JOURNAL OF SEMICONDUCTOR TECHNOLOGY AND SCIENCE, VOL.11, NO.1, MARCH, 2011 DOI:10.5573/JSTS.2011.11.1.001

Real-time *In-situ* Plasma Etch Process Monitoring for Sensor Based-Advanced Process Control

Jong Hwan Ahn, Ja Myong Gu, Seung-Soo Han, and Sang Jeen Hong*

***Abstract*—To enter next process control, numerous approaches, including run-to-run (R2R) process control and fault detection and classification (FDC) have been suggested in semiconductor manufacturing industry as a facilitation of advanced process control. This paper introduces a novel type of optical plasma process monitoring system, called plasma eyes chromatic system (PECSTM) and presents its potential for the purpose of fault detection. Qualitatively comparison of optically acquired signal levels vs. process parameter modifications are successfully demonstrated, and we expect that PECSTM signal can be a useful indication of onset of process change in real-time for advanced process control (APC).**

***Index Terms*—AEC/APC, in-situ monitoring, plasma process monitoring**

I. INTRODUCTION

In the semiconductor manufacturing industry, market demands and technology trends drive chip manufacturers towards increases in wafer size and decreases in device size. With the continued efforts on developing device technology, fabrication process and manufacturing technology suffers from minimal allowance of process margin. Literally speaking, 10% of process margin at 0.18 μm technology node became the size of critical dimension (CD) in the next level of device technology node in 2011. Thus, the manufacturing process and tool operations should be strictly controlled for higher yield in high volume semiconductor manufacturing.

Previously pursued statistical process control (SPC) was successful for 200 mm wafer manufacturing with relatively smaller number of chips per wafer; however, 300 mm wafer fabs with fully automated wafer production features are not satisfied for losing production hours by measurements of quality wafers, and the next level of semiconductor manufacturing process control become work in force.

Application of advanced process control (APC) techniques down to the wafer-to-wafer (W2W) level control capability is a preferred choice to cope with such demanding situation. Today, APC strategies developed about a decade ago were implemented in a process-centric fashion on an R2R basis to increase accuracy, minimize equipment downtime ensure highly efficient processes, and reduce variability in the processes [1-3]. To ensure R2R process control, the role of sensor is extended, not only monitoring in specific character, for instance, endpoint detection in etch process, but also monitoring process shift or drift in real-time, to make a direct comparison between current and previous production.

Hundreds of tool data acquired in tens of hertz may contains much of detailed information on what take place in the system, but the analysis of such a huge data set became arduous. In addition, not all the tool parameters can be regarded as independent and time invariant variables with respect plasma, which is the most critical matter in plasma processing. Direct monitoring of plasma can be beneficial for understanding plasma process better, but the existing system is not capable with

---

Manuscript received Nov. 18, 2010; revised Mar. 3, 2011.
Dept. of Electronic Engineering, Myongji University, Korea
E-mail : samhong@mju.ac.kr

either fast data acquisition or non-invasiveness to the plasma. Manufacturing process control should resolve the two constraints in advance to the performance capability. To meet these goals, a real-time plasma process monitoring techniques employing plasma eyes chromatic system (PECS^{TM}) has introduced, and it suggested that the PECS^{TM} provides quality response relative to the following process parameter: RF power (Top-Bottom), chamber pressure and gas flows [4].

In this paper, we ensure the potential for the application to R2R control using PECS^{TM} by providing timely resolved information within a wafer-in-process. We have performed three sets of experiment for initial sensor response test, expanded capability test with 200 mm production tool set, and practical application test with very small change of process shifts (as small as 1 sccm modification in process gas). From the series of experiments, we have demonstrated the capability of the proposed monitoring system and confirmed the practical feasibility to help successful FDC and R2R for achieving sensor based-advanced process control (SB-APC). In Section II, a brief explanation of the optical monitoring system will be provided, and the acquired experimental results will be provided in Section III. Finally, conclusion and future work is provided in Section IV.

II. OPTICAL PLASMA PROCESS MONITORING SYSTEM

Advanced process monitoring sensors should be able to identify any suspicious behaviors early in their occurrence and operate in real-time. The primary function of a process sensor is sensing and identifying anomalies, and notifying to fault detection and classification module in the system software or framework. However, no feasible suggestions have made for the real-time monitoring and notifying, yet in reality.

The most widely utilized *in-situ* sensor is optical emission spectroscopy (OES) for endpoint detection and FDC as well [5-6]. OES can provide much of information including plasma properties and process chemistries, but it is limited in the speed of data acquisition due to the large dimensionality. To alleviate this concern, principal component analysis (PCA) for the dimensionality reduction is suggested performed in many applications.

Table 1. Experiment table to compare the process run

No	Recipe	TYPE
RUN1	Baseline (No disturbance)	Nominal
RUN2	During normal process run, bring Top Power disturbance within +/- 5 watt variation.	Abnormal
RUN3	During normal process run, bring Pressure disturbance, within +/- 2 mTorr variation.	Abnormal
RUN4	During normal process run, bring C_4F_8 Gas disturbance, within +/- 1 sccm variation	Abnormal
RUN5	Compare run (No disturbance)	Nominal

In this research, we suggest the usage of chromatic monitoring system, in-house fabricated by *Intelligent Micro-Nano Process Fab*., Myongji University, Korea, for plasma process monitoring. The chromatic monitoring system provided significant speed advantages over the equivalent spectroscopic technique.

PECS^{TM}, the suggested chromatic monitoring system, is devised to collect optical emission spectra and represent them in three individual RGB values. Data collected in the master controller are ADC converted, signal-processed via DSP, and transferred to a PC for data visualization. A graphical illustration of the *in-situ* sensor-based process monitoring employed in this research is presented in Fig. 1. The system must satisfy the requirements of *in-situ* process monitoring sensor, such as no perturbation of the plasma, high sensitivity, a high data acquisition speed, and being fab automation friendly; PECS^{TM} detects of anomalous processes, identifies process shift and drift, and interfaces with operators in front of tools. For *in-situ* sensor data acquisition, a single-port PECS is mounted on a side window.

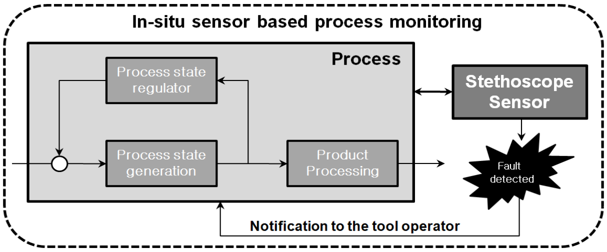

Fig. 1. Illustration of *In-situ* sensor based-process monitoring.

III. PLASMA PROCESS MONITORING

To analysis process status, the experiment was employed a 200 mm production etching tool, five

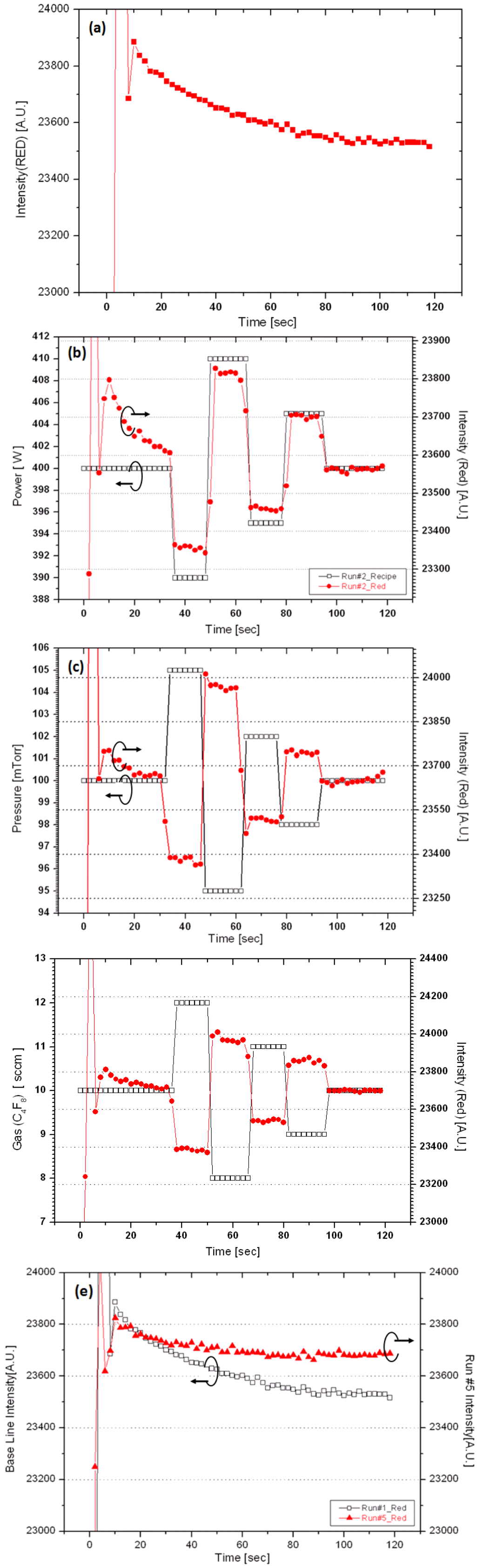

Fig. 2. Extended experimental results for the sensor response w. r. t. small process shift via blind test.

consecutive blanket oxide etch run were performed while monitoring the plasma condition using PECS^{TM}. The etching tool employed was an Exellan^{TM}, 200 mm dielectric etcher, manufactured by Ram Research, located at the National Nano FAB Center in Korea.

To monitor compare the process run, we separate status two process statuses, normal runs (RUN1 and RUN5), and abnormal runs (RUN2-RUN4). Two baseline runs were designed to check the repeatability of the sensor outputs, and the rest of three runs were designed to relate the sensor output to the change of power, pressure and amount of gas by small percentages.

To make abnormal runs, the process engineer intentionally perturbed the parameters, during the process within small changes, and even without providing any information. For example, in RUN2, Top Power was shift 4 times within 60 sec, each lease than 10sec. After then, the normal process was doing in 30 sec. It is easy to quantify the relative changes of the process parameter. Moreover, the optical sensor can detect small amount of changes in process gas. In RUN4, the amount of change was only 1 sccm. Specially, in Fig. 2, we compared between the first runs (base run, RUN1), and the last run (RUN5) using the optical sensor' data. As the result of data, in RUN5, the optical intensity (denoted in RED) is faster saturated than RUN1. One might question the behaviors of other ranges of color representation, but we also observed very similar behaviors in green and blue ranges of responses.

Plasma glow discharge is affected by small perturbations of RF power, pressure, and gas flow, and the small perturbations can be detected by the proposed optical plasma process monitoring sensors. RUN1 and RUN5 were the identical process, but a noticeable difference in their optical intensity is presented. Initially, we intended to see the repeatability of the sensor response, but we have observed more interesting phenomenon from this experiment. Fig. 2(a-e) are observed in chronological order, and one can notice that the first few runs have relatively large and sudden decrease of optical intensity comparing to that of in the 4th and 5th. As the run continued, the optical emission intensity became stable, and this can be explained by first wafer effect. Later, we found that the system was in idle for more than 8 hours, and the first wafer effect that we observed matched well with the system and process logs at the time of this experiment was performed. This supports that we have observed the first wafer effect using *in-situ* sensors.

IV. CONCLUSIONS

In this paper, we apply PECS^{TM} sensor to production tool for estimation of quantification to compare optical intensity between normal run and abnormal run, and, between two one and the same normal run. Currently, we focus on detecting, predicting, and minimizing plasma chamber arcing in volume manufacturing environment. As the experiment result, the proposed PECS^{TM} presents a great opportunity as multi-purpose in-situ monitoring sensor for realizing sensor-based APC.

ACKNOWLEDGMENTS

This work was supported by Semiconductor Process Diagnosis Research Center (SPDRC) at Myongji University. Authors are grateful to Korean Research Institute of Standard Science and Korean Ministry of Knowledge Economy.

REFERENCES

[1] J. Moyne, H. Haji, K. Beatty, R. Lewandowski, “SEMI E133-The Process Control System Standard: Deriving a Software Interoperability Standard for Advanced Process Control in Semiconductor Manufacturing,” *IEEE Trans. Semi. Manufac*., vol. 30, vo. 4, pp. 408-420, 2007.

[2] S. J. Qin, G. Cherry, R. Good, J. Wang, and C.A. Harrison, “Semiconductor Manufacturing Process Control and Monitoring: A Fab-wide Framework,” *J. of Process Control*, vol. 16, pp. 171-191, 2006.

[3] P. Kang, H. Lee, S. Cho, D. Kim, J. Park, C. Park, and S. Doh, “A Virtual Metrology System for Semiconductor Manufacturing,” *Expert Systems with Applications*, vol. 39, pp. 12554-12561, 2009.

[4] J. Ahn, D. Ryu, J. Oh, and S. Hong, “Real-Time In-Situ Plasma Etch Process Monitoring for Sensor-Based Process Control Using PECS^{TM},” *In Proc. 17th Korean Semiconductor Conference*, Busan, Korea, Feb. 2010.

[5] H. H. Yue, S. J. Qin, J. Wiseman, and A. Toprac, “Plasma Etching Endpoint Detection Using Multiple Wavelengths for small-open area wafers,” *IEEE Trans. Semi. Manufac.*, vol. 19, no. 1, pp. 66-75, 2001.

[6] S. Hong and G. May, “Neural Network-Based Real-Time Malfunction Diagnosis of Reactive Ion Etching Using In-situ Metrology Data,” *IEEE Trans. Semi. Manufac.*, vol. 17, no. 3, pp. 408-421, 2004.

Jong Hwan Ahn received the B.S. and M.S. in the Department of Electrical Engineering at Myongji University, Korea, in 2006, and 2008, respectively. He is currently pursuing his Ph. D. degree in the same university. His research interests are semiconductor manufacturing process diagnosis with emphasis is on real-time plasma process monitoring.

Ja Myong Gu received the B.S. degrees in Electronic and Electrical Engineering from Myongji University, where is currently pursuing Ph. D. degree. His research interests are optical emission spectroscopy (in-cluding SP-OES) system and its application for high volume manufacturing.

Seung-Soo Han received his B.S. and M.S. Degree in Electrical Enginee-ring from Yonsei University, Seoul, Korea in 1986 and 1988 respectively, and his Ph. D. degree in Electrical and Computer Engineering from Georgia Institute of Technology, Atlanta, in 1996. He is currently a Professor in the department of information and communication engineering, Myongji Unviersity, Korea. His research interents includes advanced process control in semiconductor manufacturing and intellignet algorithms.

Sang Jeen Hong received his B.S. in ECE from Myongji University, Korea in 1992 and his M.S. and Ph. D. degree in ECE from Georgia Institute of Technology, Atlanta, in 2001 and 2003. He is currently an associate professor in the Department of Electronic Engineering at Myongji Unviersity, where he serves as a director of semiconductor process diagnosis research center (SPDRC). His research interents are APC with in-situ sensors and tool data driven FDC in volume semiconductor manufacturing.