End Point Detection of Plasma Etching Using Optical Methods

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Abstract — The objective of this experiment is to obtain an endpoint detection unit that can be used on all plasma etch tools in the Semiconductor and Microsystems Fabrication Laboratory (SMFL). This investigation examined one of the most common methods for end point detection in plasma etching; optical emission spectroscopy. Optical emission spectroscopy involves monitoring the wavelength emission intensity of the plasma of different species within the etchant plasma. From all of the data collected in this experiment it was shown that the Ocean Optics Spectrometer can be utilized for end point detection on any toolset in the SMFL.

***Index Terms*— Optical Emission Spectroscopy, Process Control, Plasma Etch**

I. Introduction

Plasma etching is a widely used technique in the semiconductor industry and the need for in-situ process monitoring of plasma etching is becoming greater as the technology advances. Extremely tight control of all process parameters must be maintained to increase throughput and reproducibility. The greatest need for plasma process monitoring arises in the determination of the etch end point for a given process, which can reduce the degree of overetching and underetching. For endpoint detection and plasma diagnostic measurements optical emission spectroscopy and laser interferometry are the most commonly used methods in the industry today. There are other techniques that are used to obtain information about reactive ion plasmas, such as ellipsometry, mass spectroscopy, Langmuir probe measurements, laser induced fluorescence, coherent anti-stokes spectroscopy, and infared/visible region absorption spectroscopy, but these methods are primarily used for research since they are experimentally more demanding than the previous techniques.

For a typical etch process, the required film thickness is etched away and then the etch process continues until a specific over-etch time has been completed. The over-etch time must be long enough so that the etch layer has been removed at every position on the wafer surface, but must also be short enough so that the etch layer is not unacceptably eroded or the layer underlying the etch layer has not been etched.

II. Experimental Setup

A high-resolution spectrometer from Ocean Optics, along with a fiber optic cable from Ocean Optics and a Winbook laptop, was used to monitor various plasma spectra in this experiment. A photograph of the setup is shown in Fig. 1a.

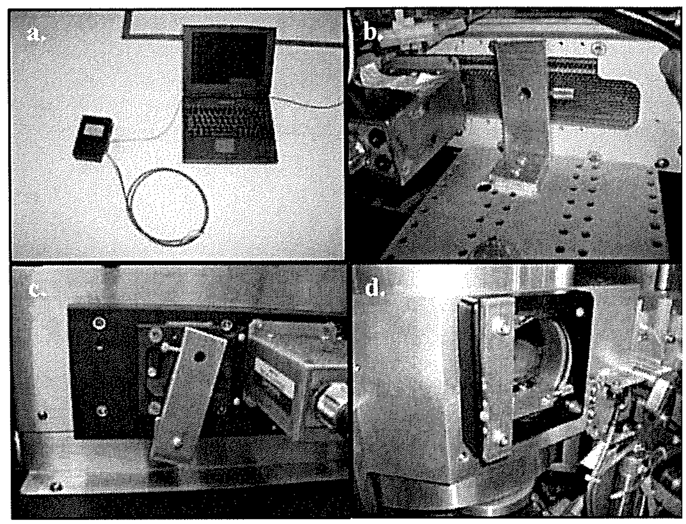

Fig. 1 a) Ocean optics spectrometer with Winbook laptop and fiber optic cable. b) Fiber optic cable mounting hardware on the LAM 490 c) Drytek Quad RIE d) LAM 4600.

The characterization of spectra during etching of thin film materials was examined on three different toolsets: (i) LAM 490 Plasma Etch, (ii) LAM 4600 Metal Etch, (iii) and Drytek Quad RIE. On each of these tools, mounting hardware for the fiber optic cable was fabricated and is shown in Figs. 1b-1d. The etching methods were done using four film stacks: (i) oxide on silicon, (ii) polysilicon on oxide, (iii) nitride on oxide, (iv) and aluminum on oxide.

III. Procedure

The end point detection was characterized for the oxide, nitride, and polysilicon films on the LAM 490 Plasma Etch tool. From each of these characterizations the end point obtained was compared to the data collected from the current

end point detection of the tool. In Fig. 2 there is a plot from the current endpoint detection system for a nitride on oxide film stack, and in Fig. 3 there is a plot from the Ocean Optics spectrometer for a nitride on oxide film stack.

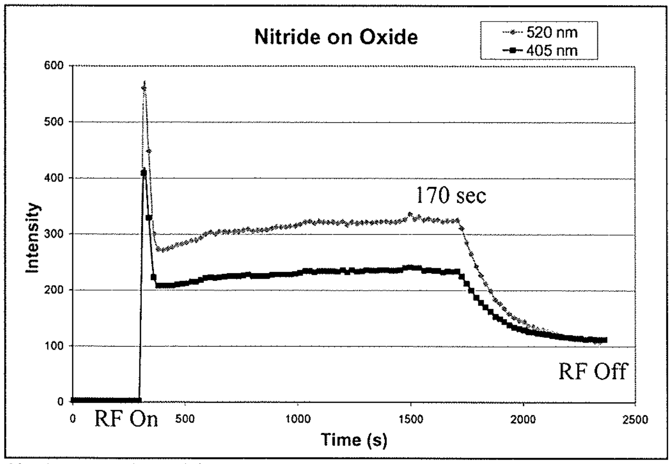

Fig. 2 Data collected from the current endpoint detection system on the LAM 490 Plasma Etch of a Nitride on Oxide film stack. The spectrum was monitored at 405 nm and 520 nm.

The recipe that was used on the LAM 490 for etching the nitride film was a power setting of 125 W, a pressure of 260 mTorr, a SF6 gas flow of 200 sccm, and a gap of 1.65 cm. The current endpoint detection on the LAM 490 is a reactive gas analyzer that filters light at wavelengths of 405 nm and 520 nm. The bandwidth at each of these settings is approximately 40 nm.

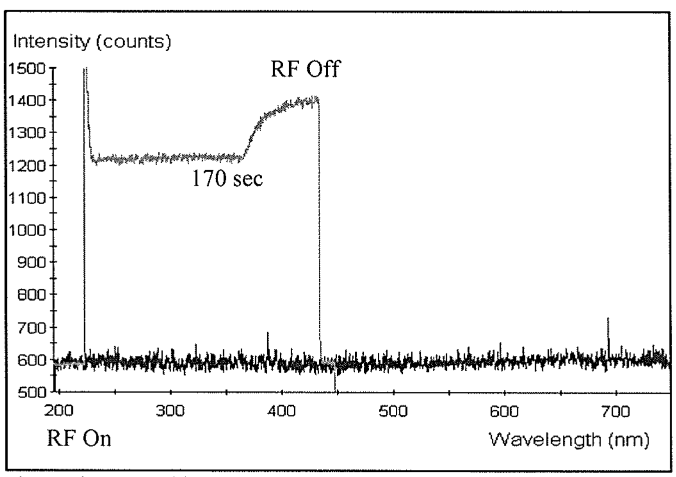

Fig. 3 Time acquisition collected from the Ocean Optics spectrometer on the LAM 490 Plasma Etch of a Nitride on Oxide film stack. The spectrum was monitored at 706 nm.

The spectrometer settings for the above plot were set to monitor the plasma wavelength at 706 nm, a bandwidth of 5 pixels, in which one pixel is approximately ½ a nanometer, an integration time of 250 ms, and a multiplying factor of one. Even though each end point detection unit was monitoring a different wavelength, the increase or decrease in the plasma intensity response was consistent. This verified that the Ocean Optics spectrometer could in theory be used to detect the end point on various other plasma etch tools in the SMFL. The next tool that was utilized was the Drytek Quad RIE. The end point detection was characterized for nitride film on a silicon substrate, and oxide on silicon films stack.

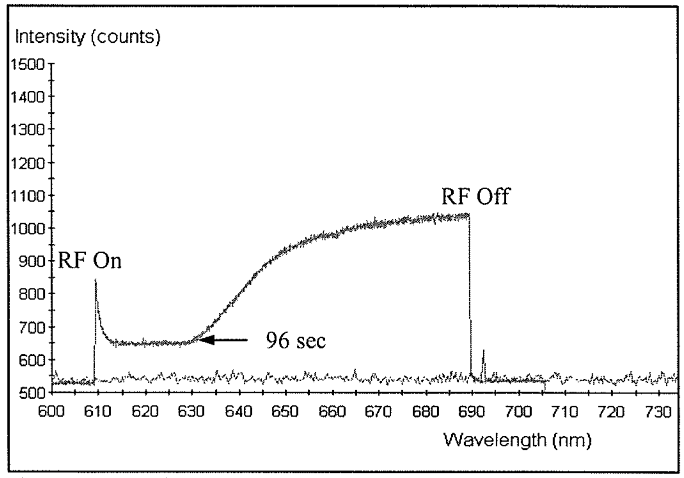

Fig. 4 Time acquisition collected from the Ocean Optics spectrometer on the Drytek Quad RIE of a Nitride on Oxide film stack. The spectrum was monitored at 706 nm.

Fig. 4 shows a plot from the Ocean Optics spectrometer for a nitride on oxide film stack using the Drytek Quad RIE. The recipe used on the Drytek Quad RIE for the nitride film was a power setting of 200 W, a pressure of 250 mTorr, a SF6 gas flow of 20 sccm. The spectrometer settings for the Drytek plot were set to monitor the plasma wavelength at 706 nm, a bandwidth of 5 pixels, an integration time of 200 ms, and a multiplying factor of one. The characterization of aluminum on oxide film stack was also done on the LAM 4600 Metal Etch tool.

A pattern density experiment was done in order to monitor the change in wavelength intensity during an endpoint with the pattern area on the wafer.

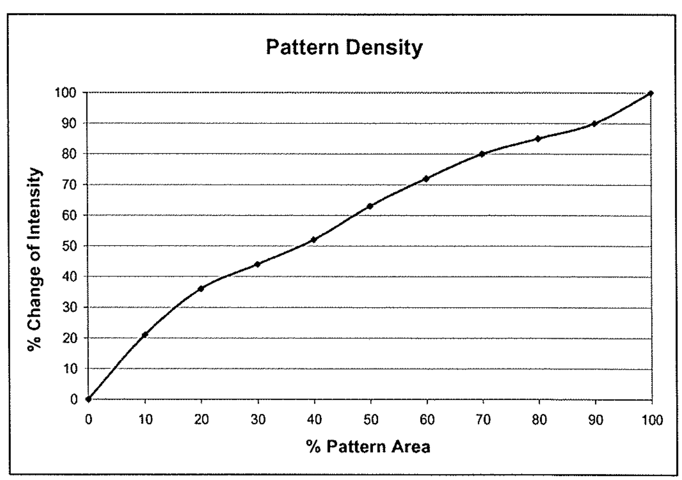

Fig. 5 A plot of the percentage of pattern area vs. the percentage of change in the intensity of the endpoint.

Fig. 5 shows the data collected and verifies that as the open pattern area decreases the change in intensity decreases linearly. The slope is approximately 1.1, which is very close to the expected slope of one. As a result when etching small pattern areas, such as contact cuts, it would be wise to have test areas outside of the devices to enhance the signal of the spectra.

IV. Conclusion

From all of the data collected in this experiment it was shown that the Ocean Optics Spectrometer can be utilized for end point detection on any toolset in the SMFL. It was verified that the Ocean Optics Spectrometer endpoint compares favorably with current endpoint detection on LAM 490. From the result of this data the spectrometer was moved over to the Drytek Quad RIE, which does not have an endpoint detection system currently on the tool. By successfully characterizing the endpoint for multiple film stacks on this tool it was verified that the Ocean Optics spectrometer can be used for end point detection on any of the plasma etch tools in the RIT cleanroom. Being unsure of what size an open pattern area must be in order to clearly obtain an endpoint, it was showed that the relationship between the open pattern area and the change in wavelength intensity is linear. Therefore, when etching small patterns, such as contact cuts, it will be difficult to obtain an endpoint. This experiment took approximately 60 tool hours in the cleanroom at a cost of approximately $3000, which is well under the $5000 budget that was given.

References

[1] D.A. White, B.E. Goodlin, A.E.Gower, D.S. Boning, H. Chen, H.H. Sawin, T.J. Dalton, "Low open-area endpoint detection using a PCA-based T^2 statistic and Q statistic on optical emission spectroscopy measurements," IEEE *Transactions*, vol.13, Issue 2, May 2000, pp. 193-207.

[2] Sang Jeen Hong, G.S. May, Dong-Cheol Park, "Neural network modeling of reactive ion etching using optical emission spectroscopy data," IEEE Transactions, vol. 16, Issue 4, Nov. 2003, pp. 598-608.

[3] K. Miwa, Y. Kawabata, "In-situ quantification of deposition amount in a poly-Si etch chamber using optical emission spectroscopy of etching plasmas," IEEE International Symposium, Sept. 30-Oct. 2, pp. 95-98.

[4] T. Reis, "In-situ plasma etch process endpoint control in integrated circuit manufacturing," IEEE/SEMI, April 2001, pp. 55-57.

[5] P.P. Ward, "Plasma process control with optical emission spectroscopy," Electronics Manufacturing Technology Symposium, 1995. 'Manufacturing Technologies – Present and Future', Seventeenth IEEE/CPMT International, Oct. 1995, pp. 166-169.

[6] M.A. Graf, V. Benveniste, "Real-time monitoring of ion source plasma using optical emission spectroscopy," Ion Implantation Proceedings, 1998 International Conference, vol. 1, June 1998, pp. 304-307.

[7] V.N. Tsaneva, T.C. Nurgaliev, T.I. Donchev, M.E. Vickers, J.H. Durrell, A. Purnell, L.F. Cohen, Z.H. Barber, "Optical emission spectroscopy of the plasma during sputter deposition of YBCO films for microwave applications," Applied Superconductivity, IEEE Transactions, vol. 13, Issue 2, Part 3, June 2003, pp. 2769-2772.

[8] M. Dineen, "Plasma etching – An essential tool for failure analysis," Oxford Plasma Technology, July 2004. Available: http://www.oxford-instruments.com/pdf/FailureAnalysis.pdf

[9] S. Wolf, R.N. Tauber, "Silicon processing for the VLSI Era," Lattice Press, vol. 1, 2000, pp. 695-698.

[10] S.M. Rossnagel, J.J. Cuomo, W.D. Westwood, "Handbook of plasma processing technology – fundamentals, etching, deposition, and surface interactions," William Andrew Publishing/Noyes, 1990, pp. 225-228.

[11] G.E. McGuire, "Semiconductor materials and process technology handbook," William Andrew Publishing/Noyes, 1988, pp. 249.

[12] E. Aperathitis, Z. Hatzopoulos, A. Georgakilas, L. Richeboeuf, "Laser interferometry as a diagnostic tool for the fabrication of reactive ion etching-edge-emitting lasers," Journal of Vacuum Science & Technology B (Microelectronics and Nanometer Structures, vol. 20, n 5, Sept. 2002, pp. 1994-1999.