Reduction of Device Damage During Dry Etching of Advanced MMIC Devices Using Optical Emission Spectroscopy

D. Johnson, R. Westerman, M. DeVre, Y. Lee, J. Sasserath
Unaxis USA, Inc.
10050 16th Street North
St. Petersburg, FL 33716
www.it.unaxis.com

Introduction

An important consideration in MMIC device fabrication is device damage induced during dry etching. Low damage etching is most important for critical layer etching, such as silicon nitride (SiN) and GaAs/AlGaAs/InGaP frontside etching when the transistor structure is being fabricated. A highly versatile Optical Emission Spectroscopy (OES) endpoint system has been developed to monitor the process and help minimize device damage for these critical process steps. Data is presented that demonstrates its application for both the silicon nitride and frontside etch processes described earlier.

Technology Discussion

Production based SiN and frontside etch processes typically utilize an Inductively Coupled Plasma (ICP) source. In this work, a 2 MHz coil provides power to generate a high-density plasma: a separate 13.56 MHz power supply is used to independently bias the substrate and hence control the ion energy and the process results. Wafers were actively cooled using an electrostatic clamping subsystem and He backside cooling.

The OES endpoint system that has been developed employs a CCD spectrometer. This was chosen to provide

- multi-wavelength capability,
- good resolution over a wide spectral range, and
- fast data acquisition through solid state circuitry.

This configuration offers significant improvements over conventional single wavelength endpoint detectors. A fiber optic cable is used to interface the process chamber to the detector, and the system is fully integrated into the process control system to allow for true production implementation.

Process Results

Although the use of OES is a proven technique in silicon wafer manufacturing, it's utility in production GaAs wafer manufacturing has only recently been shown. The fabrication of MMIC devices is one area where OES offers significant benefits, especially for critical etches. Results from two such processes are discussed below.

Silicon Nitride

Silicon nitride can be etched using various processes, with the best process determined by the desired etch results. For example, a CF_4 based process is appropriate for etching relatively thin films where good uniformity and CD control are required. Even though a low dc bias process is used to reduce ion bombardment, to avoid device damage it is imperative that the degree of over etch is also minimized. This requires precise end point detection. The challenge is to achieve reliable endpoint detection when only small areas of SiN are exposed.

The multi-wavelength capabilities of the CCD based OES system allow for not only the primary wavelengths to be monitored (in this instance CN bands at ~ 388nm), but also appropriate background regions of the spectrum. Subtracting out the adjacent plasma background and using a signal ratio technique, allows significant enhancement of the signal change at endpoint while reducing signal fluctuations due to inevitable plasma instabilities. This results in an improved signal-to-noise ratio allowing the detector to accurately determine process endpoint at lower SiN loads.

Figure 1 shows the endpoint trace recorded while etching a ~1cm^2 area of SiN (<1% of a 150mm wafer). By plotting both the raw signal and the signal differential, it can be seen that etch endpoint for this area was clearly detected. Repeating this experiment over a number of different sample areas yields a plot of differential peak height *vs* SiN area (Figure 2). This graph gives an indication of the sensitivity of this technique. The resolution of end point detectability for this configuration is < 0.5% open area on a 150 mm wafer.

In order to demonstrate the importance of minimizing overetch during SiN etching, experiments to determine the effect of overetch on damage were performed. In these experiments, the sheet resistance of doped GaAs films was measured prior to processing. Once measured, the wafers were cleaned with HCl followed by 1 kA SiN deposition. The samples were then etched using a standard low damage SiN process with various overetch times. Damage due to the etch process was then estimated by taking post-etch sheet resistivity measurements. Figure 3 shows that the measured damage increased with increasing overetch time.

Frontside Etch

Frontside etching of transistor level films also has been shown to benefit from the use of OES end point detection. Typical material systems include GaAs/InGaP, AlGaAs/GaAs as well as GaAs/AlGaAs. As device requirements become more stringent, these underlayers are becoming thinner, requiring more precise process control. OES offers the user an additional technique for providing this added control.

An example of this capability has been demonstrated in a HEMT fabrication process flow. In this case a gate was defined in 2500A of GaAs stopping on 500A of $Al_{0.25}Ga_{0.75}As$ using a SiN mask. A process has been previously developed having a low GaAs etch rate with a high GaAs:AlGaAs etch selectivity to minimize overetch into the AlGaAs stop layer. Details regarding this process have been described elsewhere[1].

In order to set up the emission endpoint system for this application it was necessary to first collect emission spectra during the etch and over etch portions of the HEMT etch process. To obtain these spectra, a test wafer was etched and the emission data collected. Figure 4 shows the emission spectra from two points in the process. The top spectra was collected at the beginning of the process (while the GaAs layer was being etched) while the bottom spectra was collected later in the process when the GaAs layer had already been removed (an overetch condition). For process reasons nitrogen was added to the etch and hence the spectra are relatively complex with emission peaks attributable to both the process gases as well as the etch products. From the two spectra in Figure 4 an endpoint strategy is not obvious.

In order to detect more subtle changes between the two spectra, it is helpful to construct a difference plot. Figure 5 shows the difference between the main etch and overetch spectra. The difference plot shows four regions that are candidates for endpoint detection: the 325 – 342 nm band assignable to GaCl emissions that decrease once endpoint is reached, the 403 nm and 417nm Ga lines which also decrease at endpoint, and the family of lines from 725 – 792 nm assignable to Cl which increase once endpoint has been reached.

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[1] J. Lee, et. al, *Proceedings from Mantech 2000,* p. 13.

Ideally, the spectral region used for endpoint detection will

- exhibit a large change in magnitude at etch endpoint,
- reside in a “low noise” area of the spectra, and
- be assignable to one of the etchant gases or etch products

Applying these criteria, both the 403 and 417 nm Ga lines are good candidates for endpoint detection. Figure 6 shows an expanded view of the emission spectra for both of these lines during the etch and over etch conditions. For this work, the 417 nm Ga line was monitored to detect the process endpoint while the two shaded regions on either side were used for background correction.

Using this algorithm, an endpoint trace for the HEMT etch process is shown in Figure 7. Using the derivative from the corrected Ga signal, a clear, distinct endpoint time was determined. Using the fully automated endpoint system in conjunction with a highly uniform process, etching was completed prior to damaging the thin AlGaAs underlayer. This was confirmed through device damage measurements.

Summary

The above clearly demonstrates the application of OES to critical etch processes in MMIC manufacturing. Low damage processes are available for silicon nitride and frontside etching where critical layers are exposed. By fully integrating the OES into the production etch system, a fully automated process is available for high volume GaAs wafer manufacturing.

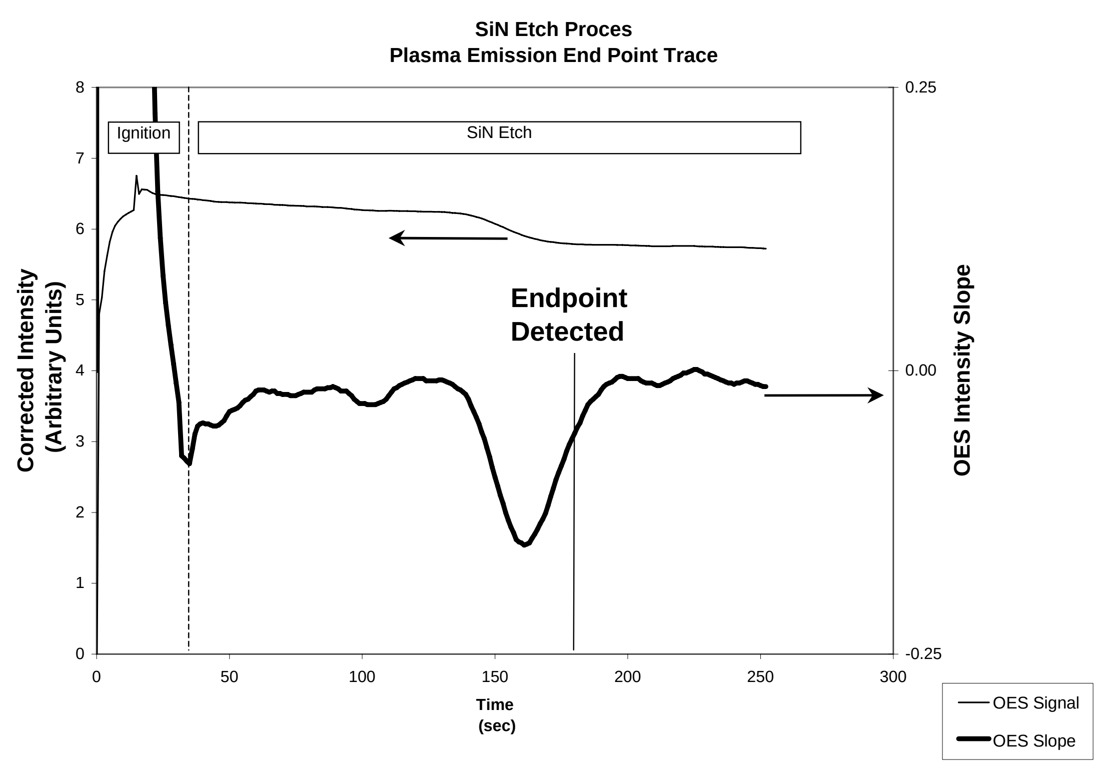

Figure 1. . Endpoint trace from 1 cm^2 exposed area of SiN

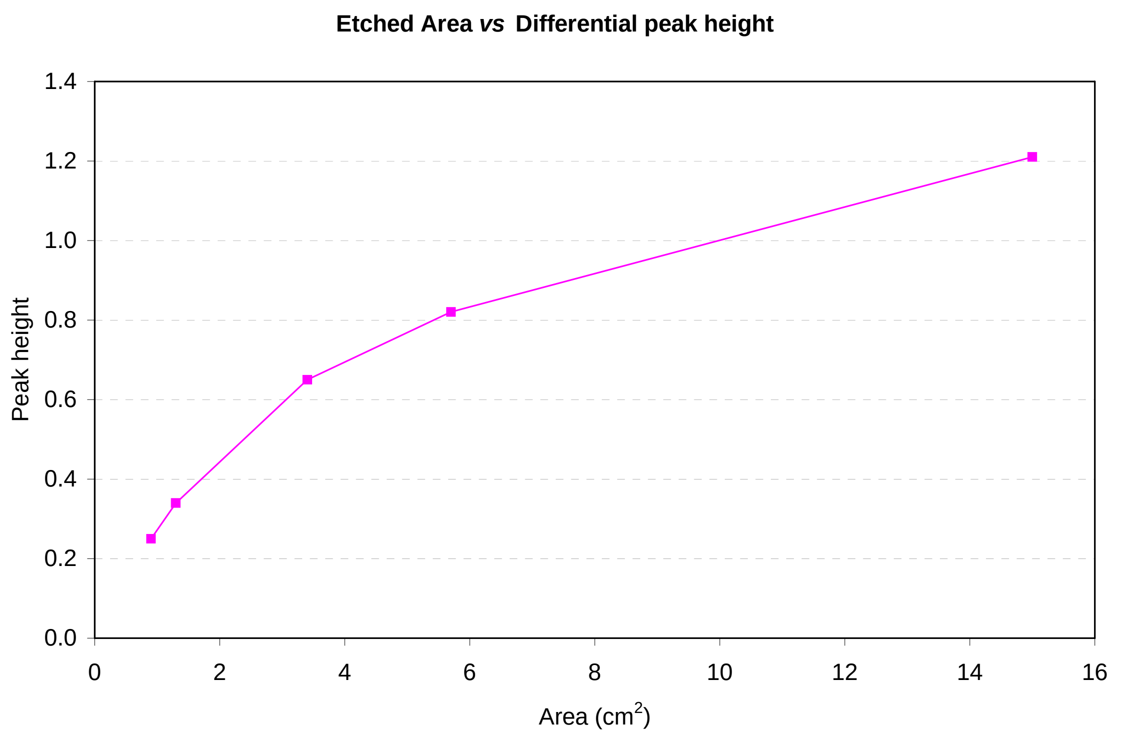

Figure 2. Variation of differential signal peak height with area of SiN etched

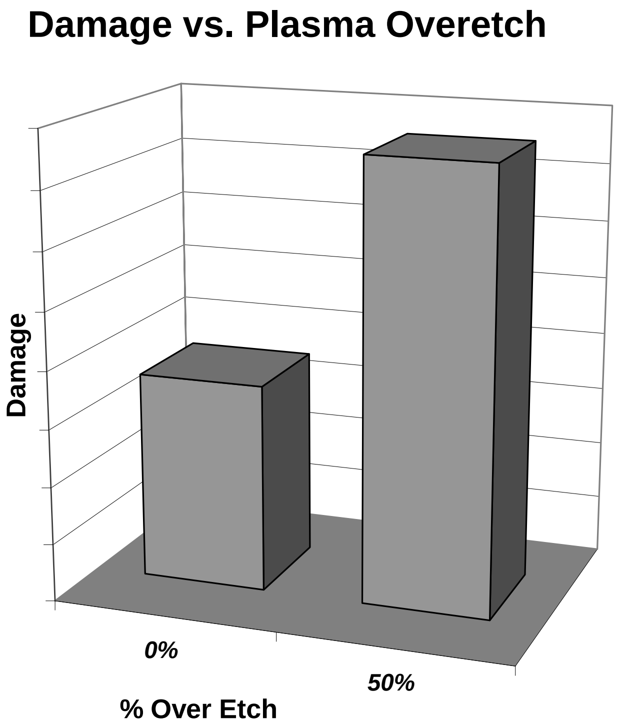

Figure 3. Results for Device Damage Experiments

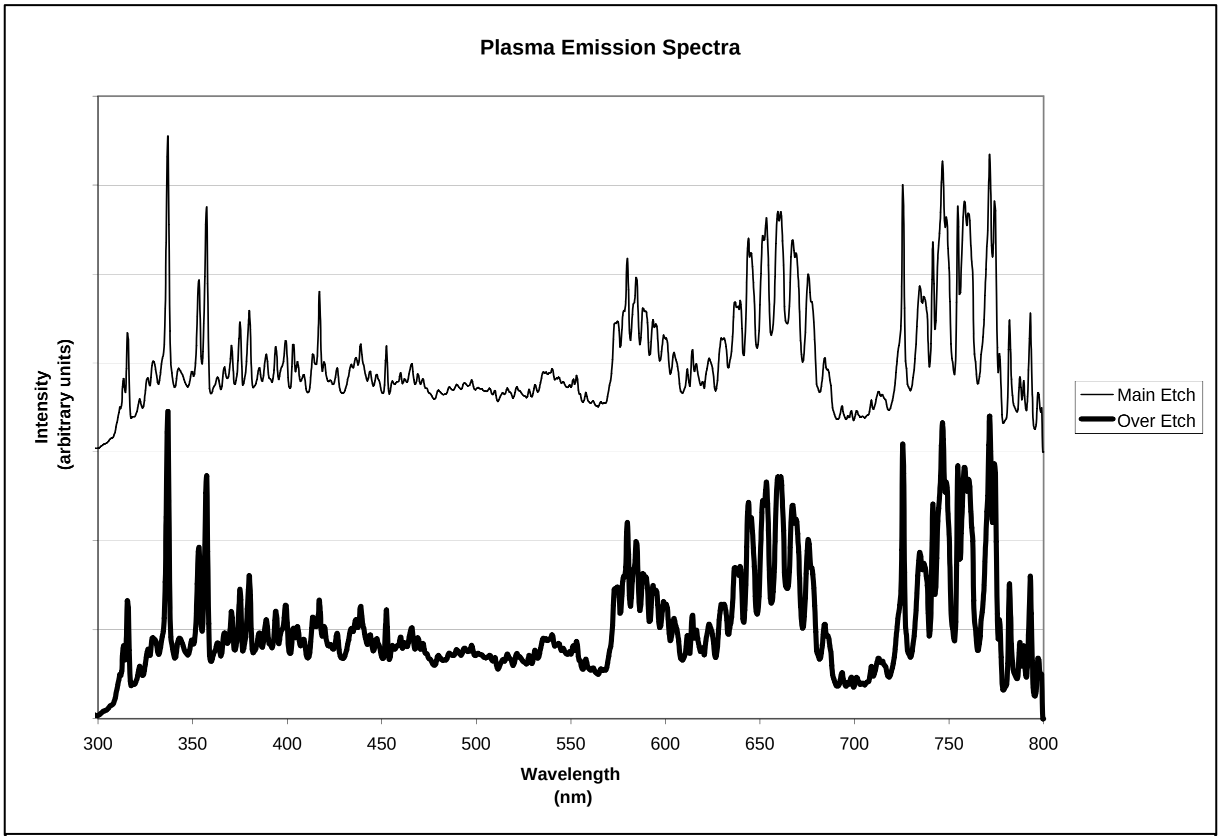

Figure 4. Plasma emission spectra from the HEMT etch process during the main etch and overetch segments of the process.

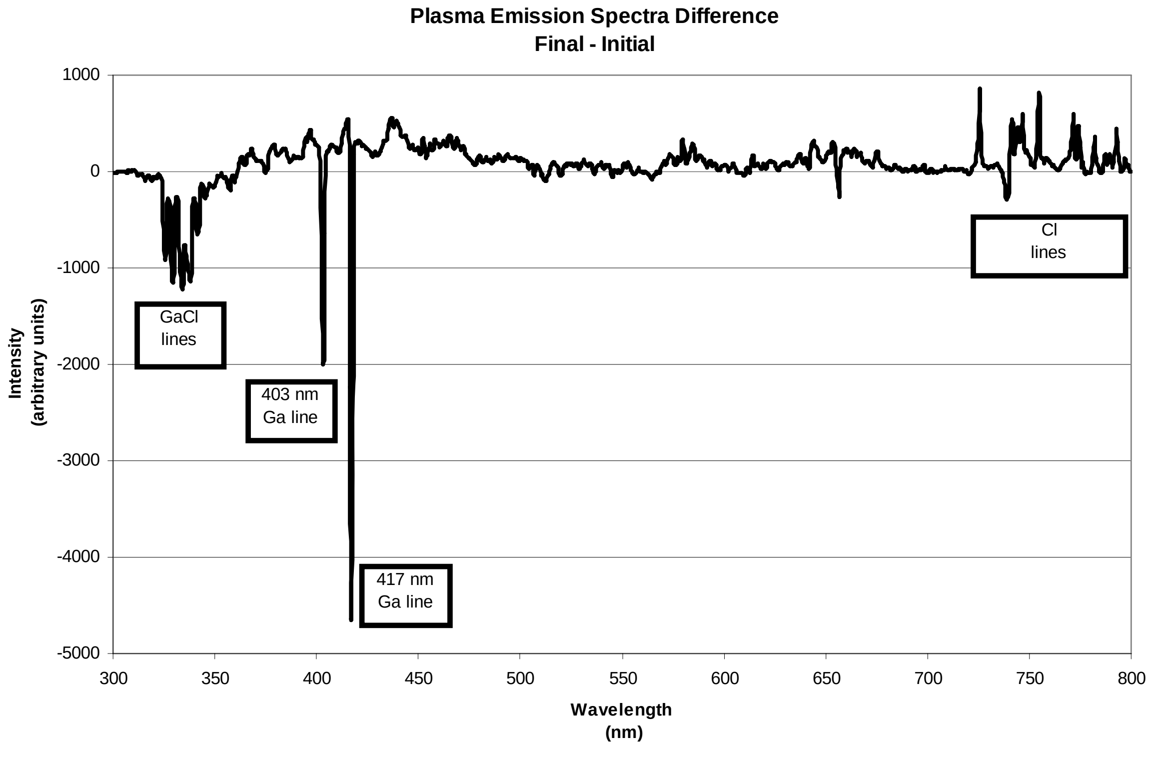

Figure 5. Difference spectra from the HEMT etch process highlighting emission changes between the main etch and overetch steps

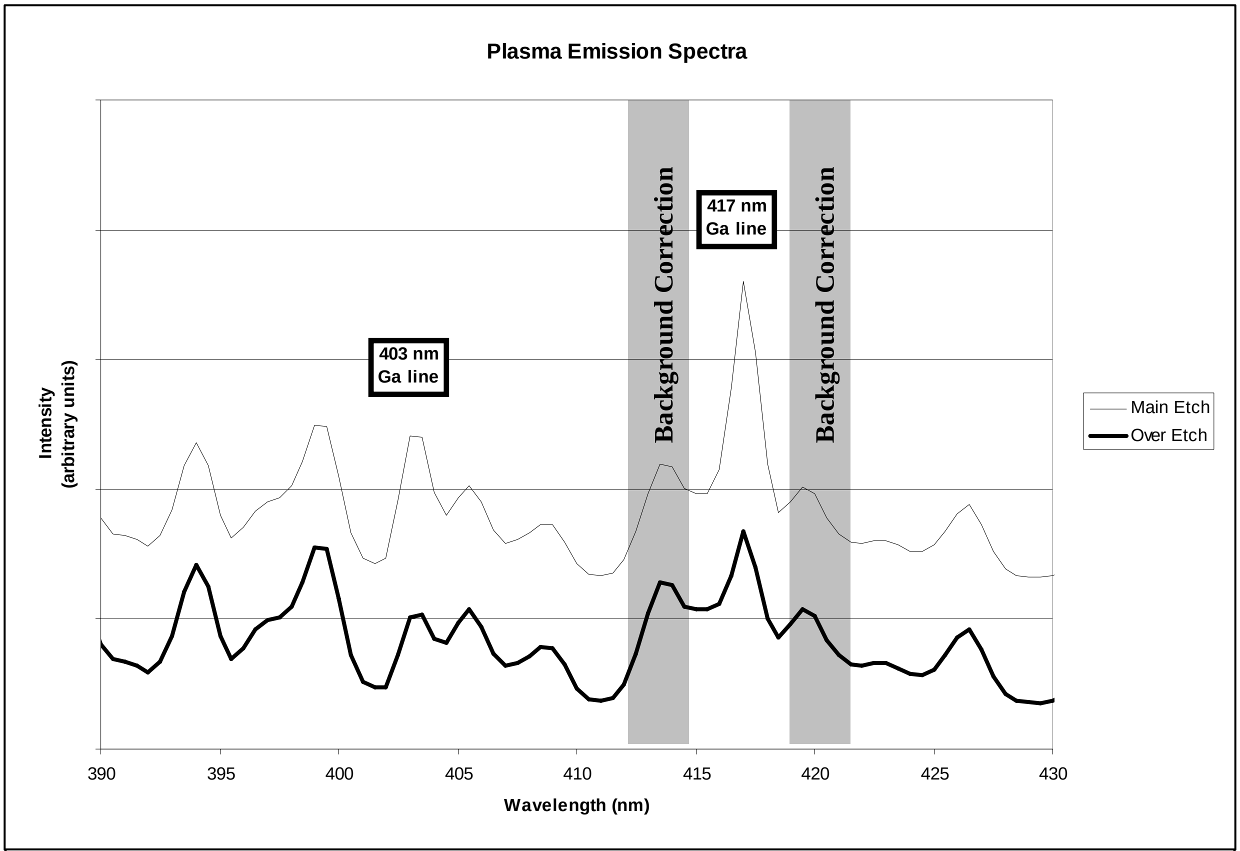

Figure 6. Expanded plasma emission spectra from the HEMT etch process during the main etch and overetch segments of the process. 417 nm Ga line used for emission endpoint. Shaded areas used for background correction.

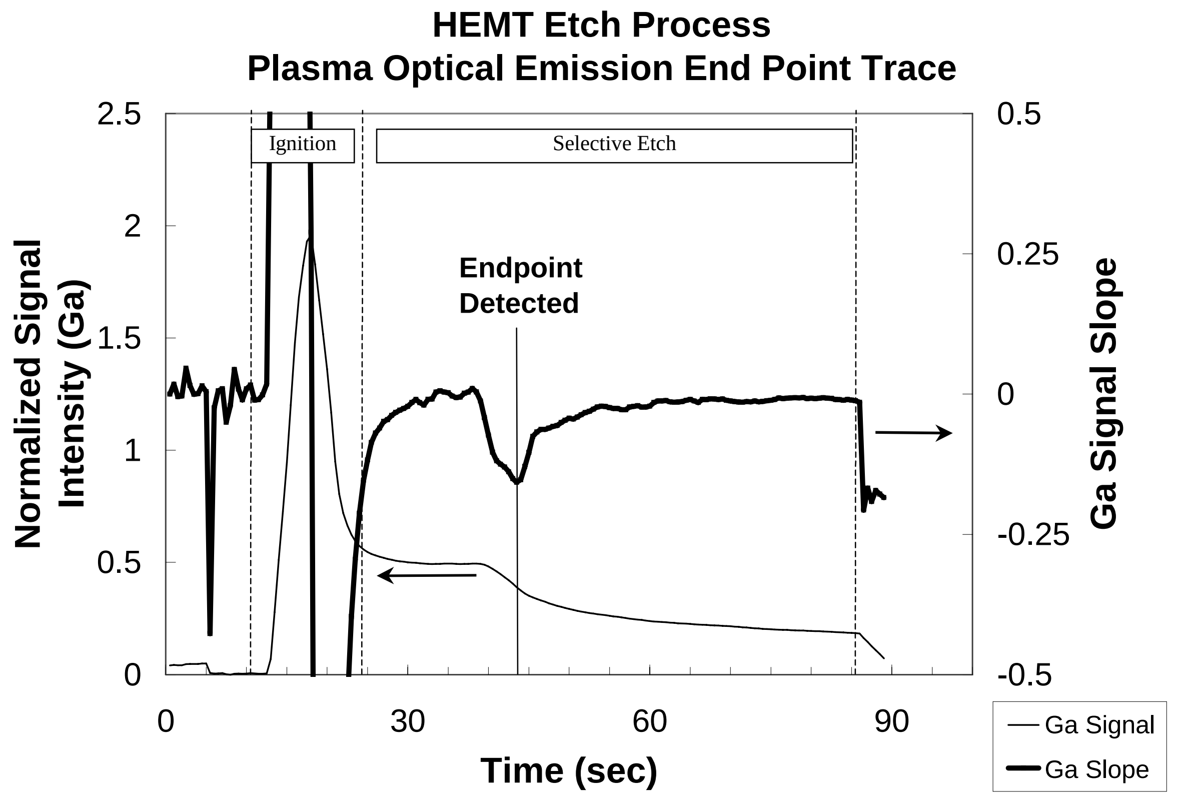

Figure 7. Optical emission endpoint trace for HEMT process using the 417 nm Ga line.