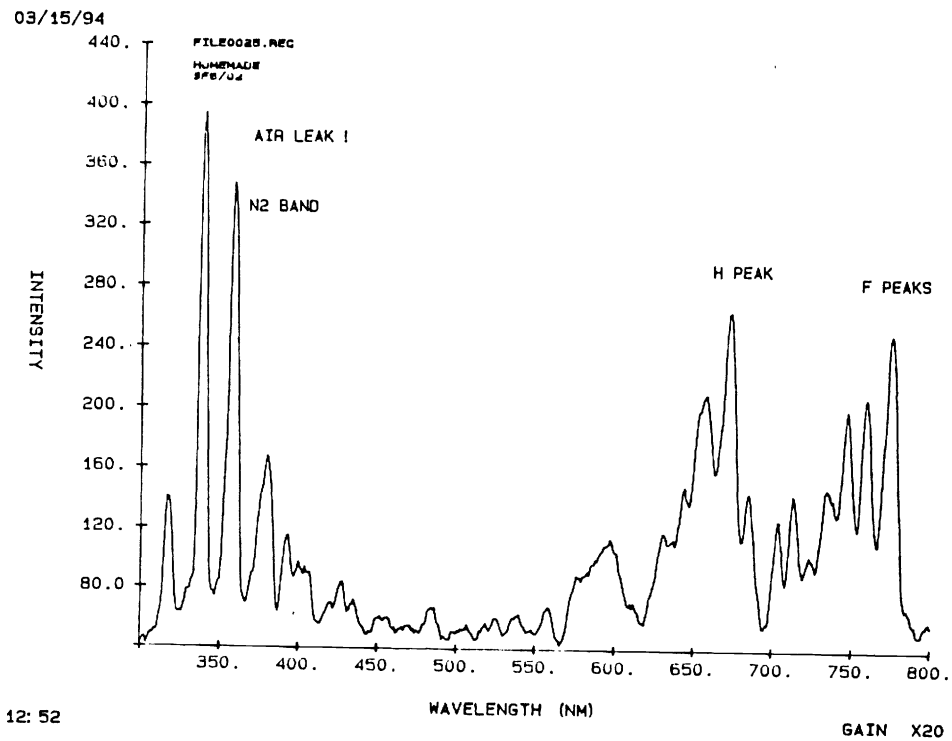


Figure 5. SF6/O2 Spectrum with Air Leak

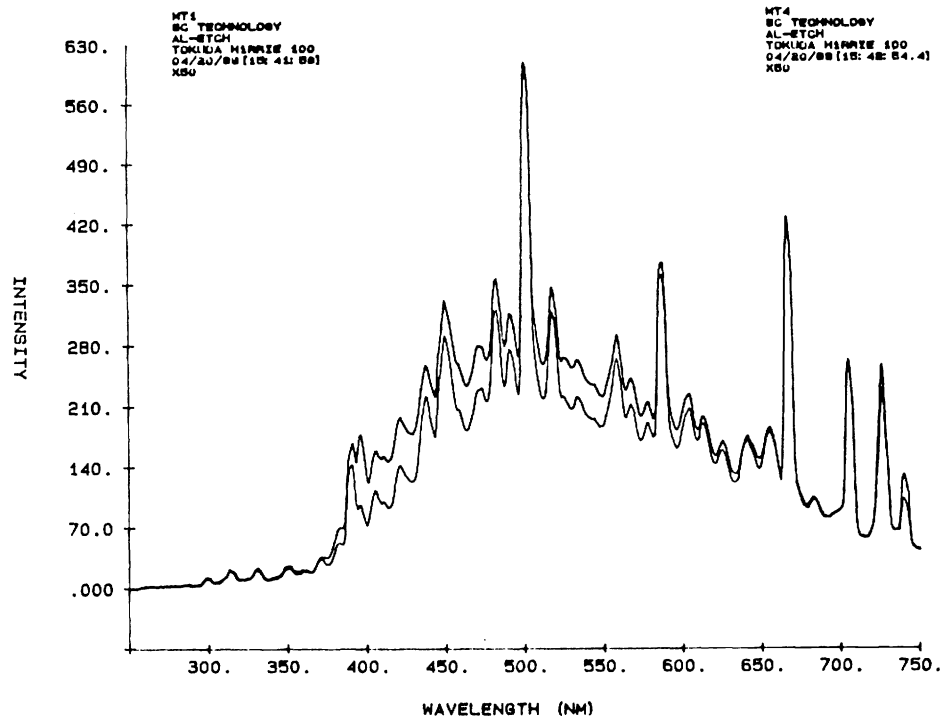


Figure 6a. Chemical Specie Overlay of Al on Al etch Spectra

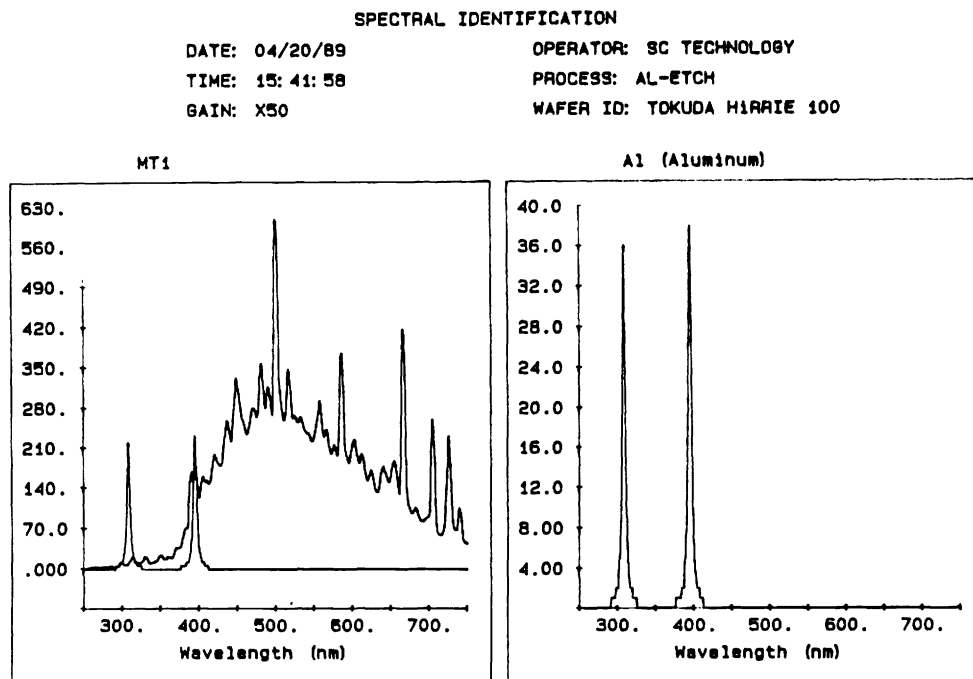


Figure 6b. Chemical Specie Overlay of Al on Al etch Spectra



SPECTRAL IDENTIFICATION

DATE: 04/20/89  
TIME: 15: 41: 58  
GAIN: X50

OPERATOR: SC TECHNOLOGY  
PROCESS: AL-ETCH  
WAFER ID: TOKUDA HIRRIE 100

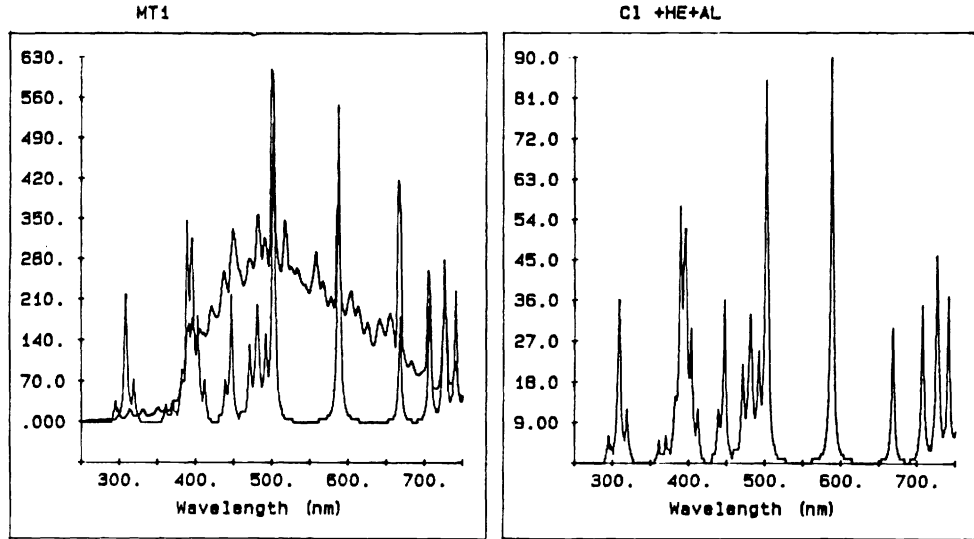


Figure 7. Example of Spectral Model Building

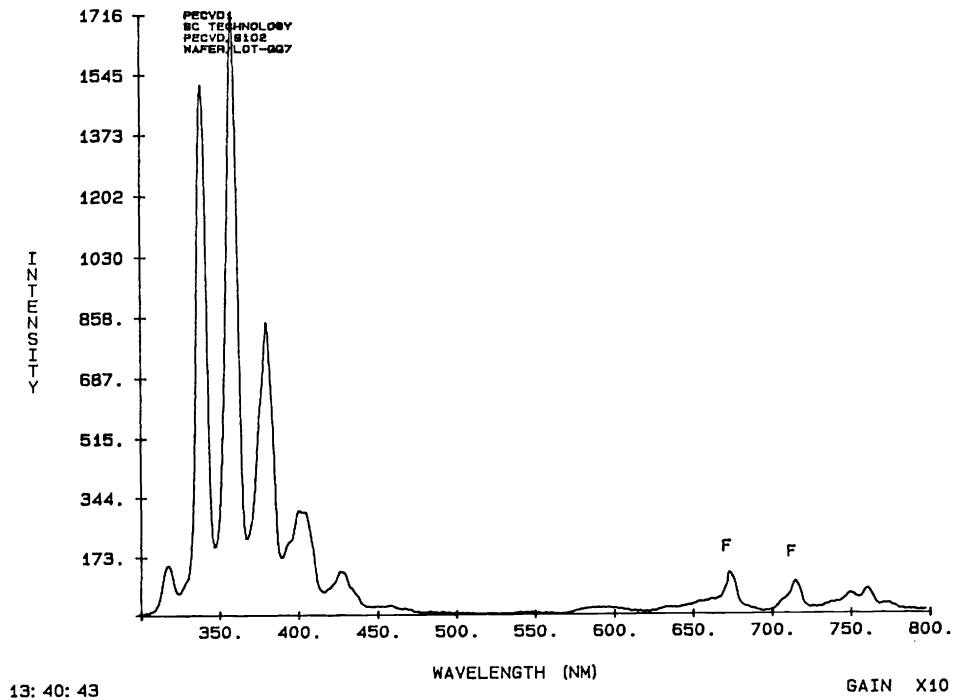


Figure 8. PECVD Spectrum with Trace Fluorine Contaminant

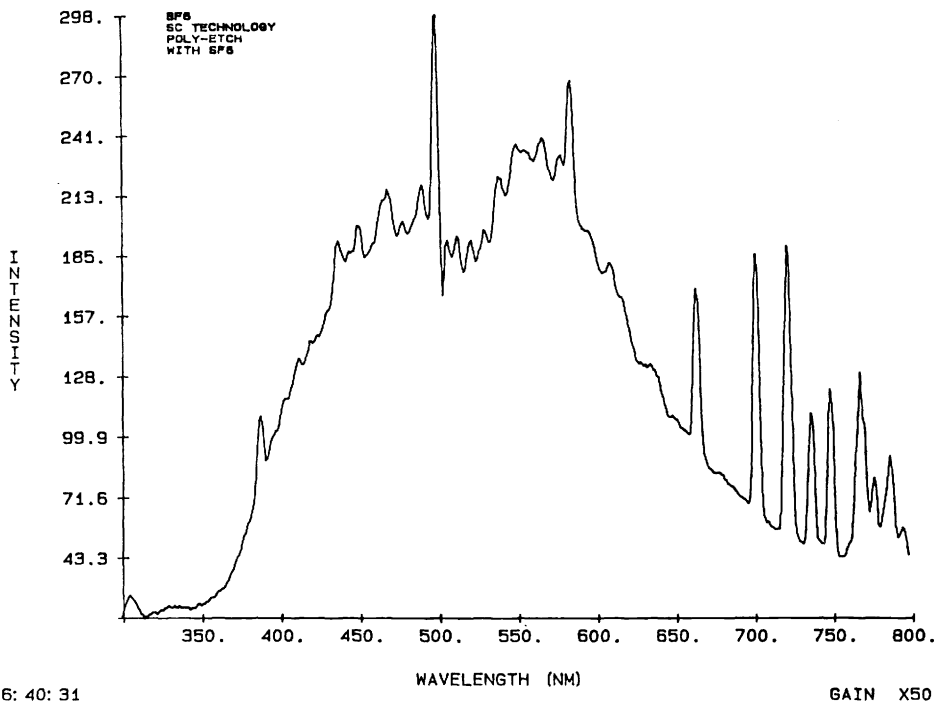


Figure 9a. CCl<sub>4</sub>/He Spectra with SF<sub>6</sub> added

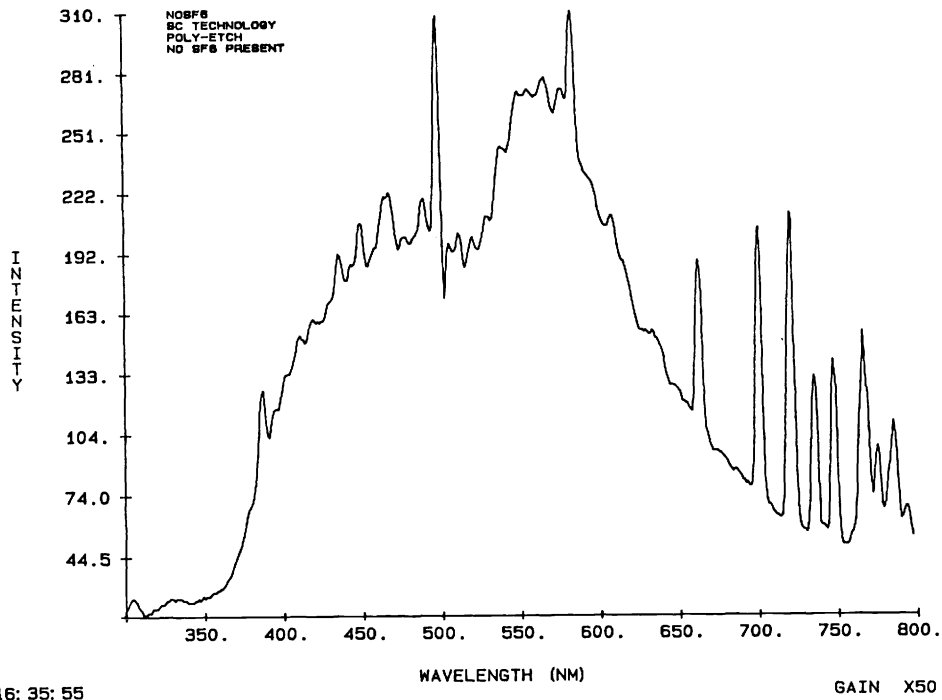


Figure 9b. CCl<sub>4</sub>/He Spectra without SF<sub>6</sub>

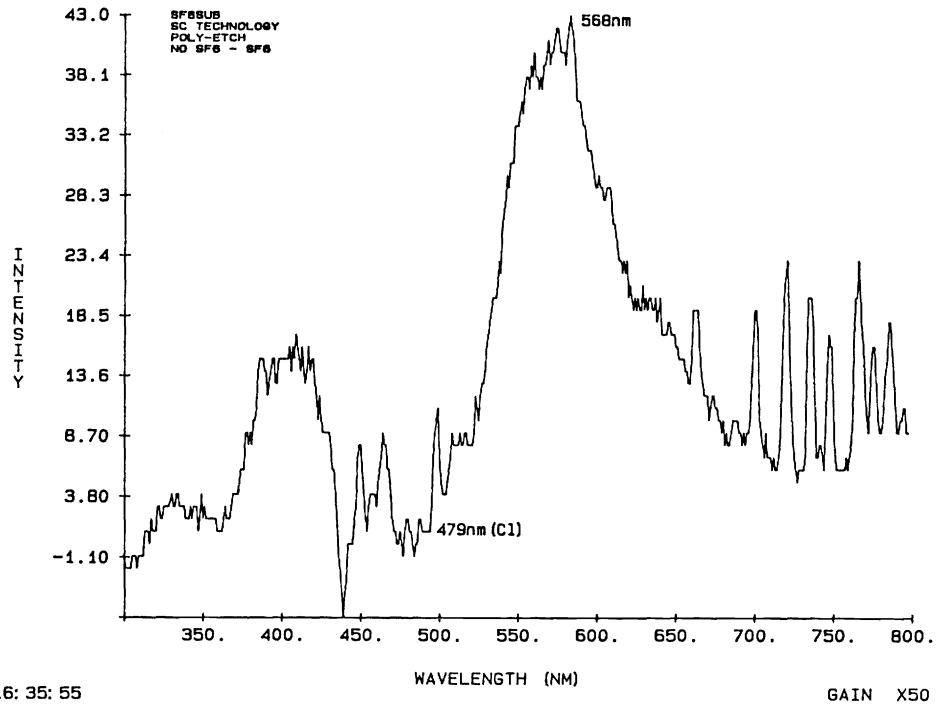


Figure 10. Spectral Subtraction of Spectra w/SF<sub>6</sub> and w/o SF<sub>6</sub>

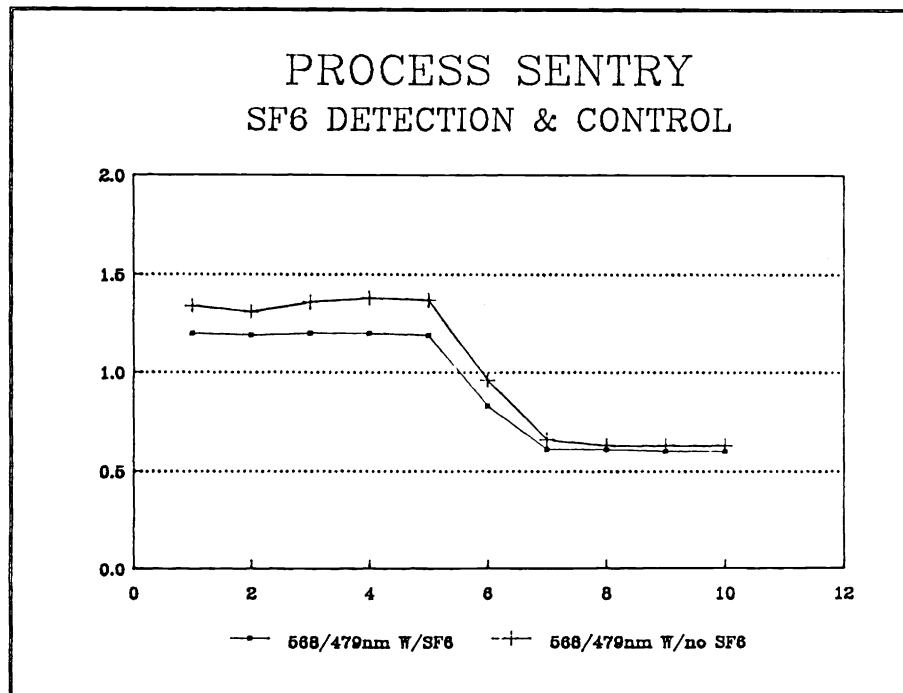
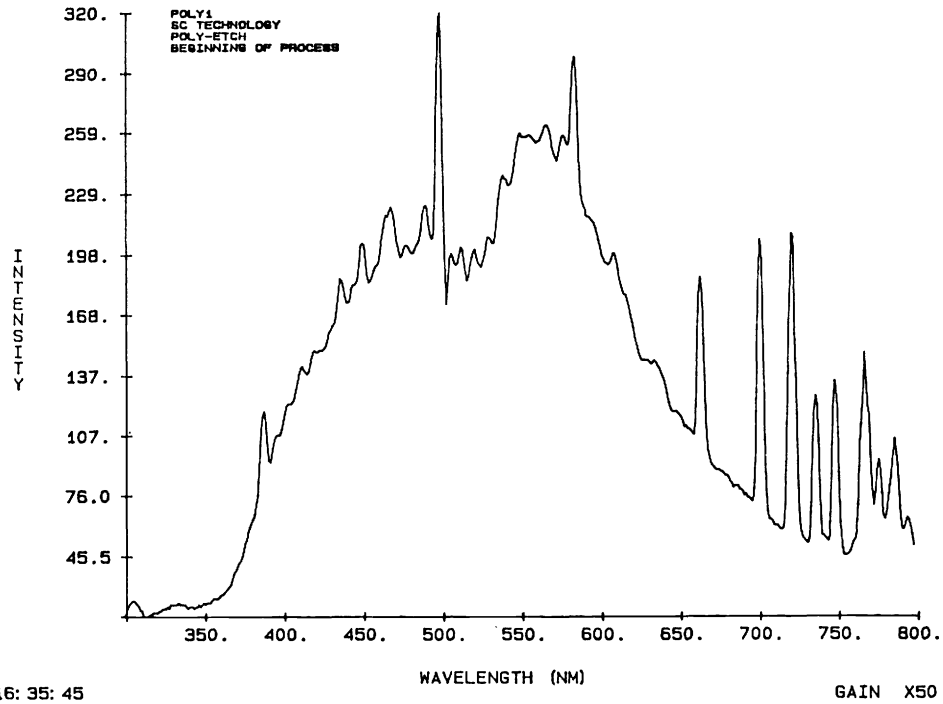
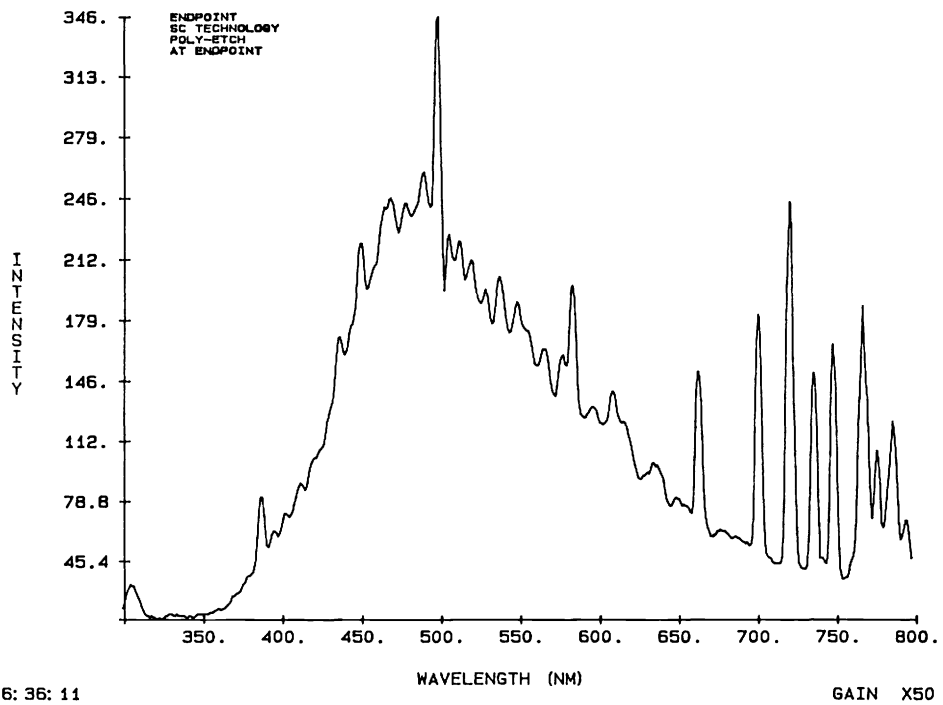


Figure 11. Ratio of 568nm/479nm vs. Time w/SF<sub>6</sub> added and without SF<sub>6</sub>



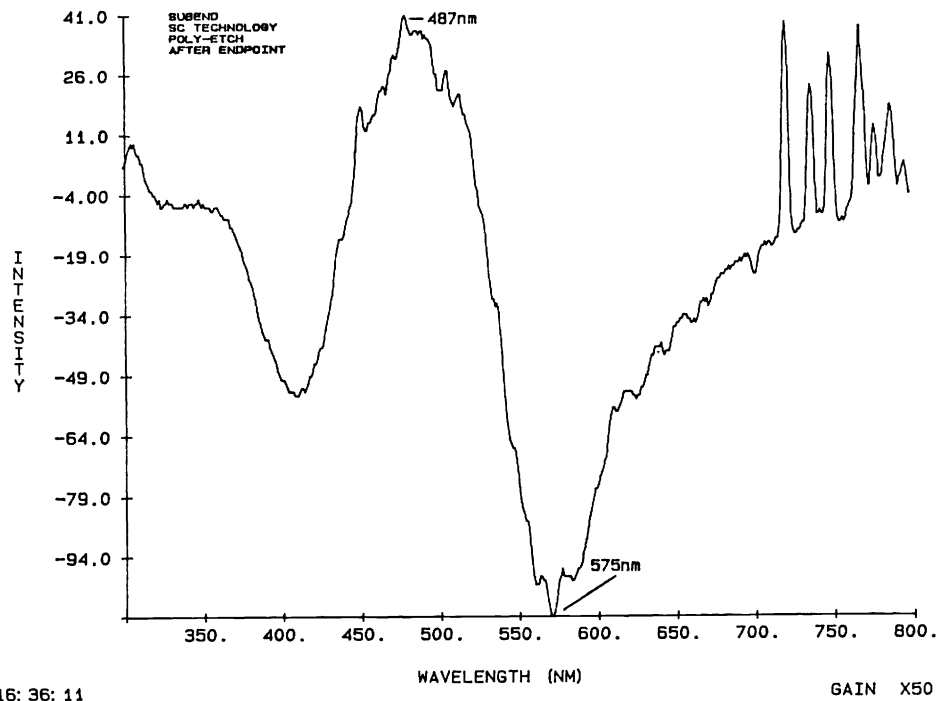
16: 35: 45

Figure 12a. Spectra of Poly Etch at Beginning of Process



16: 36: 11

Figure 12b. Spectra of Poly Etch Process at Endpoint



16: 36: 11

Figure 12c. Spectral Subtraction of Spectra at Beginning of Process and at Endpoint

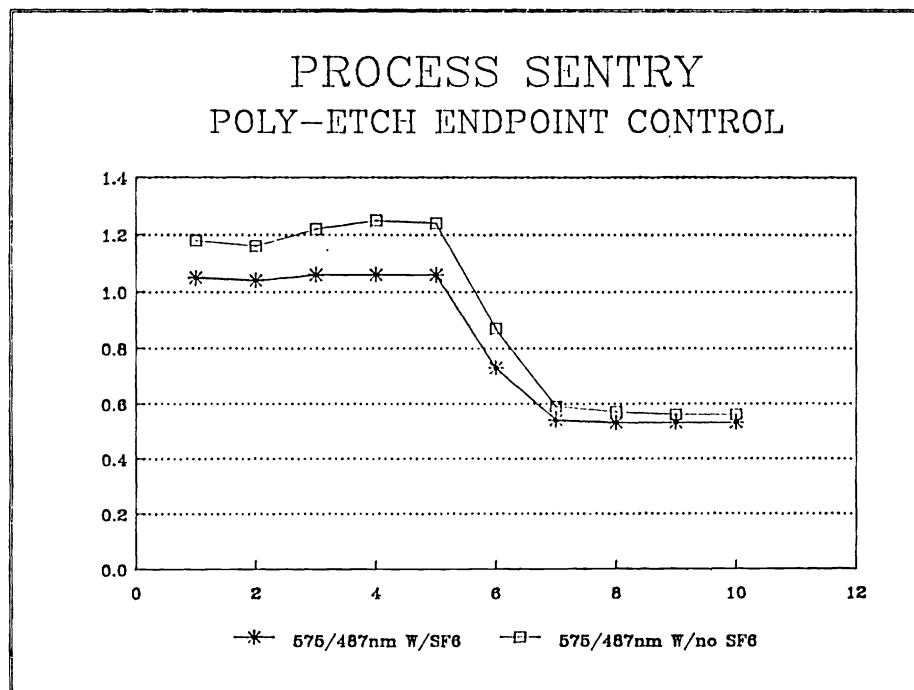


Figure 13. Ratio of 575nm/487nm vs Time for Endpoint Detection