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Sandia/SEMATECH Contamination Free Manufacturing Research Center, Novel Sensor Development Activities for Enhanced Process Control

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A. Introduction

The Sandia/SEMATECH Contamination Free Manufacturing Research Center (CFMRC) was founded in 1992 with the goal of providing research and development support to the U.S. semiconductor industry in the area of defect reduction in manufacturing equipment and processes. The program encompasses topics in equipment/process contamination modeling, advanced wafer cleaning, water use reduction, organic contamination, wafer-map defect data analysis and contamination sensor development.

The Contamination Sensor development activity focuses on producing advanced tools for the semiconductor industry by development and commercialization of in-line cost-effective sensors for measurement of contaminants in critical process tools. There are three phases to the CFMRC sensor development activities as outlined in Figure 1. Initially, efforts focus on sensor feasibility testing whereby several potential sensors are evaluated for technical and business issues such as sensitivity, reproducibility, cost, size, etc. After this initial screening, subsequent refinement of one or more chosen sensors occurs through beta-testing in a manufacturing environment to ensure viability for manufacturing applications. Lastly, commercialization with an existing supplier is critical in ensuring availability of the sensors for the industry. The examples described below cover sensor development at all three stages in this evolutionary process.

INVITED TALK

CFM Research Center
Sensor Development Activities

Goal: Develop and provide commercialization path for novel sensors for semiconductor applications.

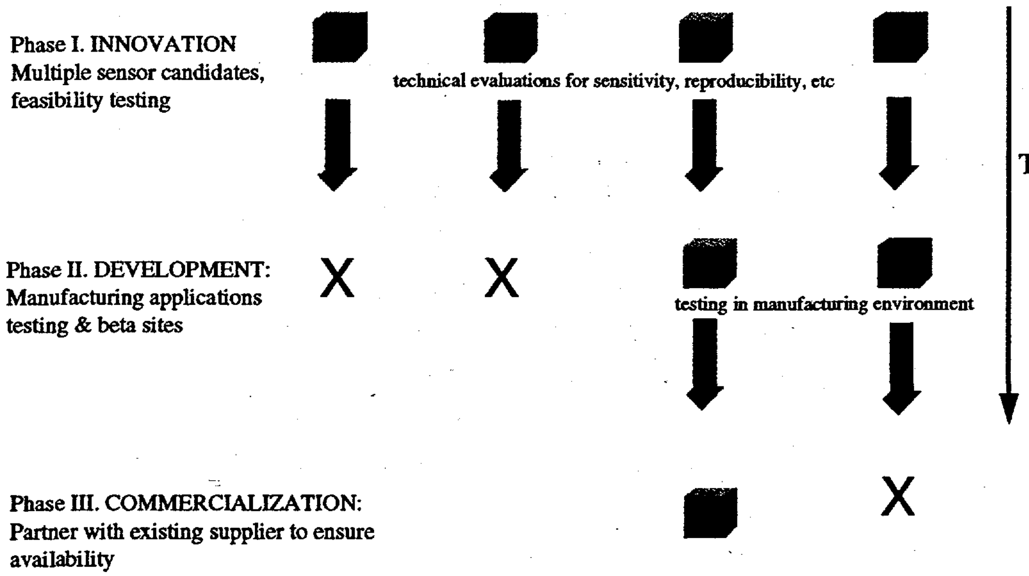

Figure 1: Sensor Development activities at SEMATECH/Sandia CFM Research Center

B. Monitoring of wall residues and gas phase contaminants in deposition and etch chambers using optical emission spectroscopy (OES), quartz crystal microbalance (QCM) monitors and fiber optic reflectance (FOR) monitors.

As an example of the Research phase of our program (Phase I, Figure 1), there are presently three sensor technologies that are under investigation for applications as monitors for deposition, flaking, and cleaning of polymeric by-products in plasma etch tools and as monitors of the actual etch processes. A fiber optic reflectivity (FOR) sensor and a quartz crystal microbalance (QCM) sensor are being tested as wall monitors in polysilicon and oxide etch tools to determine if they can predict when a chamber clean will be required before a catastrophic flaking of the polymeric residue results in particle contamination of the process wafers. The FOR is shown schematically in Figure 3. The film buildup at the tip of the fiber is characterized by a modification in the optical reflectance as shown in Figure 4 for carbon deposition using butene and an oxygen plasma cleaning process. The reflectivity vs. time curve is calibrated and used in a cumulative mode so as to determine an absolute film thickness.

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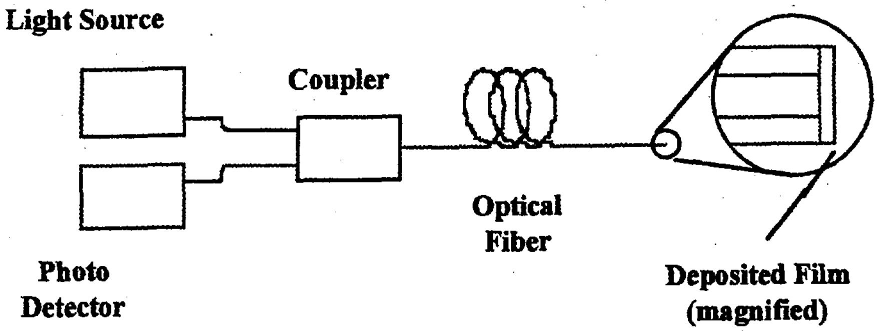

Figure 3: Schematic diagram of a fiber optic reflectivity (FOR) sensor for detection of thin film residues

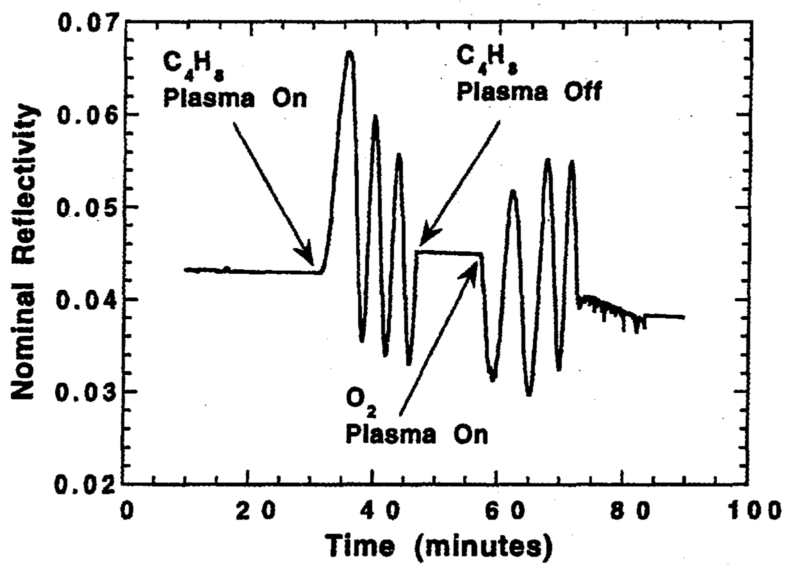

Figure 4: Reflectivity vs. time for FOR sensor in butene (C4H8) and oxygen plasmas

Optical emission spectroscopy (OES) is also being tested in several applications for use as an endpoint and contamination detector for manufacturing applications. (1) There are stability and reliability issues related to the use of OES over long time periods due to film buildup on windows and there is need for enhanced data analysis to filter the spectra especially when looking for contaminant species. Application of full spectral analysis to OES data to improve the information content of data collected during production, and development of fault detection/upset alarm software to fully integrate OES into the factory environment is a requirement for use of OES as a contamination monitor in high volume manufacturing.

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C. Detection of trace moisture in vacuum tools using the Porous Silicon Capacitor (PSC) sensor

Sensors for detection of trace moisture in vacuum tools have long been a requirement so as to detect leaks, incoming wafer contamination and source gas impurities. The traditional quadrupole mass spectrometer is a high sensitivity sensor for these applications, however, there is a need for development of a smaller, less expensive alternative. The porous silicon capacitor sensor (2) is presently under development (Phase II, Figure 1) for these applications. The PSC is a small, inexpensive sensor that uses porous silicon as a moisture-sensitive dielectric material in a simple capacitor structure. The sensor has been shown to have good sensitivity as a partial pressure monitor for moisture in vacuum chambers, with a lower limit of detection of about 0.1 millitorr. However, the relatively long response times to changes in moisture at these partial pressures will probably preclude its use for detection of low moisture levels in many tool applications. However, its relatively rapid response to higher moisture levels (Figure 2) may lend itself to other types of manufacturing applications, such as an upset alarm for a leak in a loadlock chamber. This sensor is undergoing beta site evaluation at this time.

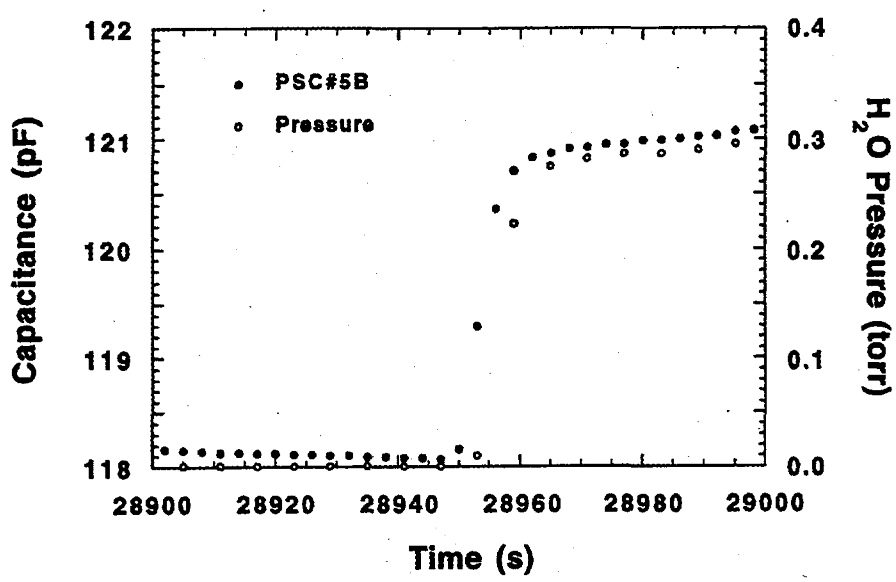

Figure 2: PSC sensor response and water pressure (torr) as function of time for step increase in moisture

D. Trace moisture detection in corrosive gases using an FTIR spectrometer with a specialized gas cell

Finally, the application of FTIR for the measurement of trace moisture in corrosive gases is an example of a sensor development activity which has completed all three phases of the process outlined in Figure 1. The need for development of a robust, high sensitivity sensor for moisture in corrosive gases is driven by concerns for gas delivery system corrosion leading to particle contamination in the process tool and potentially catastrophic system failure. Application of this sensor for both in-line measurement of gas delivery systems and for purity evaluations of incoming source gases is expected. (3)

Originally, four different types of sensors were evaluated for potential application to this problem. The Intracavity Laser Spectrometer (ILS) (4), porous silicon capacitor (PSC) (2), and Surface Acoustic Wave (SAW) devices (2) were all evaluated in addition to the FTIR apparatus. The development and testing of all 4 sensors, led to the conclusion that both the ILS and FTIR applications hold significant promise for this application, while the solid state sensors (PSC, SAW) were shown to be of lower sensitivity due to high background counts in the presence of HCl. To date, the FTIR sensor has a lower limit of detection of <10ppb for water in nitrogen, HCl, or HBr (3). Figure 5 illustrates the application of this apparatus for dry-down of a gas line showing the high precision (5-8ppb) of the measurement at a high concentration of moisture. The FTIR gas accessory which was developed as part of this can be attached to any FTIR system. In addition, a turnkey FTIR system combining this cell with a commercial spectrometer is also commercially available (5). The schematics of the Single and Dual Beam turnkey FTIR systems for corrosive gases is shown in Figure 6.

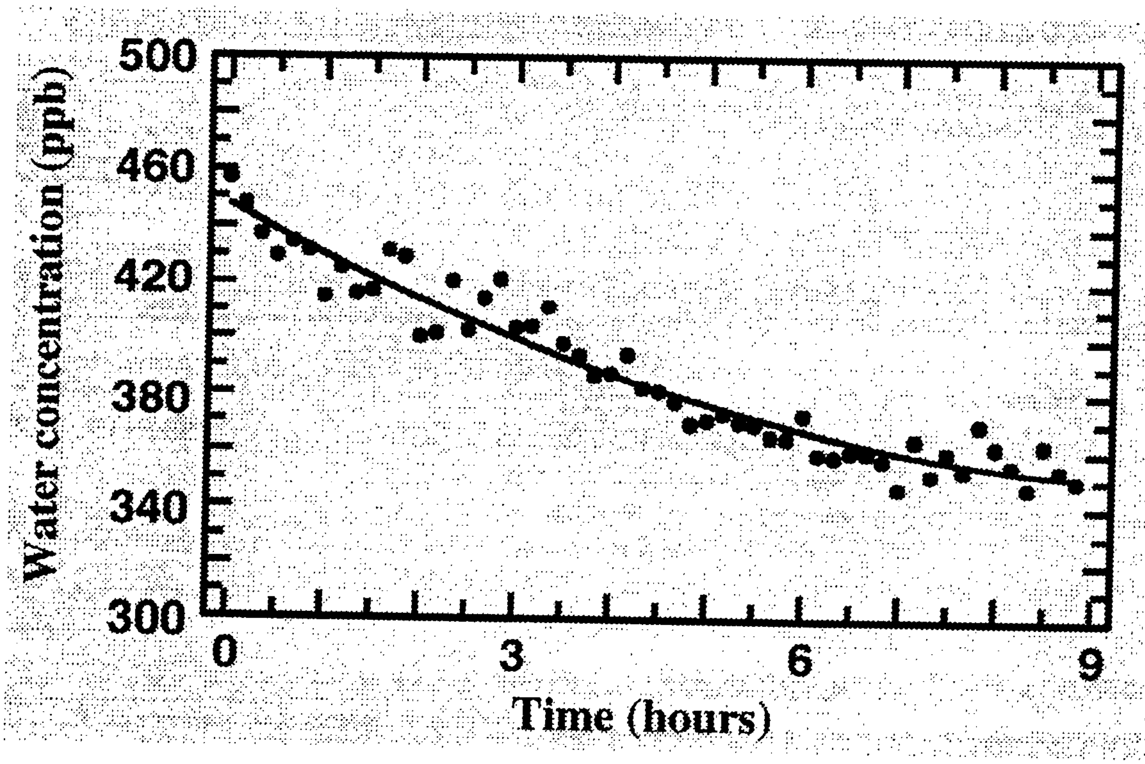

Figure 5: Water concentration (in HCl) vs. time as measured by FTIR

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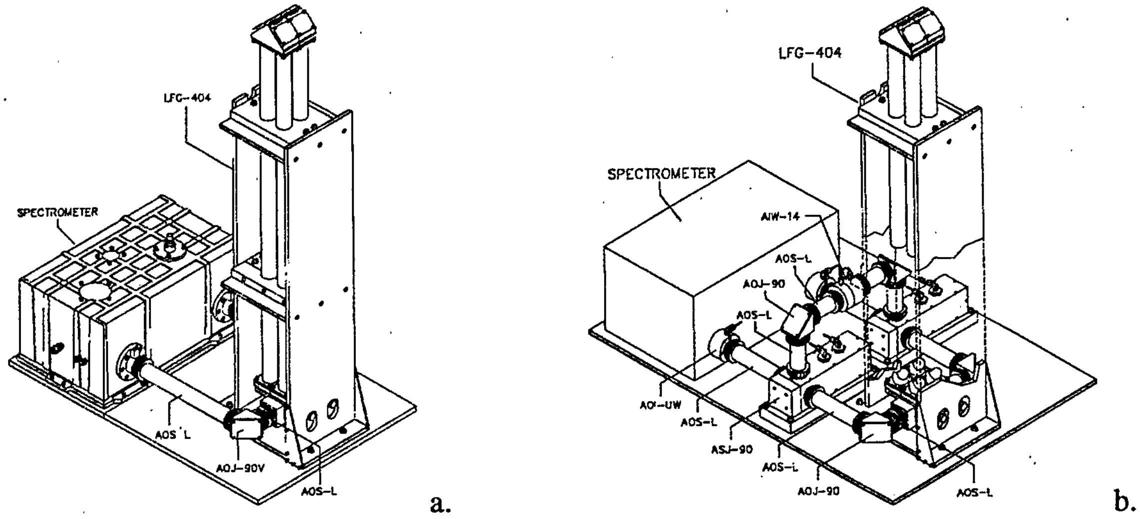

Figure 6: Schematics of (a) single and (b) dual beam FTIR turnkey systems (5)

E. Summary

In summary, the need for reliable, high sensitivity sensors for in-situ monitoring and control of semiconductor process equipment will continue to be driven by the ever increasing need for improved equipment productivity and lower cost of ownership. Sensor development activities that bring new tools to the marketplace in a timely manner are critical to this productivity enhancement effort.

This work was performed at Sandia National Laboratories, Innovative Lasers Corporation, Axiom Analytical, MIDAC Corporation, and the University of New Mexico, and was supported jointly by the U.S. Department of Energy under Contract No. DE-AC04-94AL85000 and by SEMATECH under Cooperative Research and Development Agreement No. SC92-1082. The authors also acknowledge the contributions of R. S. Blewer, B. R. Stallard, M. J. Garcia, K. B. Pfeifer, R. L. Jarecki, T. R. Guilinger, D. W. Peterson, M. R. Tuck, J. N. Sweet, K. R.Zavadil, G. T. Cordes, P. P. Ward, M. L. Smith, J. O. Stevenson, G. H. Atkinson, W. M. Doyle, J. Auth, T. M. Niemczyk, and L. H. Espinoza.

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4. G.H. Atkinson, "High Sensitivity Detection of Water Via Intracavity Laser Spectroscopy", Microcontamination Conference Proceedings, p. 98, Canon Communications, Santa Monica, CA (1994).
5. FTIR gas accessory from Axiom Analytical (Irvine, CA) and turnkey FTIR system with gas cell and MIDAC Corporation (Irvine, CA) spectrometer both available.

INVITED TALK

Sandia/SEMATECH Contamination Free Manufacturing Research Center: Novel Sensor Development Activities for Enhanced Process Control*

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(INVITED PRESENTATION)

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*This work was performed at Sandia National Laboratories, the University of New Mexico, Axiom Analytical, and MIDAC Corporation, and was supported jointly by the U.S. Department of Energy under Contract No. DE-AC04-94AL85000 and by SEMATECH under Cooperative Research and Development Agreement No. SC92-1082. The authors acknowledge the technical contributors to this project: R. S. Blewer, B. R. Stallard, M. J. Garcia, K. B. Pfeifer, R. L. Jarecki, T. R. Guilinger, D. W. Peterson, M. R. Tuck, J. N. Sweet, K. R. Zavadil, G. T. Cordes, P. P. Ward, M. L. Smith, J. O. Stevenson, W. M. Doyle, J. Auth, T. M. Niemczyk, and L. H. Espinoza.