William H. Manning (*pro hac vice*)
E-Mail: WHManning@rkmc.com
Cole M. Fauver (*pro hac vice*)
E-Mail: CMFauver@rkmc.com
Anthony G. Beasley (*pro hac vice*)
E-Mail: AGBeasley@rkmc.com
Robins, Kaplan, Miller & Ciresi L.L.P.
2800 LaSalle Plaza
800 LaSalle Avenue
Minneapolis, MN 55402-2015
Telephone: 612-349-8500
Facsimile: 612-339-4181

John P. Bovich (SBN 150688)
E-mail: JBovich@reedsmith.com
Reed Smith LLP
Two Embarcadero Center, Suite 2000
San Francisco, CA 94111
Telephone: 415-543-87000

Attorneys for Plaintiffs and Counterclaim-Defendants Advanced Micro Devices, Inc. and ATI Technologies ULC

UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

SAN FRANCISCO DIVISION

SAMSUNG ELECTRONICS CO., LTD. Counterclaim-Plaintiff, v. ADVANCED MICRO DEVICES, INC., et al., Counterclaim-Defendants.	Case No. CV-08-0986-SI **DECLARATION OF THOMAS F. EDGAR, PH.D IN SUPPORT OF COUNTERCLAIM-DEFENDANTS' RESPONSIVE CLAIM CONSTRUCTION BRIEF**

1. I make all of the statements in this Declaration of my own personal knowledge and in accord with 28 U.S.C. § 1746.

I. INTRODUCTION AND QUALIFICATIONS

2. My name is Thomas F. Edgar. I am a Professor of Chemical Engineering at the University of Texas, Austin. I have been retained by Advanced Micro Devices, Inc. (AMD) in this case. I make this Declaration in connection with AMD's papers relating to claim construction concerning U.S. Patent No. 5,740,065 (the '065 patent), which I understand Samsung is asserting against AMD in this case. The '065 patent is in the field of process control for semiconductor manufacturing.

3. My qualifications include 40 years' experience in the field of process modeling and control, with 25 years' experience applying these principles to the manufacturing of semiconductor devices. In 1967, I received the B.S. degree in Chemical Engineering from the University of Kansas. In 1968, I received the M.A. degree in Chemical Engineering from Princeton University. In 1971, I received the Ph.D. degree in Chemical Engineering from Princeton University. I became Assistant Professor of Chemical Engineering at the University of Texas at Austin in that same year, and I became full professor in 1981. I currently hold the George T. and Gladys H. Abell Endowed Chair in Engineering at the University of Texas. I have also held administration positions at the University of Texas as Department Chair (1984-93), Associate Dean of Engineering (1993-96), and Associate Vice President for Computing (1996-2001).

4. I have published over 200 journal papers in the field of process control since 1972, along with more than 150 proceedings articles. In 1989, I co-authored a book entitled "Process Dynamics and Control." A third edition will be published in late 2009. I have also supervised over 60 Ph.D. theses in process modeling, optimization, and control; since 1989, 22 dissertations have been concerned with control of semiconductor manufacturing. Among my honors in the field are the Warren K. Lewis Award (2005) and the Computing in Chemical Engineering Award (1995) from the American Institute of Chemical Engineers (AIChE), and the Control Engineering Prize from the International Federation of Automatic Control (IFAC) (2005). I have been named

an AIChE Fellow (1994), an IFAC Fellow (2008), and in 2007 was named to the Process Automation Hall of Fame by Control Magazine. I also have an extensive background in chemical engineering education at both the undergraduate and graduate levels, and I teach the required senior-level process control course for chemical engineering students each year.

5. I was the lead author of a survey paper published in 2000 about the use of process control in the semiconductor industry. T. Edgar, et al., "Automatic Control in Microelectronics Manufacturing: Practices, Challenges, and Possibilities," Automatica, Vol. 36, pp. 1567-1603 (November, 2000). I personally participated in and followed the published literature in the field for 15 years before that survey was written, as I have continued to do ever since.

6. I have been collaborating with various process control researchers at AMD since 1995. A number of my Ph.D. students have worked as interns at AMD and some of them subsequently accepted full-time employment there. AMD has periodically provided research grants to support graduate students in process control at the University of Texas, including a new project to be initiated in 2009. I have also had a number of consulting engagements with AMD, and have been contracted to teach short courses on advanced process control to AMD employees in the late 1990s.

7. I have also had ongoing research collaborations with other semiconductor companies, including Texas Instruments, Applied Materials, Tokyo Electron, and Samsung. In the case of Samsung, they sent a research engineer from Korea to reside in my research group for one year , where we worked on specific problems related to selection of measurement variables for process control of plasma etching. In return for my advising this engineer, Samsung made a financial contribution to my research program.

8. I am being compensated by AMD at my standard rate of $400 per hour for my time spent working on this case. My compensation is not in any way related to the outcome of the case. Attached as Ex. A is my full CV including a list of my publications authored in the last 10 years and a list of legal matters in which I have testified as an expert within the last four years.

II. BASIS FOR OPINIONS

9. I have read the '065 patent, including the written specification, drawings, and claims, and the patent's file history which is the record of exchange between the applicant and the Patent Office. I understand the patent to be in the area of process control in semiconductor manufacturing, in particular, for the alignment and exposure of wafers in lithography. I have also reviewed the parties' Joint Claim Construction and Prehearing Statement. I have been actively involved in process control applied to semiconductor manufacturing since 1984 and thus am aware of the technical literature that is pertinent to this subject.

III. BACKGROUND OF THE TECHNOLOGY

10. Semiconductor manufacturing follows an assembly line format, with wafers of semiconductor material undergoing various processes in sequence. The goal of process control is to maintain the wafer properties at or near the target for each step of the process by measuring the errors introduced and adjusting manipulated variables in tools in both the upstream and downstream directions so that the wafer properties move toward the desired target properties. Two distinct approaches to process control have traditionally been used in semiconductor manufacturing.

11. Statistical process control (SPC) is a technique in which the process output is monitored (usually by measurements external to the process, or ex situ) in order to detect an "out of control" process. A process is considered "out of control" if output variance can be attributed to an assignable cause. SPC does not define the control action necessary to return a process to an "in control" state. This decision is left to the control engineer. Tools such as SPC control charts discussed in the book "Statistical Quality Control" by D.C. Montgomery are examples of methods used in SPC.

12. The second approach to process control is automatic process control (APC). APC uses measurements of process variables to implement feedback or feedforward control to keep the product on target. APC has its origins in industrial process applications during the 1940s, where feedback control was implemented using electronic and pneumatic devices known as PID controllers. The application of feedforward control to deal with disturbances was first carried out

in the 1960s. Computer control of industrial processes became more common during the 1970s, with the availability of inexpensive microprocessors. Thus a significant technology base for process control has been developed in the continuous process industries for petrochemicals manufacture, petroleum refining, and pulp and paper production. APC began to grow in importance in semiconductor manufacturing during the 1990s. Because most semiconductor tools operate as a batch process, a technique called run-to-run control (run-by-run control) has been used since at least 1993 to reduce product variability. *See* Butler and Stefani, "Application of Predictor Corrector Control to Polysilicon Gate Etching," from Proceedings of the 1993 American Control Conference (June 2-4, 1993) (Ex. B). APC practitioners view run-to-run (RtR) control as a supervisory controller that manipulates the setpoints of underlying tool controllers. By analyzing the results of previous batches, the run-to-run controller is able to manipulate the batch recipe in order to reduce output variability for each batch.

13. Use of metrology information after a batch is processed on the same tool is generally referred to as "feedback control," while use of the same information for a subsequent processing tool is called "feedforward control." The purpose of run-to-run feedback control is to keep the controlled variable at or close to its target or set point. This task can be achieved by computing the difference between the set point and the measurement of the controlled variable at the end of the previous run and sending this as the input to the feedback controller. By its design, the feedback controller will take corrective action to reduce the size of the deviation from target.

14. A feedback controller can only take action after the controlled variable deviates from its desired set point and generates a non-zero error. However, the response to disturbances can require many successive corrections if the process or measurement changes very slowly. In such a situation a feedforward controller can improve the performance of the control system. The feedforward controller predicts the effect that the disturbances will have on the controlled variable and takes control action that will counteract the influence of the disturbances. Since this control action is taken based upon model predictions, it can minimize the effect that the disturbances have on the controlled variable before any unwanted deviations occur. As an example of feedforward control, if the entering film thickness for a plasma etcher is measured,

then the manipulated variable like etch time can be adjusted so that the desired film thickness can be obtained. In this case, the previous processing step generates the disturbance to be treated by feedforward control.

15. Lithography is one aspect of semiconductor manufacturing. The goals of lithography are to create a pattern on the surface of the wafer that satisfies the design requirements for each layer. A lithography tool carries out the following separate steps:

(a) deposition of photoresist;

(b) spinning (rotation) of the wafer to create a uniform film;

(c) heat treatment of the photoresist (soft bake);

(d) alignment of the layers of each device, also called "overlay";

(e) exposure of the photoresist using a light source; and

(f) development (dissolution) of the exposed photoresist and heat treatment (hard bake).

Alignment ensures the correct alignment of each layer with respect to a previous layer as well as the global position. It is but one of many process steps involved in lithography. The steps are repeated multiple times in order to build up a device consisting of multiple layers of different geometries.

16. After alignment and exposure, the wafer is moved to a different machine to perform etching. Other unit operations (tools) involved in semiconductor manufacturing besides lithography include chemical vapor deposition (CVD), plasma etching, oxidation, sputtering, doping followed by ion implantation, and chemical mechanical planarization.

IV. LEVEL OF ORDINARY SKILL IN THE ART

17. It is my opinion that a person with the level of skill in the field of the Jang '065 patent would have an undergraduate degree in science or engineering and either graduate work in areas related to semiconductor manufacturing and process control or a comparable level of experience in implementing process control software and algorithms in semiconductor fabs.

V. HOW ONE OF ORDINARY SKILL IN THE ART WOULD VIEW THE JANG '065 PATENT

18. The '065 patent discloses a specific technique for process control in lithography, in which a new tool setting is calculated by an accumulative average over previous settings on that same machine, and adjusted by a correction term based on previous registration errors. The patent specifically describes the alignment step used in lithography. The patent presents equations to be used to correct the alignment of a given layer. Examples of parameters that can be corrected during alignment are focus offset, spatial shifts, scaling, wafer rotation, and orthogonality.

19. One advantage cited by the inventors of the patent was the reduction of waste product by reducing or eliminating the need for test wafers, which would be used for calibration of a tool. Tool settings could be adjusted based on the measured results of these test wafers, but the wafers produced after the test were in turn often unfit for further processing and therefore discarded. When such test wafers are run, no product wafers are processed, which reduces the throughput or capacity of the fab. Adjusting process parameters based on results of previous runs allows for incremental reduction of the error from the target, which reduces the need for test wafers. The applicants also argued that a novel feature of their invention lay in the application of operating strategies to "lots" of wafers. For efficiency reasons, many processes in semiconductor manufacturing may be simultaneously applied to a large number of wafers known as a "lot." The patent teaches that lot sizes can range from 25 to 50 wafers. The '065 patent teaches processing an entire lot of wafers using one set of process parameters, and adjusting these parameters only between lots.

20. I understand that the term "extracting a correction condition" from the '065 patent claims is at issue. I also recognize that in the context of the '065 claims, the "correction condition" is related to information "corresponding to an alignment state," and that the correction condition is to be added to a value determined by "accumulatively averaging working conditions." I therefore also consider these other terms as they relate to "correction condition." I am not a lawyer and am not an expert in the legal complexities associated with patent

interpretation. However, I do understand that the words used in a patent are supposed to be interpreted as those words would be understood by a person skilled in the appropriate technical field, in the context of the patent specification and the patent file history.

VI. CLAIM TERMS AT ISSUE IN THE JANG '065 PATENT

21. Equation (1) of the '065 patent describes accumulative averaging over settings from a pre-specified number of previous runs (lots) on a particular tool as follows:

$$Xtn = \frac{1}{n-1} \sum_{i=1}^{n-1} (Xti \pm \mathscr{E}) \qquad (1)$$

where X_{tn} is the nth value of the lithography variable, n-1 is the number of previous runs, and $\mathscr{E}$ is the "correction element obtained by subtracting an objective value from a resultant value." Equation (1) is an example of an "accumulative average," where parameter values are individually summed and then the result is divided by the total number of terms in the summation. An "accumulative average" is one type of calculation. Moving averages, weighted averages, and exponentially weighted moving averages ("EWMA") are recognized as distinct calculations that would have various similarities and differences from "accumulative averages" depending on the application.

22. The term "working condition" does not have a generally-accepted meaning in the field of process control. I understand "working conditions" as used in this patent to be equivalent to "operating conditions" for the tool, namely those variables (also referred to as "parameters" in the '065 patent) that are set by the operator or by the computer system that will yield the desired performance of the tool. There are four main types of variables in process control: measurement variables, controlled variables, manipulated variables and disturbance variables. In the specification of the '065 patent, parameters cited by the inventors as part of the "working condition" are all manipulated alignment variables, which are variables that can be directly programmed or "set" in a machine by a user. This is consistent with AMD's construction of a working condition being "settable parameter values."

23. The term "correction condition" does not have a generally-accepted meaning the field of process control. The '065 patent also does not precisely define "correction condition." However, it is my opinion that AMD's proposed construction is consistent with what one of ordinary skill in the art would understand the patent to teach. Equation (1) of the '065 patent describes accumulative averaging over settings from a pre-specified number of previous runs (lots) on a particular tool as follows:

$$Xtn = \frac{1}{n-1} \sum_{i=1}^{n-1} (Xti \pm \mathcal{E}) \qquad (1)$$

where X_{tn} is the nth value of the lithography variable, n-1 is the number of previous runs, and $\mathcal{E}$ is the "correction element obtained by subtracting an objective value from a resultant value." Viewing Equation (1) as a control algorithm, it is unclear why epsilon does not have a subscript, to denote it is changed at each run. Interpreted in terms of standard control terminology, it appears that the "objective value" is the same as "target" or "set point," and the "resultant value" is the process variable measurement. Equation (1) thus includes both an accumulative average component and a correction component.

24. The "correction element" or term epsilon is applied in Equation (1). The summation expression indicates that this term is applied at each step in the summation. The sentence in 3:46-48 states that if a process is performed with the correction value applied, the process can be performed without error. This suggests that epsilon is selected at each run to compensate for the error, and if it is chosen exactly, the error is forced to zero. On the other hand, the ideal correction may not be chosen at each step due to noise and other unmodeled effects. This means that the arithmetic average in Equation (1) is not an average of the X_{ti}'s, but rather an average of the parameters after the correction is applied.

25. Equation (2) is intended to show a correction to an alignment parameter,

$$A_{xy}' = A_{xy} + (E \times G) \qquad (2)$$

where A_{xy}' is the new corrected value obtained by adding A_{xy} from the previous run to the term $(E \times G)$ E and G are not defined in the '065 patent. It is stated that "the gain has the value 0.00 – 1.00 and indicates the correlation between the reference layer and the layer expected to be currently performed." The patent does not indicate how such a correlation would be calculated, and if it would be based on a statistical analysis of certain data collected from the tool. It is possible that G = gain but this is not specified. The patent does not define "E" in Equation (2) or explain how it is derived.

26. AMD's proposed construction for "extracting a correction condition" is consistent with what one of ordinary skill in the art understands the patent to teach. It is common in semiconductor manufacturing, and process control in general, to compare a measured result with a target value and calculate the difference between them. This error can then be used as a correction in subsequent processing. As defined in ¶ 12, this relates to feedback control. Theoretically, applying the correction allows the process to operate at or near the target with a small amount of variation. If the subsequent processing refers to the next run of the same tool, then it is referred to as run-to-run (RtR) feedback control. Sometimes the operating conditions for a given layer in tool B are based on a previous layer created in the previous tool (tool A) in the processing sequence. In this sense tool B is using feedforward control information from tool A, however, this is different from the lot-to-lot modification described in the '065 patent, where the same tool is employed repetitively for a series of lots.

27. Samsung's proposed construction for "extracting a correction condition," which is "creating a value or data set to be used to affect the determination of a current working condition," is not precise. At 2:36-38, the patent states "extracting the correction condition by extracting information for the alignment state of a lower layer performed by the expectation

process." However, referring to Equations (1) and (2), the "correction element" (3:44) and the "correction value" (3:46) are defined mathematically in Equation (1), and the adjustment or correction to the alignment parameter is given in Equation (2), where presumably each alignment parameter can be adjusted based on the errors for those parameters in the previous layer. It is unclear what is meant by the word "expectation," which in mathematical terms means arithmetic average. As pointed out earlier, the term in Equation (2), (E x G), is not clearly defined, although G is determined from the correlation between reference layer and current layer. Practically speaking, this would be a user-selected parameter between zero and one that can be adjusted to give the best performance for each alignment parameter.

28. Samsung's proposed construction fails to specify a particular "value or data set." There are many examples of values or datasets that can affect the determination of an operating parameter, but not all would necessarily improve or correct it, and not all of them are consistent with the teachings of the '065 patent. In fact, Samsung's proposed construction overlaps significantly with its construction for "accumulatively averaging working conditions." Equation (1) of the '065 patent could be viewed both as "a mathematical operation on a set of working conditions to determine a value representative of the set" and as "creating a value or data set to be used to affect the determination of a current working condition." In other words, this equation embodies both accumulative averaging and extracting a correction condition. An additional inconsistency in the construction refers to the creation of a "data set" to be used to determine a correction condition; this correction condition would need to be a single value in order to perform a correction in a given operating condition.

29. Samsung asserts in its brief that an identification of particular equipment can be a "correction condition." The '065 patent does not support this. The patent contains no teaching or explanation of how equipment identification could be used in process control, and no indication that this could be a "parameter" used in the calculations, e.g., in Equations (1) and (2). A parameter value identifying a piece of equipment could not be added (mathematically) to an "optimal working condition" to set a "current working condition" as required by the claims. Further, the patent contains no teaching on how to apply the information on equipment

identification in a control algorithm such as given in Equations (1) and (2).

30. Claim 1 states that the correction condition is extracted "by extracting information corresponding to an alignment state." As disclosed in the patent, the alignment state is determined by comparing the relative position of one layer as opposed to a different layer. Alignment can also refer to positioning a mask over a layer of semiconductor material and projecting a light pattern that can then be used to form new features on the device. This projection of light is referred to as "exposure," and alignment and exposure together are two steps carried out in a "photolithography" tool. Proper positioning of the mask is critical so that the patterns on upper layers align well with patterns on lower layers. Further, in my review of the patent, I see no instances where an "alignment state" refers to anything other than photolithography. The term "working conditions" is not illustrated beyond its application to alignment and exposure. In fact, the particulars of the patent as embodied in Equations (1) and (2) would not be directly applicable to other semiconductor processing tools because the relationship between manipulated and controlled variables depends on process cause and effect, whereas in alignment the manipulated and controlled variables are both mechanical alignment (distance) errors. In essence, you select the manipulated variable adjustment to cancel out the alignment error (controlled variable), an extremely simple algorithm that would not be successful for other semiconductor control applications. The patent does not teach how to extend the disclosed control algorithm for alignment to other processes such as etching or chemical mechanical deposition, for example. Further, it would not have been apparent to one skilled in the art how to extend the disclosed control algorithm to these processes.

31. Samsung asserts in its brief that an identification of particular equipment can be "information corresponding to an alignment state." The '065 patent does not support this. The patent contains no teaching or explanation of how equipment identification could be used in process control, and no indication that this could be a "parameter" used in the calculations, e.g., in Equations (1) and (2). Identifying a piece of equipment is not information that quantifies how one layer aligns relative to another. The patent contains no teaching on how to apply the information on equipment identification in a control algorithm such as given in Equations (1) and

(2). It would not have been apparent to one skilled in the art how to apply equipment identification information to these Equations.

The statements made in this declaration are made based on my personal knowledge and on my years of experience in the field of process control for semiconductor manufacturing. I declare under oath and under penalty of perjury that the foregoing is true and correct to the best of my knowledge, information and belief. Executed on this 30 day of March, 2009, at Austin, Texas.

Thomas F. Edgar

Thomas F. Edgar, Ph.D

ROBINS, KAPLAN, MILLER & CIRESI L.L.P.
ATTORNEYS AT LAW
MINNEAPOLIS

EDGAR
EXHIBIT A

Updated 3/30/2009

THOMAS F. EDGAR
Department of Chemical Engineering
University of Texas, Austin, Texas 78712
(512) 471-3080

September, 2008

PERSONAL

Date of birth: April 17, 1945   Place of birth: Bartlesville, Oklahoma

EDUCATION

Princeton University, Ph.D., Chemical Engineering, 1971
Princeton University, M.A., Chemical Engineering, 1968
University of Kansas, B.S., Chemical Engineering, 1967

EMPLOYMENT

1968-1969	Process Engineer, Continental Oil Company, Baltimore, Maryland
1971-1976	Assistant Professor of Engineering, The University of Texas at Austin, Austin, Texas
1976-1981	Associate Professor of Chemical Engineering
1978 (Spring)	Visiting Professor of Chemical Engineering, University of California at Berkeley, Berkeley, California
1979-1985	Graduate Advisor
1981-1985	Professor of Chemical Engineering
1983-1991	The Paul D. and Betty Robertson Meek Centennial Professorship
1985-1993	Department Chairman, Chemical Engineering
1993-1996	Associate Dean for Academic Affairs, College of Engineering
1996-2001	Associate VP for Academic Computing & Instructional Technology Services
1991-present	George T. and Gladys H. Abell Endowed Chair in Engineering and Professor of Chemical Engineering

CONSULTING

Advanced Micro Devices
Camp, Dresser, McKee
Chemstations
E. I. DuPont de Nemours, Inc.
Elgin-Butler Brick Company
Fisher Controls
Fulbright and Jaworski
Heller - Ehrman
Millipore
Mobil Oil Corporation
National Bureau of Standards
Perkins - Coie
Resource Assessments
Renesas
Ropes-Gray
Teknekron
Texas Instruments
Tokyo Electron
Tres-Ark
United Nations Development Program
Whitfield Law

AWARDS

1974 Outstanding Student Chapter Counselor Award, AIChE
1976 Outstanding Young Member, South Texas Section AIChE
1977 Honorable Mention, Best Paper Award, Joint Automatic Control Conference
1978 Outstanding Young Men of America
1978 Who's Who in the South and Southwest
1980 Allan P. Colburn Award for Excellence in Publications (AIChE)
1982 Katz Lectureship, University of Michigan
1984 Who's Who in America
1988 Amick Lecturer, Columbia University
1988 George Westinghouse Young Educator Award, (ASEE)
1988 Chemical College Lecturer, Institution of Engineers-Australia
1989 Joe J. King Professional Engineering Achievement Award
1990 Distinguished Engineering Service Award (University of Kansas)
1990 Meriam-Wiley Distinguished Author Award (ASEE)
1992 American Automatic Control Council Education Award
1993 Eckman Education Award (ISA)
1994 AIChE Fellow
1994 Who's Who in the U.S.
1994 Who's Who in Engineering
1995 Computing in Chemical Engineering Award (AIChE)
1996 Henske Lecturer, Yale University
1996 Union Carbide Lectureship - Chemical Engineering Division Award (ASEE)
1999 Phillips Lectureship, Oklahoma State University
1999 Wilbur Lecture, Rice University
1999 Chemical Engineering Academy Lecture, University Missouri-Rolla
2005 ASEE Fellow
2005 IFAC Control Engineering Prize
2006 Warren K. Lewis Award in Chemical Engineering Education (AIChE)
2007 Process Automation Hall of Fame (Control Magazine)
2008 International Federation of Automatic Control (IFAC) Fellow

HONORARY SOCIETY MEMBERSHIPS

Phi Lambda Upsilon
Omega Chi Epsilon
Omicron Delta Kappa
Tau Beta Pi
Phi Kappa Phi

PROFESSIONAL SOCIETY MEMBERSHIPS

American Institute of Chemical Engineers
Registered Professional Engineer, State of Texas
Trustee, CACHE Corporation
American Chemical Society
American Society of Engineering Education
Instrument Society of America

A. PUBLICATIONS -- Journals

[1] L. Lapidus and T.F. Edgar. The Computation of Optimal Singular and Bang-Bang Control I: Linear Systems. *AIChE Journal,* Vol. 18, pp. 774-779, 1972.

[2] L. Lapidus and T.F. Edgar. The Computation of Optimal Singular and Bang-Bang Control II: Nonlinear Systems. *AIChE Journal*, Vol. 18, pp. 780-786, 1972.

[3] J.J. McKetta and T.F. Edgar. Synthetics: A New Energy Frontier. *Panhandle Magazine*, special issue, January 1973.

[4] L. Lapidus, J. Vermeychuk, and T.F. Edgar. The Linear-Quadratic Control Problem: A Review of Theory and Practice. *Chem. Engr. Commun.*, Vol 1, pp. 57-76, 1973.

[5] J. Tsing, J.O. Hougen, and T.F. Edgar. Application of the Minicomputer to the Feedback Control Problem. *ISA Trans.*, Vol. 12(4), pp. 375-380, 1973.

[6] J.B. Riggs and T.F. Edgar. Model Discrimination Difficulties in Diffusion Systems. *Chem. Engr. J.*, Vol. 6, pp. 69-73, 1974.

[7] J.B. Riggs and T.F. Edgar. Least Squares Reduction of Linear Systems Using Impulse Response. *Intl. J. Cont.*, Vol. 20, pp. 213-223, 1974.

[8] T.F. Edgar. A Course in Multivariable Control and Estimation. *Chem. Engr. Educ.*, Vol. 8, pp. 168-171, 1974.

[9] T.H. Tsang, D.M. Himmelblau, and T.F. Edgar. Optimal Control via Collocation and Nonlinear Programming. *Intl. J. Cont.*, Vol. 21, pp. 763-768, 1973.

[10] T.F. Edgar. Least Squares Model Reduction Using Step Response. *Intl. J. Cont.*, Vol. 23, pp. 261-270, 1975.

[11] T.F. Edgar. The Sensitivity of Time Domain Response to Frequency Domain Errors. *Intl. J. Sys. Sci.*, Vol. 7, pp. 691-698, 1976.

[12] T.H. Tsang, J.O. Hougen, and T.F. Edgar. Estimation of Heat Transfer Parameters in a Packed Bed. *Chem. Engr. J.*, Vol. 11, pp. 57-66, 1976.

[13] T.F. Edgar. Multivariable Process Control: Assessment and Needs. *AIChE Symposium Series*, Vol. 72(159), pp. 99-111, 1977.

[14] T. Bickel, D.M. Himmelblau, and T.F. Edgar. Optimal Design of Gas Transmission Networks. *Chem. Engr. Prog.*, Vol. 72, pp. 72-80, 1976.

[15] A. Dogru, T.N. Dixon, and T.F. Edgar. Confidence Limits on the Parameters and Predictions of One-Dimensional Slightly Compressible, Single Phase Reservoir. *Soc. Petr. Engr. J.*, pp. 42-56, Feb 1977.

[16] T.F. Edgar and J. Schwartz. Analytical Model Reduction of Large Scale Linear Dynamic Systems. *AIChE Journal,* Vol. 23, pp. 948-951, 1977.

[17] J.M. Galland, B. Dinsmoor, and T.F. Edgar. The Mechanism of Channel Growth During Underground Coal Gasification. *J. Petr. Technology*, pp. 698-704, May 1977.

[18] T.F. Edgar. Technical, Economic, and Environmental Evaluation of Underground Coal Gasification. *In Situ*, Vol. 1, pp. 75-102, 1977.

[19] T.W. Thompson, S. Sen, K.E. Gray, and T.F. Edgar. The Influence of Drying and Stress on the Permeability of Texas Lignite. *ASME J. Pressure Vessel Technology*, Vol. 99, pp. 634-640, 1977.

[20] D.W. Gregg and T.F. Edgar. In Situ Coal Gasification (Journal Review). *AIChE Journal,* Vol. 24, pp. 753-781, 1978.

[21] T.W. Thompson, K.E. Gray, and T.F. Edgar. An Assessment of Overburden Stability in the In Situ Gasification of Texas Lignite. *AIME J. Pressure Vessel Technology*, Vol. 100, pp. 285-290, 1978.

[22] J.E. Murray and T.F. Edgar. Optimal Scheduling of Production and Compression in Gas Fields. *J. Petr. Technology*, pp. 109-116, Jan 1978.

[23] D.M. Himmelblau, T.C. Bickel, and T.F. Edgar. Optimal Design of Gas Transmission Networks. *SPE J.*, pp. 96-104, April 1978.

[24] C.O. Schwanke, J.O. Hougen and T.F. Edgar. Development of Multivariable Control Strategies for Distillation Coluumns. *ISA Trans.*, Vol. 16, pp. 69-81, 1978.

[25] D. Webb and T.F. Edgar. Decoupling Controller Simplification via Model Reduction. *ISA Trans.*, Vol. 18(4), pp. 67-74, 1979.

[26] L.S. Tung and T.F. Edgar. Analysis of Control-Output Interactions in Dynamic Systems. *AIChE Journal*, Vol. 27(4), pp. 690-693, 1981.

[27] M.J. Humenick, H.B. Cooper, W.R. Kaiser, and T.F. Edgar. Technical, Economic, and Environmental Factors for In Situ Gasification of Gulf Coast Lignite. *Technology and the Use of Lignite*, pp. 207-231, 1980.

[28] T.F. Edgar. Modeling of Underground Coal Gasification Systems. *Foundations of Computer Aided Process Design*, Vol. II, Engineering Foundation, pp. 367-378, 1981.

[29] M.J. Rabins, H.H. Richardson, J. Zaborszky, and T.F. Edgar. High Priority Research Relevant to Energy Issues in the Field of Process and Systems Dynamics and Control. *ASME Trans. J. of Dyn. Sys., Meas. Cont.*, Vol. 102, pp. 202-207, 1980.

[30] R. S. Schechter and T.F. Edgar. Research on In Situ Processing. *Chem. Engr. Educ.*, Vol. 14(4), pp. 156-161, 1980.

[31] T.F. Edgar. Computer Graphics in Chemical Engineering Education. *Chem. Engr. Prog.*, Vol. 77(3), pp. 55-59, 1981.

[32] J. O. Hougen and T.F. Edgar. Other Synthesis Methods: Feedback Controller Design. In *AIChEMI Modular Instruction Series A*, Vol. 2, Module A2.8, 1981.

[33] R. Heeb, J.O. Hougen, and T.F. Edgar. Computer Aided Process Control System Design Using Interactive Graphics. *Comp. Chem. Engr.*, Vol. 5, pp. 225-232, 1981.

[34] T.F. Edgar. Coal Extraction without Mining. *Discovery*, pp. 16-19, 1982.

[35] H.P. Tseng, P.G. Christman, and T.F. Edgar. Computer Control and Data Acquisition for a Thermogravimetric Analyzer. *Chem. Bio. Env. Inst.*, Vol. 11, pp. 377-409, 1981.

[36] T.F. Edgar. New Results and the Status of Computer Aided Process Control System Design in North America. In *Chemical Process Control*, Engineering Foundation, New York, pp. 213-221, 1981.

[37] M.P. Athans, P. G. Christman, and T.F. Edgar. The Sulfur Balance in Pyrolysis and Combustion, *AIChE Symp. Ser.*, Vol. 78(216), pp. 30-41, 1982.

[38] D.M. Himmelblau H.L. Chang and T.F. Edgar. Flow Characteristics in Underground Coal Gasification *In Situ*, Vol. 6(2), pp. 143-182, 1982.

[39] P.G. Christman and T.F. Edgar. Distributed Pore Size Model for the Sulfation of Limestone. *AIChE Journal*, Vol. 29, pp. 388-395, 1983.

[40] J.B. Riggs and T.F. Edgar. Sweep Efficiency Models for Underground Coal Gasification: A Critical Assessment, *AIChE Symp. Ser.*, Vol. 79(226), pp. 108-119, 1983.

[41] T.F. Edgar. Research and Development on Underground Gasification of Texas Lignite,*AIChE Symp. Ser.*, Vol. 78(216), pp. 66-76, 1983.

[42] M. J. Humenick, R. J. Charbeneau, and T.F. Edgar. Environmental Effects of In Situ Coal Gasification, *AIChE Symp. Ser.*, Vol. 78(216), pp. 139-153, 1983.

[43] H. P. Tseng and T.F. Edgar. Identification of the Combustion Behavior of Lignite Char Between 350 and 900 C. *Fuel,* Vol. 63, pp. 385-393, 1984.

[44] H.P. Tseng and T.F. Edgar. Combustion Behavior of Bituminous and Anthracite Coal Char Between 425 and 900 C. *Fuel*, Vol. 64, pp. 373-379, 1985.

[45] K.Y. Park and T.F. Edgar. Simulation of the Hot Carbonate Process for Removal of CO_2 and H_2S from Medium Btu Gas. *Energy Prog.*, Vol. 4(3), pp. 174-180, 1984.

[46] J.M. Rogers and T.F. Edgar. Specifying Control and Isolation Dampers: Proper Application Ensures Efficient Operation. *Hyd. Proc.*, Vol. 63(1), pp. 125-129, 1984.

[47] F.W. Hammesfahr et al. and T.F. Edgar. Underground Coal Gasification. *Energy Prog.*, Vol. 2(2), pp. 95-99, 1982.

[48] G.V. Reklaitis, R.S.H. Mah, and T.F. Edgar. Computer Graphics in the ChE Curriculum.*Engr. Educ.*, Vol. 73, pp. 147-151, 1983.

[49] E.F. Vogel and T.F. Edgar. Application of an Adaptive Pole Zero Placement Controller to Chemical Processes with Variable Dead Time. In *Instrumentation Exchange*, *International,* Instrument Society of America, 1983.

[50] T.H. Tsang and T.F. Edgar. Modeling of Drying and Pyrolysis During Underground Coal Gasification- I. *In Situ,* Vol. 7(3), pp. 237-264, 1983.

[51] T.H. Tsang and T.F. Edgar. Modeling of Drying and Pyrolysis During Underground Coal Gasification-II. *In Situ,* Vol. 7(3), 265-299, 1983.

[52] T.F. Edgar. Conversion of Continuous Time Models to Discrete-Time Models. In *AIChEMI Modular Instruction, Series A* (Process Control), Vol. 3, Module A3.6, 1983.

[53] T.F. Edgar. Sampling and Filtering for Discrete-Time Systems. In *AIChEMI Modular Instruction, Series A* (Process Control), Vol. 3, Module A3.7, 1983.

[54] K.Y. Park M. Mai and T.F. Edgar. Analysis of Early Cavity Growth in Underground Coal Gasification *In Situ,* Vol. 9(2), pp. 119-147, 1985.

[55] H.L. Chang, D.M. Himmelblau, and T.F. Edgar. Modeling and Simulation of Self-Gasification of Coal. *In Situ,* Vol. 9(2), pp. 149-184, 1985.

[56] D.E. Seborg and T.F. Edgar. Feedforward Control. In *AIChEMI Modular Instruction, Series A*, (Process Control), Vol. 4, Module A4.4, 1984.

[57] D.E. Seborg and T.F. Edgar. Adaptive Control. In *AIChEMI Modular Instruction, Series A*, (Process Control), Vol. 4, Module A4.5, 1984.

[58] D.M. Himmelblau H.L. Chang and T.F. Edgar. A Sweep Efficiency Model for Underground Coal Gasification. *In Situ,* Vol. 9(2), pp. 185-221, 1985.

[59] G.V. Reklaitis R.S.H. Mah and T.F. Edgar. Use of Computers in Chemical Engineering Education. *Chem. Engr. Prog.*, Vol. 81, pp. 9-13, 1985.

[60] S.L. Shah D.E. Seborg and T.F. Edgar. Adaptive Control Strategies for Process Control: A Survey. *AIChE Journal,* Vol. 32(6), pp. 881-913, 1986.

[61] S.S. Poon, K.Y. Park and T.F. Edgar. The Combustion Rates of Texas Lignite Cores. *In Situ,* Vol. 10(2), pp. 109-143, 1987.

[62] K.Y. Park and T.F. Edgar. Modeling of Early Cavity Growth for Underground Coal Gasification. *IEC Research,* Vol. 26, pp. 237-246, 1987.

[63] W. Min and T.F. Edgar. The Dynamic Behavior of a Fixed-Bed Steam-Oxygen Coal Gasifier Disturbed by Water Influx. I. Experimental Results. *Chem. Engr. Commun.*, Vol. 52, pp. 109-125, 1987.

[64] W. Min and T.F. Edgar. The Dynamic Behavior of a Fixed-Bed Steam-Oxygen Coal Gasifier Disturbed by Water Influx.II. Model Development and Verification. *Chem. Engr. Commun.*, Vol. 52, pp. 195-213, 1987.

[65] T.F. Edgar. What's New in Hardware and Software. *Chem. Engr. Prog.*, Vol. 82, p.5, 1986.

[66] H.P. Tseng and T.F. Edgar. On Analyzing the Combustion Characteristics of Coal Char. *Fuel.* Vol. 66(5), pp. 722-723, 1987.

[67] T.F. Edgar. Current Problems in Process Control. *IEEE Control Syst. Soc. Magazine*, Vol. 7, pp. 13-15, 1987.

[68] E.F. Vogel and T.F. Edgar. An Adaptive Pole Placement Controller for Chemical Processes with Variable Dead Time. *Comp. Chem. Engr.*, Vol. 12, pp. 15-26, 1988.

[69] M.C. Wellons and T.F. Edgar. The Generalized Analytical Predictor. *IEC Research*, Vol. 26, pp. 1523-1536, 1987.

[70] S. Venkateson, I. Trachtenberg, and T.F. Edgar. Effect of Flow Direction on Etch Uniformity in Parallel Plate Isothermal Plasma Reactors. *J. Electrochem. Soc.*, 134, Vol. 134(12), pp. 3194-3197, 1987.

[71] H.P. Tseng and T.F. Edgar. The Change of the Physical Properties of Coal Char during Reaction. *Fuel*, Vol. 68, pp. 114-119, 1988.

[72] D.T. Dalle Molle, B.J. Kuipers, and T.F. Edgar. Qualitative Modeling and Simulation of Physical Systems. *Comp. Chem. Engr.*, Vol. 12(9), pp. 853-866, 1989.

[73] B.W. Bequette and T.F. Edgar. Interaction Index Based on Setpoint Transmittance. *AIChE Journal*, Vol. 34, pp. 849-852, 1988.

[74] M. Mai and T.F. Edgar. Calcination and Sintering Induced Surface Area Evolution. *AIChE Journal,* Vol. 35, pp. 30-36, 1989.

[75] T.S. Westby, Dangtran, K., and T.F. Edgar. Fluidized Bed Combustion of Texas Lignite: An Experimental Investigation on Carbon Conversion and Sulfur Dioxide Emission. *Fuel,* Vol. 69, pp. 590-599, 1990.

[76] R.S.H. Mah, G.V. Reklaitis, D. M. Himmelblau, and T.F. Edgar. Computer Aids in Chemical Education. *ChemTech*, Vol. 18, pp. 277-283, 1988.

[77] A.W. Alsop and T.F. Edgar. Nonlinear Heat Exchange Control Through the Use of Partially Linearized Control Variables. *Chem. Engr. Commun.*, Vol. 75, pp. 155-170, 1989.

[78] B.W. Bequette and T.F. Edgar. Non-interacting Control System Design Methods in Distillation. *Comp. Chem. Engr.*, Vol. 13(6), pp. 641-650, 1989.

[79] T. Setalvad, I. Trachtenberg, B. W. Bequette, and T.F. Edgar. Optimization of a Low Pressure CVD Reactor for the Deposition of Thin Films. *IEC Res.*, Vol. 28, pp. 1162-1170, 1989.

[80] S. Venkatesan, I. Trachtenberg, and T.F. Edgar. On the Dynamics of an Isothermal Radial-Flow Plasma Etcher. *J. Electrochem. Soc.*, Vol. 136(9), pp. 2532-2545, 1989.

[81] A. Patwardhan, J. B. Rawlings, and T.F. Edgar. Nonlinear Model Predictive Control Using Simultaneous Solution and Optimization. *Chem. Engr. Commun.*, Vol. 87, pp. 123-141, 1990.

[82] T.F. Edgar. Process Control Education in the Year 2000. *Chem. Engr. Educ.*, Vol. 24, pp. 72-77, 1990.

[83] A.W. Alsop and T.F. Edgar. Nonlinear Control of a High Purity Distillation Column by the Use of Partially Linearized Control Variables. *Comp. Chem. Engr.*, Vol. 14(6), pp. 665-678, 1990.

[84] S. Venkatesan and T.F. Edgar. Modelling of Silicon Etching in $CF_4/0_2$ and CF_4/H_2 Plasmas. *J. Electrochem. Soc.*, Vol. 137(7), pp. 2200-2290, 1990.

[85] M.J. Liebman, I. Kim, and T.F. Edgar. Robust Error in Variables Estimation Using Nonlinear Programming Techniques. *AIChE Journal*, Vol. 36(7), pp. 985-993, 1990.

[86] T.F. Edgar. Will Computers Control the World?. *AIChE Magazine for Students*, Vol. 1(1), pp. 17-22, 1990.

[87] R.R. Horton, B.W. Bequette, and T.F. Edgar. Improvements in Dynamic Compartmental Modeling for Distillation. *Comp. Chem. Engr.*, Vol. 15(3), pp. 197-201, 1991.

[88] I. W. Kim and T.F. Edgar. A Sequential Error in Variables Method for Nonlinear Dynamic Systems. *Comp. Chem. Engr.*, Vol. 15, pp. 663-679, 1991.

[89] I.W. Kim, N.H. Bell, and T.F. Edgar. Parameter Estimation for Laboratory Water Gas Shift Reactor Using Nonlinear Error-in-Variables Method. *Comp. Chem. Engr.*, Vol. 15(5), pp. 361-367, 1991.

[90] N.H. Bell and T.F. Edgar. Modeling of a Fixed-Bed Water Gas Shift Reactor - I. *J. Proc. Cont.*, Vol. 1(1), pp. 22-31, 1990.

[91] N.H. Bell and T.F. Edgar. Modeling of a Fixed-Bed Water Gas Shift Reactor - II. *J. Proc. Cont.*, Vol. 1(2), pp. 59-67, 1991.

[92] J. L. Bravo, A.A. Patwardhan, and T.F. Edgar. Influence of Effective Interfacial Areas in the Operation and Control of Packed Distillation Columns. *IEC Research*, Vol. 31, pp. 604-607, 1992.

[93] K.J. McLaughlin, S.W. Butler, I. Trachtenberg, and T.F. Edgar. Development of Techniques for Real-Time Monitoring and Control in Plasma Etching I. Response Surface Modeling of CF_4/O_2 and CF_4/H_2 Etching of Silicon and Silicon Dioxide. *J. Electrochem. Soc.*, Vol. 138, pp. 789-799, 1991.

[94] S.W. Butler, K.J. McLaughlin, I. Trachtenberg, and T.F. Edgar. Development of Techniques for Real-Time Monitoring and Control in Plasma Etching II. Multivariable Control System Analysis of Manipulated, Measured and Performance Variables. *J. Electrochem. Soc.*, Vol. 138, pp. 2727-2735, 1991.

[95] J. Lee, W. Cho and T.F. Edgar. An Improved Technique for PID Controller Tuning from Closed-Loop Tests. *AIChE Journal,* Vol. 36(2), pp. 1891-1895, 1990.

[96] K.J. McLaughlin, I. Trachtenberg, and T.F. Edgar. Real-time Monitoring and Control for Plasma Etching. *IEEE Cont. Sys. Soc. Magazine*, Vol. 11(3), pp. 3-10, 1991.

[97] A.A. Patwardhan, G.T. Wright, and T.F. Edgar. Nonlinear Model Predictive Control of Distributed Parameter Systems. *Chem. Engr. Sci.*, Vol. 47, pp. 721-735, 1992.

[98] T.A. Badgwell, I. Trachtenberg, J.K. Elliott, and T.F. Edgar. Experimental Verification of a Fundamental Model for Multiwafer LPCVD of Polysilicon. *J. Electrochem. Soc.*, Vol. 139, pp. 524-532, 1992.

[99] T.A. Badgwell, I. Trachtenberg, J.K. Elliott, and T.F. Edgar. In-Situ Measurement of Wafer Temperatures in a Multiwafer LPCVD Furnace. *IEEE Trans. Semicond. Manuf.*, Vol. 6(1), pp. 65-71, 1993.

[100] M.J. Liebman, L. Lasdon, and T.F. Edgar. Efficient Data Reconciliation and Estimation for Dynamic Processes Using Nonlinear Programming Techniques. *Comp. Chem. Engr.*, Vol. 16, pp. 963-986, 1992.

[101] T.A. Badgwell, I. Trachtenberg and T.F. Edgar. Modeling and Scaleup of Multiwafer LPCVD Reactors. *AIChE Journal,* Vol. 38, pp. 926-937, 1992.

[102] T.F. Edgar. (Featured Educator), *Chem. Engr. Educ.*, Vol. 26, pp. 2-7, Winter, 1992.

[103] S. Chatterjee, I. Trachtenberg, and T.F. Edgar. Mathematical Modeling of a Single Wafer Rapid Thermal Reactor. *J. Electrochem. Soc.*, Vol. 139, pp. 3682-3689, 1992.

[104] C. Ling and T.F. Edgar. The Tuning of Fuzzy Heuristic Controllers. *Asia-Pacific Engr. J.* (A), Vol. 3, pp. 83-104, 1993.

[105] C. Ling and T.F. Edgar. A New Fuzzy Gain Scheduling Algorithm for Process Control. *Asia-Pacific Engr. J.* (A), Vol. 3, pp. 129-141, 1993.

[106] A.J. Toprac, I. Trachtenberg, and T.F. Edgar. Modeling of Gas Phase Chemistry in the Chemical Vapor Deposition of Polysilicon in a Cold Wall System. *J. Electrochem. Soc.*, Vol. 140, pp. 1809-1813, 1993.

[107] A. Patwardhan and T.F. Edgar. Nonlinear Model Predictive Control of a Packed Distillation Column. *IEC Research*, Vol. 32, pp. 2345-2356, 1993.

[108] T.A. Badgwell, I. Trachtenberg, and T.F. Edgar. Modeling the Wafer Temperature Profile in a Multiwafer LPCVD Furnace. *J. Electrochem. Soc.*, Vol. 141(1), pp. 161-172, 1994.

[109] G.T. Wright and T.F. Edgar. Nonlinear Model Predictive Control of a Fixed Bed Water Gas Shift Reactor: An Experimental Study. *Comp. Chem. Engr.*, Vol. 18(2), pp. 83-102, 1994.

[110] A.J. Toprac, I. Trachtenberg, and T.F. Edgar. A Predictive Model for the Chemical Vapor Deposition of Polysilicon in a Cold Wall, Rapid Thermal System. *J. Electrochem. Soc.*, Vol. 141(6), pp. 1658-1663, 1994.

[111] Y.L. Huang and T.F. Edgar. An Artificial Intelligence Approach to the Synthesis of a Process for Waste Minimization. *Emerging Technologies in Hazardous Waste Management, Amer. Chem. Soc.*, Chapter 6, pp. 96-113, 1994.

[112] Y.L. Huang, T.F. Edgar, D.M. Himmelblau, and I. Trachtenberg. Constructing a Reliable Neural Network Model for a Plasma Etching Process Using Limited Experimental Data. *IEEE Trans. Semicond. Manuf.*, Vol. 7(3), pp. 333-343, 1994.

[113] J.R. Bosley and T.F. Edgar. An Efficient Dynamic Model for Batch Distillation. *J. Proc. Cont.*, Vol. 4(4), pp. 195-204, 1994.

[114] T.F. Edgar et al. T.A. Badgwell. Modeling and Control of Microelectronics Processing. *Comp. Chem. Engr.*, Vol. 19, No. 1, pp. 1-41, 1995.

[115] R. Dunia, S.J. Qin, T.F. Edgar and T.J. McAvoy. Identification of Faulty Sensors Using Principal Component Analysis. *AIChE Journal.* Vol. 42, No. 10, pp. 2797-2812, 1996.

[116] K. McBrayer and T.F. Edgar. Bias Detection and Estimation in Dynamic Data Reconciliation. *J. Proc. Cont.* Vol. 5(4), pp. 285-293, 1996

[117] T.F. Edgar. Control of Unconventional Processes. *J. Proc. Cont.* Vol. 6, pp. 99-110, 1996.

[118] I. Kim, S.W. Park, and T.F. Edgar. Data Reconciliation for Input-Output Models in Linear Dynamic Systems. *Korean Journal of Chemical Engineering*, Vol. 13(2) pp. 211-215, 1996.

[119] R. Dunia, S.J. Qin, T.F. Edgar, and T.F. McAvoy. Use of Principal Component Analysis for Sensor Fault Identification. *Computers Chem Engng.* Vol. 20, Suppl. pp. S713-S718, 1996.

[120] R. Dunia and T.F. Edgar. An Improved Generic Model Control Algorithm for Linear Systems. *Computers Chem. Engng.* Vol. 20, No. 8, pp. 1003-1016, 1996.

[121] S.W. Butler and T.F. Edgar. Case Studies in Equipment Modeling and Control in the Microelectronics Industry. *Chemical Process Control* - CPC-V, Lake Tahoe, CA. *AIChE Symp. Ser.* Vol. 93, No. 316 p. 133-144, 1997.

[122] T.F. Edgar. Process Control: From Classical to the Postmodern Era. *Chem. Engr. Educ.,* Vol. 31(2), pp. 12-18, 1997.

[123] R. Dunia, B. Fernandez, and T.F. Edgar. Effect of Process Uncertainties on Generic Model Control: A Geometric Approach. *Chem. Engr. Sci.*, Vol. 52, pp. 2205-2222, 1997.

[124] I. Kim, M.S. Kang, S.W. Park, and T.F. Edgar. Robust Data Reconciliation and Gross Error Detection: The Modified MIMT using NLP. *Comp. Chem. Engr.*, Vol. 21, No. 7, pp. 775-782, 1997.

[125] J.T. Lee, W. Cho, and T.F. Edgar. Control System Design Based on a First Order Plus Time Delay Model. *J. Proc. Cont.,* Vol. 7, No. 1, pp. 65-73, 1997.

[126] S. Bushman, I. Trachtenberg, and T.F. Edgar. Radio Frequency Diagnostics for Plasma Etch Systems. *Journal of the Electrochemical Society*, Vol. 144, No. 2, pp. 721-732, 1997.

[127] S. Bushman, I. Trachtenberg, and T.F. Edgar. Modeling of Plasma Etch Systems Using Ordinary Least Squares, Recurrent Neural Network, and Projection to Latent Structure Models. *Journal of the Electrochemical Society*, Vol. 144, No. 4, pp. 1379-1389, April 1997.

[128] Zhong-Xiang Zhu, J.T. Lee, and T.F. Edgar. Steady State Structural Analysis and Interaction Characteristics in Multivariable Control Systems. *IEC Research,* Vol. 36, pp. 3718-3726, 1997.

[129] C. Ling, and T.F. Edgar. Real-time Control of a Water-Gas Shift Reactor by Model-Based Fuzzy Gain Scheduling Technique. *J. Proc. Cont.*. Vol. 7, No. 4, pp. 239-253, 1997.

[130] J.T. Lee, W. Cho, and T.F. Edgar. Effects of Diagonal Input Uncertainties and Element Uncertainties in Ill-conditioned processes. *IEC Research*, Vol. 37, pp. 1009-1017, 1998.

[131] J.T. Lee, W. Cho, and T.F. Edgar. Iterative Identification Methods for Ill-conditioned Processes. *IEC Research*, Vol. 37, pp. 1018-1023, 1998.

[132] K. Edwards, V.I. Manousiouthakis, and T.F. Edgar. Kinetic Model Reduction Using Genetic Algorithms. *Comp. Chem. Engr.*, Vol. 22, No. 1-2, pp. 239-246, 1998.

[133] J.T. Lee and T.F Edgar. Multiloop PI Controller Tuning for Interacting Multivariable Processes. *Comp. Chem. Engr.* Vol. 22. No. 11, pp. 1711-1723, 1998.

[134] J.D. Stuber, I. Trachtenberg, and T.F. Edgar. Design and Modeling of Rapid Thermal Processing Systems. *IEEE Trans. Semiconductor Manufacturing*. Vol. 11, No. 3, pp. 442-457, August, 1998.

[135] K.F. McBrayer, T. Soderstrom, T.F. Edgar, and R. Young. The Application of Nonlinear Dynamic Data Reconciliation to Plant Data. *Comp. Chem. Engr.* Vol 22. No. 12, pp. 1907-1911, 1998.

[136] K. Teague, and T.F. Edgar. Predictive Dynamic Model of a Small PSA Separation Unit. *IEC Research*, Vol. 28, No. 10, pp. 3761-3775, 1999.

[137] Y. Huang, J.P. Gong, and T.F. Edgar. Fuzzy Model Predictive Control. *IEEE Trans. Fuzzy Systems,* Vol. 8(6), pp. 665-678, 2000.

[138] T.F. Edgar, S. Butler, W.J. Campbell, C. Pfeiffer, C. Bode, S.B. Hwang, K.S. Balakrishnan and J. Hahn. Automatic Control in Microelectronics Manufacturing: Practices, Challenges, and Possibilities. *Automatica,* Vol. 36(11): pp. 1567-1603, 2000.

[139] K.S. Balakrishnan and T.F. Edgar. Model-based Control in Rapid Thermal Processing. *J. Thin Solid Films*, Vol. 365(2), pp. 322-333, 2000.

[140] T.F. Edgar. Information Technology and Chemical Engineering Education. Evolution or Revolution? *Chem Engr. Educ,* pp. 290-295, March, 2000.

[141] T.F. Edgar. Process Information. Achieving a Unified View. *Chem. Engr. Prog.*, Vol. 96, pp. 51-57, January, 2000.

[142] B.S. Ko, and T.F. Edgar. Performance Assessment of Cascade Loop Using Minimum Variance Principles. *AIChE Journal*, Vol. 46, pp. 281-291, 2000.

[143] J.T. Lee, J.Y. Choi and T.F. Edgar. Use of Sequential Loop Closing Method for Iterative Identification of Ill-Conditioned Processes. *IEC Res*earch, Vol. 39, pp. 2404-2409 (2000).

[144] K. Edwards and T.F. Edgar. Reaction Mechanism Simplification Using Variable Selection Techniques. *Chem. Engr. Sci.*, 55, pp. 551-572, 2000.

[145] J.T. Lee and T.F. Edgar. Phase Conditions for Stability of Multiloop Control Systems. *Comp. Chem. Engr.* Vol. 23, pp. 1623-1630, 2000.

[146] T. Soderstrom, R. Young, L. Russo and T.F. Edgar. Industrial Application of a Large-Scale Dynamic Data Reconciliation Strategy. *IEC Res*, Vol. 39(6), pp. 1683-1693, 2000.

[147] J.T. Lee, and T.F. Edgar. Computational Methods for Decentralized Integral Controllability of Low Dimensional Processes. *Comp. Chem. Engr.* Vol. 24, pp. 847-852, 2000.

[148] J.T. Lee, D.G. Koo, and T.F. Edgar. Robust Controller Design Method for Systems with Parametric Uncertainties. *Trans. Cont., Auto. & Systems . Engr.*, Vol. 2, No. 2, pp. 140-148, June, 2000.

[149] K. Edwards and T.F. Edgar. Reaction Mechanism Simplification Using Mixed-Integer Nonlinear Programming. *Comp. Chem. Engr.* 24, pp. 67-79, 2000.

[150] J. Hahn and T.F. Edgar. A Gramian Based Approach to Nonlinearity Quantification and Model Classification. *IEC Research*, Vol. 40, pp. 5724-5731, 2001.

[151] J. Hahn, T. Edison and T.F. Edgar. A Note on Stability Analysis Using Bode Plots. *Chemical Engineering Education,* Vol. 35, No. 3, pp. 208-211, 2001.

[152] J.T. Lee and T.F. Edgar. Real Structured Singular Value Conditions for D-Stability. *Systems and Control Letters*, Vol. 44, pp. 273-277, 2001.

[153] J.T. Lee, B.S. Ko and T.F. Edgar. "Adaptive Slow/Fast Control Systems for Interacting Multivariable Processes," *IEC Research,* Vol. 40, pp. 5929-5934, 2001.

[154] T.A. Soderstrom and T.F. Edgar. A Mixed Integer Optimization Approach for Simultaneous Data Reconciliation and Identification of Measurement Bias. *Control Engineering Practice,* Vol. 9, pp. 869-876, 2001.

[155] B.S. Ko and T.F. Edgar. Performance Assessment of Constrained Model Predictive Control Systems, *AIChE J.* Vol. 47(6), pp. 1363-1372, 2001.

[156] J. Hahn and T.F. Edgar. An Improved Method for Nonlinear Model Reduction using Balancing of Empirical Gramians. *Computers & Chem. Engr.*, Vol. 26, pp. 1379-1397, 2002.

[157] S. Alici and T.F. Edgar. Nonlinear Dynamic Data Reconciliation Via Process Simulation Software and Model Identification Tools, *IEC Research*, Vol. 41, pp. 3984-3992, 2002.

[158] J. Lee and T.F. Edgar. "An Improved PI Controller with Delayed or Filtered Integral Mode", *AIChE Journal*, Vol. 48, pp. 2844-2850, 2002.

[159] J. Peng, S. Lextrait, T.F. Edgar and R.B. Eldridge. A Comparison of Steady State Equilibrium and Rate-based Models for Packed Reactive Distillation Columns, *IEC Research*, Vol. 4, pp. 2735-2744, 2002.

[160] J.T. Lee and T.F. Edgar. Subspace Identification Method for Simulation of Closed-loop Systems with Time-Delays. *AIChE Journal*, Vol. 48, pp. 417-420, 2002.

[161] J. Hahn and T.F. Edgar. A Balancing Approach to Minimal Realization of Nonlinear Systems. *IEC Research,* Vol. 41, pp. 2204-2212, 2002.

[162] J. Hahn, T. Edison and T.F. Edgar. Adaptive IMC Control for Drug Infusion for Biological Systems. *Control Engineering Practice*, Vol. 10, pp. 45-56, 2002.

[163] S.B. Hwang, W.D. Kim and T.F. Edgar. Modeling of Dry Development in Bilayer-Resist Process for 140nm Contact Hole Patterning, *IEEE Trans*action *on Semiconductor Manufacturing,* Vol. 15, pp. 245-252, 2002.

[164] J. Hahn, S. Lextrait and T.F. Edgar. Nonlinear Balanced Model Residualization via Neural Networks. *AIChE Journal,* Vol. 48, pp. 1353-1357, 2002.

[165] J.T. Lee and T.F. Edgar. Conditions for Decentralized Integral Controllability, *J. Process Control*, Vol. 12, pp. 797-805, 2002.

[166] J. Hahn, T.F. Edgar and W. Marquardt. Observability and Controllability Covariance Matrices for the Analysis and Order Reduction of Stable Nonlinear Systems. *J. Process Control*, Vol. 13, pp. 115-127, 2002.

[167] J.J. Peng, T.F. Edgar and R.B. Eldridge. Dynamic Rate-Based and Equilibrium Models for a Packed Reactive Distillation Column. *Chemical Engineering Science*, Vol. 58, pp. 2671-2680, 2003.

[168] T.F. Edgar. ChE Curriculum of the Future: Re-Evaluating the Process Control Course. *Chem. Engr. Educ.*, Vol. 37(2), pp. 1, 2003.

[169] D.W. Kim, S.B. Hwang, T.F. Edgar and S. Banerjee. "Characterization of Si-Ge Quantum Dot on SiO2 and HfO2 Grown By Rapid Thermal Chemical Deposition for Nanoelectric Devices", *Electrochemical Society*, Vol.150 (4), pp. G240-G243, 2003.

[170] J.T. Lee and T.F. Edgar. Dynamic Interaction Measures for Decentralized Control of Multivariable Processes, *IEC Research*, Vol. 43, pp. 283-287, 2004.

[171] C.A. Bode, B.S. Ko and T.F. Edgar. "Run-to-Run Control and Performance Monitoring of Overlay in Semiconductor Manufacturing", *Control Engineering Practice*, Vol. 12, pp. 893-900, 2004.

[172] Y. Chen, T.F. Edgar and V. Manousiouthakis. "On Constrained Infinite-Time Nonlinear Quadratic Optimal Control", *Systems and Control Letters,* Vol. 51(3-4): 259-268, 2004.

[173] B.S. Ko, J.T. Lee and T.F. Edgar. "An Analytic Expression for Closed-Loop Output Behavior Under Multiloop PID Control, *Korean, J. Chem. Engr.*, Vol. 21 No. 1, pp. 1-5, 2004.

[174] B.S. Ko and T.F. Edgar. "PID Control Performance Assessment: The Single-Loop Case", *AIChE J.*, Vol. 50, pp. 1211-1218, 2004.

[175] J.T. Lee and T.F. Edgar. "Simulations of Stable Non-conventional and Large Linear Processes Using the FFT Method", *Computers Chem. Engr.*, Vol. 28, pp. 479-485, 2004.

[176] J.T. Lee and T.F. Edgar. "ISE Tuning Rule Revisited", *Automatica*, Vol. 40, pp. 1455-1458, 2004.

[177] S. Lextrait, R.B. Eldridge and T.F. Edgar. "Steady-State Rate-based Simulation for Packed Reactive Distillation: Spatial Discretization", *IEC Research*, Vol. 43, pp. 3855-3869, 2004.

[178] T.F. Edgar. "Process Operations: When Does Controllability Equal Profitability? *Computer Chem. Engr.*, Vol. 29, pp. 41-49, 2004.

[179] S.A. Harrison, D. Yu, G.S. Hwang, T.A. Kirichenko, S.K. Banerjee and T.F. Edgar. "Origin of Vacancy and Interstistical Stablization at the Amorphous Crystalline Interface", *J. Appl. Phys*., Vol. 96, No. 6, pp. 3334-3338, 2004.

[180] S.A. Harrison, G. Hwang and T.F. Edgar. "Interactions between Interstitials and Arsenic Vacancy Complexes in Crystalline Silicon", *Applied Physics Letters*, Vol. 85(21), pp. 4935-4937, 2004.

[181] T.F. Edgar, "Computing Practices of New Engineers", *Control Engineering*, p. 81, June, 2004.

[182] T.F. Edgar, "Controllability and Profitability", *Control Engineering*, p. 59, November, 2004.

[183] A.J. Pasadyn, A.J. and T.F. Edgar. "Observability and State Estimation for Multiple Product Control in Semiconductor Manufacturing", *IEEE Transactions on Semiconductor Manufacturing,* Vol. 18(4), pp. 592-604, 2005.

[184] J.D. Hedengren and T.F. Edgar. "In Situ Adaptive Tabulation for Real-time Control", *IEC Research*, Vol. 44, pp. 2716-2724, 2005.

[185] J.T. Lee and T.F. Edgar. "Static Decouplers for Control of Multivariable Processes", *AIChE J.*, Vol. 51(10), pp. 2712-2720, 2005.

[186] J.D. Hedengren and T.F. Edgar. "Order Reduction of Large Scale DAE Models", *Computers Chem. Engr.*, Vol. 29, pp. 2069-2077, 2005.

[187] S.A. Harrison, T.F. Edgar and G.S. Hwang. "Structure, Stability, and Diffusion of Arsenic-Silicon Interstitial Pairs", *Applied Physics Letters*, Vol. 87(23), pp. 231905-1-3, 2005.

[188] J.T. Lee and T.F. Edgar. "Continuation Method for the Modified Ziegler-Nichols Tuning of Multiloop Control Systems", *IEC Research*, Vol. 44, pp. 7428-7434, 2005.

[189] S.A. Harrison, T.F. Edgar and G.S. Hwang. "Structure and Diffusion of the Diarsenic Complex in Crystalline Silicon" *Phys. Rev. B*, Vol. 72(19), pp. 195414-1-5, 2005.

[190] T.F. Edgar, "Take a Systems Approach", *Control Engineering* , p. 16, May, 2005.

[191] T.F. Edgar, "Lab Courses Go Virtual", *Control Engineering*, p.22, December, 2005.

[192] S. Firth, A. Toprac, J. Campbell and T.F. Edgar. "Just-in-Time Adaptive Disturbance Estimation, *IEEE Trans. Semiconductor Manufacturing*, Vol. 19(3), pp. 298-315, 2006.

[193] J. Lee and T.F. Edgar. "Multiloop PI/PID Control System Improvement via Adjusting the Dominant Poleor the Peak Amplitude Ratio", *Chem. Engr. Science*, Vol. 61, No. 5, pp.1658-1666, 2006.

[194] T.F. Edgar. "Enhancing the Undergraduate Computing Experience", *Chem. Engr. Educ.*, Vol. 38, p.231-238, 2006.

[195] W. Cho, J. Lee and T.F. Edgar. "Closed-loop Identification of Wafer Temperature Dynamics in a Rapid Thermal Process", *Korean J. Chem Engr.*, Vol. 23, pp.171-175, 2006.

[196] T.F. Edgar, "Process Control: What to Teach?", *Control Engineering*, p.26, May, 2006.

[197] L. Rueda, R.B. Eldridge, and T.F. Edgar. "A Novel Control Methodology for a Pilot Plant Azeotropic Distillation Column", *Ind. Eng. Chem. Res.*, Vol. 45, pp. 8361-8372, 2006.

[198] T.F. Edgar, B.A. Ogunnaike and K.R. Muske. "A Global View of Graduate Process Control Education", *Comp & Chem. Engr.* Vol. 30, No. 10-12, pp. 1763-1774, 2006.

[199] T.F. Edgar, B.A. Ogunnaike, K.R. Muske, J.J. Downs and B.W. Bequette. "Renovating the Undergraduate Process Control Course", *Comp & Chem. Engr.* Vol. 30, No. 10-12, pp. 1749-1762, 2006.

[200] D. Castiñeira and T.F. Edgar. "CFD for Simulation of Steam Addition and Air Addition on Flare Combustion Systems," *Energy and Fuels*, Vol. 20, pp. 1044-1056, 2006.

[201] S.A. Harrison, T.F. Edgar and G.S. Hwang. "Interstitial Mediated Arsenic Clustering in Ultrashallow Junction Formation", *Electrochem. Solid-State Lett.*, 9(12), G354-G357, 2006.

[202] S.A. Harrison, T.F. Edgar and G.S. Hwang. "Prediction of Anomalous Fluorine-Silicon Interstitial Pair Diffusion in Crystalline Si", *Phys. Rev. B-rapid communication* 74(12), 121201, 2006.

[203] S.A. Harrison, T.F. Edgar and G.S. Hwang. "Interstitial-Mediated Mechanisms of Arsenic and Phosphorus Diffusion in Silicon," *Phys. Rev. B74*(19), 195202, 2006.

[204] D. Castiñeira, Morales, D. M. and T.F. Edgar. "Multivariate Image Analysis for Flare Control", submitted to *Industrial & Engineering Chemistry Research*, July, 2006.

[205] Y. Chen, V. Manousiouthakis and T.F. Edgar. "Globally Optimal Nonlinear Feedback: Application to Nonisothermal CSTR Control", *Chemical Engineering Communications*, Vol. 193(2), pp. 233-245, 2006.

[206] V. Martinez and T.F. Edgar. "Control of Lithography in Semiconductor Manufacturing",*IEEE Control Systems Magazine*, Vol. 26(6) pp. 46-55, 2006.

[207] T.F. Edgar. "Fundamental Models and Process Control", *Control Engineering*, p.36, November, 2006.

[208] T.F. Edgar. "Student to Engineer, Should the Teaching of Process Control be Changed?", *Intech*, Vol. 53(9), pp. 30-36, September, 2006,

[209] M.K. Markey, A.Holmes Jr., T.F. Edgar, and K.J. Schmidt. "Student-driven Learning in Integrated Lecture-lab Classroom Environments: The Role of Mobile Computing, *Intl. Journal of Engr. Educ.*, Vol. 23(3), pp. 483-490, 2007.

[210] S.A. Harrison, T.F. Edgar and G.S. Hwang, "Prediction of B-Si_i-F Complex Formation and Its Role in B Transient Enhanced Diffusion Suppression and Deactivation", " *J. Appl. Phys.*, Vol. 101(6), 066102, 2007.

[211] A.J. Pasadyn, H.J. Lee, and T.F. Edgar. "Scheduling Semiconductor Manufacturing Processes for Simultaneous Control and Identification", accepted, *J. Process Control,* 2007.

[212] J. Lee, S.W. Sung, and T.F. Edgar. "Integrals of Relay Feedback Responses for Extracting Process Information", *AIChE J.* Vol. 53, No. 9, pp. 2329-2338, 2007.

[213] T.F. Edgar. "A Course on Energy Technology and Policy, *Chemical Engineering Education,* Vol. 41(3), pp.195-201, 2007.

[214] T. G. Farmer Jr., T. F. Edgar, and N. A. Peppas, "The Future of Open and Closed Loop Insulin Delivery for Diabetes Mellitus," *J. Pharm. Pharmacol.*, No. 60, pp. 1-13, 2008.

[215] T. G. Farmer Jr., T. F. Edgar, and N. A. Peppas, "Parameter Set Uniqueness and Confidence Limits in Model Identification of Insulin Transport Models from Simulation Data," *Diabetes Technology and Therapeutics*, Vol. 10(2) pp 128-131, 2008.

[216] T. G. Farmer Jr., T. F. Edgar, and N. A. Peppas, "Physiologically-Based Modeling of Glucoregulatory System," submitted, *Ann. Biomed. Eng.*, 2007.

[217] T. G. Farmer Jr., T. F. Edgar, and N. A. Peppas, "Effects of Model Selection on Intravenous Infusion Algorithms for Glucose Control in Diabetic Patients," submitted, *Ind. Eng. Chem. Res.*, 2007.

[218] T. G. Farmer Jr., T. F. Edgar, and N. A. Peppas, "In Vivo Simulations of pH-Responsive Cationic Hydrogels in Diabetic Patients," submitted, *Pharm. Res.*, 2007.

[219] T.F. Edgar, "Performance Monitoring and Tuning Controllers", *Control Engineering*, p. 32, May, 2007.

[220] C.A. Bode, J. Wang, Q.P. He, and T.F. Edgar. "Run-to-Run Control and State Estimation in High-Mix Semiconductor Manufacturing", *Annual Reviews in Control*, 31, pp. 241-253, 2007.

[221] A. Prabhu and T.F. Edgar, "Performance Assessment of Run-to-Run EWMA Controllers", *IEEE Trans. Semiconductor Mfg.*, 20(4), 381-385, 2007.

[222] J. Lee, W. Sung, C.H. Je, and T.F. Edgar, "Multiple Switching Relay for Identification of Frequency Responses" submitted to *AIChE J.*, October, 2007.

[223] W. Cho, J. Lee, and T.F. Edgar, "Nonlinear Model Identification for Temperature Control in a Single Wafer Rapid Thermal Processing", submitted to *Ind. Engr. Chem. Res.*, October, 2007.

[224] Y. Zhang, and T.F. Edgar, "Generalized Model Based Design of Experiments (DOE) Criteria for DAE System Parameter Estimation", accepted by *Ind. Engr. Chem. Res.*, 2007.

[225] J. Lee, and T.F. Edgar, "A Simple Graphical Method for Pulse Test", submitted to *AIChE Journal*, January, 2008.

[226] J. Wang, P. He and T.F. Edgar, "State Estimation in High-Mix Semiconductor Manufacturing", accepted by *J. Process Control,* April, 2008.

[227] T. G. Farmer Jr., T. F. Edgar, and N. A. Peppas, "In Vivo Simulations of the Intravenous Dynamics of Submicron Particles of pH-Responsive Cationic Hydrogels in Diabetic Patients", submitted *Ind. & Engr. Chem. Res.*, May, 2008.

[228] A. Prabhu, and T.F. Edgar, "Identification and Monitoring of PID-Controlled Nonlinear Processes", submitted *Journal of Process Control*, 2008.

[229] A. Prabhu, and T.F. Edgar, "New State Estimation Methods for High-mix Semiconductor Manufacturing Processes", *submitted Journal of Process Control,* 2008.

[230] A. Prabhu, and R.P. Good, and T.F. Edgar, "Missing Data Estimation for Run-to-Run EWMA Controlled Processes", submitted to *Comp. & Chem. Engr.*, 2008.

[231] T. G. Farmer Jr., T. F. Edgar, and N. A. Peppas. "Pharmacokinetic Modeling of the Glucoregulatory System," submitted, *J. Drug Delivery Sci. Tech.,* July, 2008.

[232] T.G. Farmer Jr., T.F. Edgar and N.A. Peppas. "Effectiveness of Intravenous Infusion Algorithmsfor Glucose Control in Diabetic Patients Using Different Simulation Models," submitted *Ind. Eng. Chem. Res.*, 2008.

[233] W. Cho, J.T. Lee and T.F. Edgar. "Iterative Learning Dual-Model Control of Exothermic Batch Reactors", *Control Engineering Practice*, Vol. 16, pp. 1244-1249, 2008.

[234] J. Hedengren and T.F. Edgar. "Approximate Nonlinear Model Predictive Control with In Situ Adaptive Tabulation", *Computers and Chemical Engineering,* 32, pp. 706-714, 2008.

[235] J. Davis and T.F. Edgar. "Smart Process Manufacturing: A Vision of the Future", *Ind. Eng. Chem. Research*, Commemorative Essay (web), April, 2008.

[236] Y. Zhang and T.F. Edgar. "On-line Batch Process Monitoring using EWMA Combined with Hybrid-wise Unfolding Multiway PCA", submitted to *Ind. Eng. Chem. Res.*, July, 2008.

[237] Y. Zhang and T.F. Edgar. "A Robust Derivative Dynamic Time Warping Algorithm for Batch Process Synchronization", submitted to *Computers and Chemical Engineering,* July, 2008

[238] D. Castiñeira and T.F. Edgar. "CFD for Simulation of Crosswind on the Efficiency of High Momentum Jet Turbulent Combustion Flames", *Journal of Environmental Engineering,* Vol. 134, No. 7, pp. 561-571, 2008.

[239] D. Castiñeira and T.F. Edgar. "CFD for Simulation of Wind-tunnel experiments on Flare Combustion Systems", *Energy and Fuels,* Vol. 22, pp. 1698-1707, 2008.

[240] W. Cho, J. Lee, and T.F. Edgar, "Iterative Identification of Temperature Dynamics in Single Wafer Rapid Thermal Processing", accepted, *Korean J. Chem. Engr.*, August, 2008.

[241] Y. Zhang and T.F. Edgar. "PCA Combined Model-Based Design of Experiments (DOE) Criteria for Differential and Algebraic System Parameter Estimation", *Ind. Eng. Chem. Res.* ________, 2008.

B. PUBLICATIONS -- Proceedings

[1] J.B. Riggs and T.F. Edgar. Simplification of Large-Scale Linear Dynamic Systems. *Proc. Joint Auto. Cont. Conf.*, p. 497, 1973.

[2] J. Schwartz and T.F. Edgar. The Development of Simplified Adaptive Control Models Using the Continued Fraction Expansion. *Proc. Joint Auto. Cont. Conf.*, p. 484, 1974.

[3] D.M. Himmelblau, P.A. Jensen, W.G. Lesso, and T.F. Edgar. Planning for the Optimal Expansion of Water Resource Systems. *Proc. Joint Auto. Cont. Conf.*, p. 560, 1974.

[4] D. Oakley and T.F. Edgar. Optimal Feedback Control of a Binary Distillation Column. *Proc. Joint Auto. Cont. Conf.*, p. 551, 1976.

[5] T.H. Tsang and T.F. Edgar. Chemical Reactor Modeling of In Situ Coal Gasification. *Proc. Second UCG Symp.*, p. 256, 1976.

[6] W.R. Kaiser, T.W. Thompson, and T.F. Edgar. Research on In Situ Gasification of Texas Lignite at the University of Texas. *Proc. Second UCG Symp.*, p. 90, 1976.

[7] M.J. Humenick, W.R. Kaiser, and T.F. Edgar. Technical and Environmental Factors in Underground Coal Gasification. *Proc. ANS Topical Meeting*, p. 20, 1977.

[8] T.H. Tsang, C.M. Johnson, and T.F. Edgar. Prediction of Product Composition and Sweep Efficiency in Underground Coal Gasification. *Proc. Third UCC Symp.*, p. 211, 1977.

[9] S.J. Hsia and T.F. Edgar. Oxidation Kinetics of Texas Lignite. *Proc. Third UCC Symp.*, p. 211, 1977.

[10] J. Branch, P.S. Schmidt, and T.F. Edgar. Performance of Gas Turbines and Combined Cycles Operating on Fuels Produced by In Situ Gasification of Lignite. *Proc. 12th Intersociety Energy Conversion Conf.*, p. 232, 1977.

[11] L.S. Tung and T.F. Edgar. Dynamic Interaction Analysis and its Application to Distillation Column Control. *Proc. IEEE CDC Conf.*, p. 1107, 1977.

[12] V. Krishnamoorthy and T.F. Edgar. Identification and Estimation of Discrete Models for a Distillation Column. *Proc. Joint Auto. Cont. Conf.*, p. 1370, 1977.

[13] C.O. Schwanke and T.F. Edgar. A Review of the Application of Modern Control Theory to Distillation Columns. *Proc. Joint Auto. Cont. Conf.*, p. 1370, 1977.

[14] T.F. Edgar. The Potential of In Situ Gasification for Texas Lignite. *Proc. Gulf Coast Lignite Conf.*, p. 131, 1978.

[15] S.J. Hsia, T. Wellborn, and T.F. Edgar. Measurement of Combustion Rates of Texas Lignite with Application to Underground Coal Gasification. *Proc. Fourth UCC Symp.*, p. 193, 1978.

[16] R.A. Chapman and T.F. Edgar. Assessment of the Cost and Performance of Particulate Control Devices on Low Sulfur Western Coals. *Symp. on Transfer and Utilization of Particulate Control Tech.*, 1978.

[17] T.F. Edgar. Production of Medium Btu Gas by In Situ Gasification of Texas Lignite. *Proc. Industrial Energy Conservation Conf.*, p. 11, 1979.

[18] L.S. Tung and T.F. Edgar. Least Squares Model Reduction of Multiple Input Multiple Output Linear Systems. *Proc. Joint Auto. Cont. Conf.*, p. 199, 1979.

[19] J.B. Riggs, C.M. Johnson, and T.F. Edgar. Development of a Three Dimensional Simulator for Cavity Growth During Underground Coal Gasification. *Proc. Fifth UCC Symp.*, p. 245, 1979.

[20] T.F. Edgar. A Simple Correlating Function for Analysis of ESP Performance in Coal-Fired Power Plants. *Proc. APCA*, Houston, TX, 1978.

[21] E. Vogel and T.F. Edgar. An Adaptive Dead Time Compensator for Process Control. *Proc. Joint Auto. Cont. Conf.*, p. TP5E1, 1980.

[22] R. Natarajan, G.J. Savins, and T.F. Edgar. Prediction of Product Gas Composition for UCG. *Proc. Sixth UCC Symp.*, III-15, 1980.

[23] W.C. Hunt, S.M. Matteson, J.A. Cadwell, T.H. Tsang, and T.F. Edgar. Pyrolysis Properties of Texas Lignite Under Conditions of In Situ Gasification. *Proc. Sixth UCC Symp.*, IV-9, 1980.

[24] S. Berg and T.F. Edgar. Stability of Digital Control Algorithms Subject to Model Errors. *Proc. Joint Auto. Cont. Conf.*, TA5C1, 1980.

[25] T.F. Edgar. Automatic Control Opportunities in Industry Energy Utilization. *Proc. Joint Auto. Cont. Conf.*, WP7C1, 1980.

[26] E. Vogel and T.F. Edgar. A New Dead Time Compensator for Process Control. *Proc. ISA'80 Conf.*, Houston, October 1980.

[27] H. P. Tseng, T. A. Wellborn, and T.F. Edgar. Combustion Properties of Texas Lignite. *Proc. UCC Symp.*, Conf-810923, p. 306, 1981.

[28] N. A. Massey, B. H. Glatzer, and T.F. Edgar. Estimated Costs of Methanol, Hydrogen, and Syngas from In Situ Coal Gasification of Texas Lignite. *Proc. UCC Symp.*, Conf-810923, p. 397, 1981.

[29] P.G. Christman and T.F. Edgar. Analysis of Sulfur Retention in Fluidized Bed Combustion. *Proc. Lignite Symp.*, Conf 810658, p. 606, 1981.

[30] E.F. Vogel and T.F. Edgar. Some Recent Developments in Digital Control Algorithms. *Proc. Joint AIChE CIESC Meeting, Chemical Industry Press*, Beijing, China, p. 913, 1982.

[31] J.P. Gerry, E.F. Vogel, and T.F. Edgar. Adaptive Control of a Pilot Scale Distillation Column. *Proc. Amer. Cont. Conf.*, p. 819, 1983.

[32] W. Min and T.F. Edgar. Combustion Tube Studies on the Influence of Water Influx on Steam-Oxygen Gasification of Lignite. *Proc. Ninth UCC*, p. 340, 1983.

[33] L.S. Tung and T.F. Edgar. A Study of Pole Placement in Linear Control Systems. *Proc. Amer. Cont. Conf.*, p. 518, 1984.

[34] M.P. Wellons and T.F. Edgar. A Generalized Analytical Predictor for Process Control. *Proc. Amer. Cont. Conf.*, p. 637, 1985.

[35] P.D. Pavlechko and T.F. Edgar. Pole Placement Adaptive Control of Processes Described by Discrete Convolution Models. *Proc. Amer. Cont. Conf.*, 1984.

[36] D. Little and T.F. Edgar. Predictive Control Using Constrained Optimal Control. *Proc. Amer. Cont. Conf.*, p. 1365, 1986.

[37] R.W. Horton B.W. Bequette and T.F. Edgar. Developments in Compartmental Modeling in Distillation. *Proc. Amer. Cont. Conf.*, p. 651, 1986.

[38] P.D. Pavlechko, M.C. Wellons, and T.F. Edgar. An Approach for Adaptive-Predictive Control. *Proc. IFAC Conf. on Adaptive Control of Chemical Processes* (Frankfurt/ Germany), p. 37, 1985.

[39] T.F. Edgar. A Survey of Advanced Digital Control Algorithms and Their Applications. *Proc. Cont. Engr. Conf.*, p. 345, 1986.

[30] T.F. Edgar. Computing in Chemical Engineering Education. I.*Chem. E. Symp. Ser.*, 101:173, 1987.

[31] B.W. Bequette, R.R. Horton, and T.F. Edgar. Resilient and Robust Control for Energy-Integrated Distillation Columns. *Proc. Amer. Cont. Conf.*, p. 1027, 1987.

[32] P.D. Pavlechko and T.F. Edgar. Multivariable Adaptive Control with the Generalized Analytical Predictor. *Proc. IFAC Workshop on Robust Adaptive Control*, p. 108, 1988.

[33] T.F. Edgar. Process Control Education: Past, Present, Future. *Proc. U.S.India A Seminar on Chem. Engr. Edu.*, p. 117, 1988.

[34] D.T. Dalle Molle, B.J. Kuipers, and T.F. Edgar. Qualitative Modeling of Physical Systems. *Proc. PSE'88*, p. 169, 1988.

[35] J. Eaton, J. Rawlings, and T.F. Edgar. Model-Predictive Control and Sensitivity Analysis for Constrained Nonlinear Processes. *Proc. IFAC Workshop on Model-Based Control*, p. 129, 1990.

[36] A. Patwardhan, J. B. Rawlings, and T.F. Edgar. Model Prodictive Control of Nonlinear Processes in the Presence of Constraints. *Proc. IFAC Symp. on Nonlinear Control Systems Design* (A. Isidori, Ed.), p. 456, 1989.

[37] J.R. Bosley and T.F. Edgar. Effect of Model Simplifications on the Optimal Solution of Batch Distillation Control Policy. *Proc. Amer. Cont. Conf.*, p. 120, 1989.

[38] G.T. Wright and T.F. Edgar. Adaptive Control of a Laboratory Water-Gas Shift Reactor with Dynamic Inlet Conditions. *Proc. Amer. Cont. Conf.*, p. 1828, 1989.

[39] D.T. Dalle Molle and T.F. Edgar. Qualitative Simulation for Process Modeling and Control. *Proc. Amer. Cont. Conf.*, p. 1360, 1989.

[40] K.J. Allred, I. Trachtenberg, and T.F. Edgar. Modeling, Optimization and Control of the Selective Plasma Etching of Silicon over Silicon Dioxide. *Proc. Amer. Cont. Conf.*, p. 101, 1990.

[41] J.R. Bosley A.A. Patwardhan, G.T. Wright, and T.F. Edgar. Model-Based Control: A Survey. *Proc. ADCHEM'91 Conf.*, p. 139, 1991.

[42] D. Dvorak, B.J. Kuipers, D.T. Dalle Molle, and T.F. Edgar. Qualitative Simulation for Expert Systems. *Proc. IFAC Congress.*, 7:204, 1990.

[43] K.J. McLaughlin, I. Trachtenberg, and T.F. Edgar. Development of Techniques for Real-Time Monitoring and Control in Plasma Etching. *Proc. Amer. Cont. Conf.*, p. 110, 1990.

[44] T.A. Badgwell, I. Trachtenberg, J.K. Elliott, and T.F. Edgar. Development of an Improved Fundamental Model for the Multiwafer LPCVD Reactor. *Proc. Amer. Cont. Conf.*, p. 2858, 1991.

[45] A.A. Patwardhan and T.F. Edgar. Nonlinear Model-Predictive Control of a Packed Distillation Column. *Proc. Amer. Cont. Conf.*, p. 767, 1991.

[46] G.T. Wright and T.F. Edgar. Adaptive Nonlinear Control of a Laboratory Water Gas Shift Reactor. *Proc. ITAC'91 Conf.*, Preprints, Session 2, 1991.

[47] G.T. Wright, T. Breedijk, and T.F. Edgar. On-Line Parameter Estimation and Adaptation in Nonlinear Model-Based Control. *Proc. Amer. Cont. Conf.*, p. 2782, 1991.

[48] C. Ling and T.F. Edgar. A New Fuzzy Gain Scheduling Algorithm for Process Control. *Proc. Amer. Cont. Conf.*, p. 2228, 1992.

[49] J.R. Bosley and T.F. Edgar. Application of Nonlinear Model Predictive Control to Optimal Batch Distillation. *Proc. DYCORD'92 Conf.*, p. 271, 1992.

[50] T.A. Badgwell, S.G. Bushman, A. Toprac, and T.F. Edgar. Modeling and Control of Microelectronics Materials Processing. *Proc. DYCORD'92 Conf.*, p. 243, 1992.

[51] C. Ling and T.F. Edgar. The Tuning of MIMO Fuzzy Heuristic Controllers. *Proc. IFAC Congress*, Volume 6, p. 67, 1993.

[52] T. Breedijk, I. Trachtenberg, and T.F. Edgar. A Model Predictive Controller In Multivariable Temperature Control in Rapid Thermal Processing. *Proc. Amer. Cont. Conf.*, p. 2980, 1993.

[53] S. Chatterjee, I. Trachtenberg, and T.F. Edgar. Modeling and Control of RTCVD of Polysilicon. *Proc. RTP'93 Conf.*, p. 386, 1993.

[54] G.D. Munkvold, K.G. Teague, J.J. Beaman, and T.F. Edgar. Prediction of Bed Pressure Profiles in OBOGS. *Proc. 30th Annual SAFE Conf.*, p. 58, 1993.

[55] H. Ouarti and T.F. Edgar. The Use of Approximate Models and Exact Linearization for Control of Nonlinear Processes. *Proc. Amer. Cont. Conf.*, p. 2268, 1993.

[56] T.F. Edgar and Y.L. Huang. Simultaneous Recovery of Waste Chemicals and Energy in an Oil Refinery. *I&EC Special Symposium*, ACS, Atlanta, Georgia, September 1993.

[57] S. Bushman, T.F. Edgar, and I. Trachtenberg. Process Control and Diagnostics for Plasma Etch Systems. *Proc. Electrochem. Soc.*, 1994.

[58] K.F. McBrayer and T.F. Edgar. Bias Detection and Estimation in Dynamic Data Reconciliation. *Proc. ADCHEM'94 Conf.*, p. 531, 1994.

[59] T. Breedijk and T.F. Edgar. Parameter Estimation and Nonlinear Predictive Control for RTP. *Proc. ADCHEM'94 Conf.*, p. 85, 1994.

[60] J.R. Bosley and T.F. Edgar. Appropriate Modeling Assumptions for Batch Distillation Optimization and Control. *Proc. PSE'94 Conf.*, p. 477, 1994.

[61] W. Cho, K.S. Balakrishnan, T. F. Edgar, and I. Trachtenberg. Control of Remote Plasma-Enhanced Chemical Vapor Deposition of Silicon Nitride. *Proc. PSE'94 Conf.*, p. 1235, 1994.

[62] T. Breedijk and T.F. Edgar. Model-Based Control of Rapid Thermal Processes. *Proc. Amer. Cont. Conf.*, p. 887, 1994.

[63] C. Ling and T.F. Edgar. The Experimental Verification of the Model-Based Fuzzy Gain Scheduling Technique. *Proc. Amer. Cont. Conf.*, p. 2475, 1994.

[64] T. Breedijk and T.F. Edgar. Overview of Process Control Issues in Rapid Thermal Processing. *Proc. RTP'94 Conf.*, p. 267, Monterrey, CA, 1994.

[65] K.S. Balakrishnan, W. Cho, and T.F. Edgar. Comparison of Controller Tuning Methods for Temperature Uniformity Control in a Rapid Thermal Processor. *Proc. SPIE'94 Conf.*, volume 2336, p. 71, October 1994.

[66] S. Bushman and T.F. Edgar. Radio Frequency Diagnostics for Plasma Etch Systems. *Proc. SPIE'94 Conf.*, volume 2336, p. 5, October 1994.

[67] J. Stuber, I. Trachtenberg, and T.F. Edgar. Model-Based Control of Rapid Thermal Processes. *Proc. IEEE CDC'94 Conf.*, volume 1, pp. 79-85, December,1994.

[68] D. Sourlas, T.F. Edgar, and V. Manousiouthakis. Best Achievable Low Order Dentralized Performance. *Proc. Amer. Cont. Conf.*, p. 3364, 1994.

[69] T.F. Edgar and J. Kantor. Computing Skills in the Chemical Engineering Curriculum. *Proc. Chemputers Conf.*, p. 87, February, 1995.

[70] J.D. Stuber, T. Breedijk, and T.F. Edgar. Model-Based Control of Rapid Thermal Processes. *Proc. Electrochem. Soc.*, p. 113, 1995.

[71] S. Bushman, T.W. Karjala, D.M. Himmelblau, I. Trachtenberg, and T.F. Edgar. Modeling of Plasma Etch Dynamics Using Linear and Nonlinear Models. *Proc. Electrochem. Soc.*, p. 218, 1995.

[72] K. Edwards and T.F. Edgar. General Methods of Kinetic Model Reduction. *Proc. DYCORD*, p. 63, 1995

[73] R. Dunia, Joe Qin, and T.F. Edgar. Multivariable Process Monitoring Using Nonlinear PLS Approach. *Proc. Amer. Cont. Conf.*, Seattle, WA p. 756-760, 1995.

[74] R. Dunia, T.F. Edgar, and Benito Fernandez. Application of the Sliding Surface to Generic Model Control. *Proc. Amer. Cont. Conf.*, p. 2210, 1995.

[75] R. Dunia, S.J. Qin, T.F. Edgar and T.J. McAvoy. Sensor Fault Identification and Reconstruction Using Principal Component Analysis. *IFAC Congress '96*. San Francisco, CA. pp. 259-264, July 1996.

[76] K.S. Balakrishnan, T.L. Cooper, and T.F. Edgar. Model-based Control of a Rapid Thermal Processor. *RTP '96 Symposium*, Boise, ID, September 1996.

[77] J. Stuber, I. Trachtenberg and T.F. Edgar. Optical Temperature Management in RTP by Frequency Analysis of Periodic Light Signals. *RTP '96 Symposium*, Boise, ID, September 1996.

[78] Y. Cheng, S.J. Qin and T.F. Edgar. Monitoring of Batch Processes in Semiconductor Manufacturing Using PCA. *ADCHEM '97*, June, 1997.

[79] R. Dunia, S.J. Qin, and T.F. Edgar. A Unified Approach to Process and Sensor Fault Identification Using PCA. *US/China Joint Chemical Engineering Conference*, Beijing, May 19-22, 1997.

[80] Y. Cheng, Q. Wang, T. Riley, M. Miller, and T.F. Edgar. Monitoring of a RTP Process Using Multi-PCA. *Sixth Internatonal Symposium on Semiconductor Manufacturing*, San Francisco, October 6-8, 1997.

[81] Y. Cheng, J. Qin, and T.F. Edgar. Modeling of OES Data to Estimate Etch Rate for Etching Equipment. *SPIE 1997 Symposium on Microelectronic Manufacturing*, Austin, Vol. 3213, pp. 108-118, October 1997.

[82] B. Ko and T.F. Edgar. Assessment of Achievable PI Control Performance for Linear Processes with Dead Time. *Proc. Amer. Cont. Conf.*, pp. 1548-1552, June, 1998.

[83] T.F. Edgar. Process Modeling and Control: A Vision of the Future. *US/China Joint Chemical Engineering Conference*, Beijing, May 19-22, 1997.

[84] T.F. Edgar. Process Modeling and Control: A Vision of the Future. *Advances in Control 5*, Swansea, Wales, September, 1998.

[85] C. Pfeiffer and T.F. Edgar. Robust Feedback Linearization and Fuzzy Control. Proceedings of *Amer. Cont. Conf.* San Diego, CA, pp. 1508-1514, 1999.

[86] B.S. Ko, and T.F. Edgar. Multiloop PID Control Performance Monitoring. Submitted to *The 8th Congress of Aston Pacific Confederation of Chemical Engineering (APCCHE)*, Seoul, Korea, August, 1999.

[87] W.J. Campbell, C. Bode, and T.F. Edgar. Model-based Control In Microelectronics Manufacturing. *The 38th IEEE Conference on Decision and Control*, Phoenix, AZ, p. 4185-4192, 1999

[88] D.A. Dixon, G.V. Reklaitis and T.F. Edgar. Vision 2020: Computational Needs of the Chemical Industry, *Impact of Advances in Computing and Communications Technologies on Chemical Science and Technology*, National Academy Press, 1999.

[89] T.F. Edgar. Process Engineering in the 21st Century: The Impact of Information Technology. Phillips Petroleum Lecture: Oklahoma State University, 1999.

[90] T.F. Edgar. Information Technology and Chemical Engineering Education: Evolution or Revolution? Second Chemical Engineering Academy Lecture: University of Missouri-Rolla, April, 1999.

[91] B.S. Ko, and T.F. Edgar. Performance Assessment of Multivariable Feedback Control Systems Using Plant Markov Parameters. *Proc. Amer. Control Conf.*, p. 4373-4377, 2000.

[92] T.A. Soderstrom and T.F. Edgar. A Mixed Integer Optimization Approach for Simultaneous Data Reconciliation and Identification of Measurement Bias. *ADCHEM 2000*, Pisa, Italy, 2000.

[93] T.F. Edgar. Information Technology and Chemical Engineering Education: Evolution or Revolution? *ASEE 2000*, St. Louis, 2000.

[94] T.F. Edgar. Chemical Engineering Education and the Three C's: Computing, Communication, and Collaboration. Presented at Annual *AIChE* Meeting, Los Angeles, November, 2000.

[95] C.A. Bode, A.J. Toprac, R.D. Edwards, and T.F. Edgar. Lithography Overlay Controller Formulation. *SPIE Meeting,* Fall 2000.

[96] A.J. Pasadyn, A.J. Toprac, and T.F. Edgar. Adaptive Control of Multiple Product Processes, *SPIE Meeting*, Fall 2000.

[97] J. Hahn and T.F. Edgar. Reduction of Nonlinear Models Using Balancing of Empirical Gramians and Galerkin Projections. *Proc. Amer. Control Conf.,* p.2864-2868, 2000.

[98] J. Pasadyn, A.J. Toprac, and T.F. Edgar. Online Parameter Estimation for Simultaneous Control of Multiple Products and Processes *AEC/APC Symposium XII*, pp. 319-328, Lake Tahoe, CA, September, 2000.

[99] J. Wood, T.F. Edgar et al. Deploying Computer-aided Cross-Training of Technicians and Engineers for Semiconductor Manufacturing. *Proc. of Amer. Soc. of Engr. Educ. Meeting,* Albuquerque, NM, 2001.

[100] V. Martinez, K.F. McBrayer and T.F. Edgar. Referential Lot to Lot Control of Photolithography Overlay Process, *Proc. AEC/APC*, Banff, Alberta, CA, October, 2001.

[101] M. Miller, W.J. Campbell, S. Firth and T.F. Edgar. Defining a Benchmark Suite for Comparison of Run-to-Run Controllers, *Proc. AEC/APC,* Banff, Alberta, CA, October, 2001.

[102] J. Hahn and T.F. Edgar. Nonlinearity Quantification and Model Classification using Gramians and other Variance Matrices. *Proc. AIChE 2001 Annual Meeting*, Reno, NV, November 2001.

[103] B.S. Ko and T.F. Edgar. Performance Assessment of Multivariable Feedback Control Systems. *Automatica,* 37, pp. 899-905, 2001.

[104] S. Alici and T.F. Edgar. Use of Model Reduction and Identification Tools for Dynamic Data Reconciliation, *Proc. of 15th IFAC World Congress*, pp. 1491-1495, Barcelona, Spain, 2002.

[105] S.K. Firth, W.J. Campbell and T.F. Edgar. Just in time Adaptive Disturbance Estimation for Run-to-Run Control of Photolithography Overlay, *SPIE Meeting*, Santa Clara, CA, 2002.

[106] J.T. Lee and T.F. Edgar. Interaction Measure for Decentralized Multivariable Control of Multivariable Processes, *Proc. Amer. Cont. Conf.*, pp, 454-459, 2002.

[107] J. Wood, T.F. Edgar, et al., "Closing the Loop on Cross-Training Technicians and Engineers for Semiconductor Manufacturing," *2002 ATESM Convention, MATEC*, Tempe, AZ, 2002.

[108] C. Bode, T.F. Edgar and B.S. Ko. Run-to-Run Control and Performance Monitoring of Overlay in Semiconductor Manufacturing. *15th IFAC World Congress*, pp. 1480-1484, Barcelona, Spain, 2002.

[109] J. Hahn, U. Krueger, T.F. Edgar and W. Marquardt. "Application of Model Reduction for Model Predictive Control", *15th IFAC World Congress*, pp. 684-688, Barcelona, Spain, 2002.

[110] J. Campbell, S. Firth, A. Toprac and T.F. Edgar. "A Comparison of Run-to-Run Control Algorithms", *Proc. Amer. Contr.Conf.*, pp. 2150-2155, 2002.

[111] T.F. Edgar. "Integrating Instructional Technology in the Classroom," *ASEE Chemical Engineering Summer School*, Boulder, CO, July, 2002 (on CD).

[112] T.F. Edgar. "Teaching Process Control", *ASEE Chemical Engineering Summer School*, Boulder, CO, July, 2002 (on CD).

[113] T.F. Edgar. "A Batch Process Control Framework for Semiconductor Manufacturing", Aspenworld, Washington DC, October 2002.

[114] V. Martinez, K.F. McBrayer and T.F. Edgar. "Adaptive Estimation and Control of Overlay Tool Bias, *AEC/APC XII Symposium*, Snowbird, UT, September, 2002.

[115] T.A. Soderstrom, D.M. Himmelblau and T.F. Edgar. A Mixed Integer Nonlinear Optimization Based Approach to Simultaneous Data Reconciliation and Bias Identification, *FOCAPO 2003*, Boca Raton, FL., January, 2003.

[116] S. Harrison, M. Braun, and T.F. Edgar. An Evaluation of the Effects of Product Mix and Metrology Delay on the Performance of Segregated Versus Threaded EWMA Control, *AEC/APC Conference*, 2003.

[117] V. Martinez, K.F. McBrayer and T.F. Edgar. On-line Adaptive Estimation and Control of Overlay Tool Bias, *SPIE Advanced Microelectronic Manufacturing*, Santa Clara, CA, February, 2003.

[118] Y. Chen, V. Manousiouthakis and T.F. Edgar, "On Infinite Time Nonlinear Quadratic Optical Control", *Proc. Conf. Decision and Control*, 2003.

[119] J.T. Lee and T.F. Edgar, "Upper Bounds of Structured Singular Values for Mixed Uncertainties", *Proc. Conf. Decision and Control,* 2003.

[120] R. Chong, K. Lensing, B. Swain and T.F. Edgar, "Optimizing STI Etch Process Control Using Optical Digital Profilometry", *Micromagazine.com*, June, 2004.

[121] J.D. Hedengren and T.F. Edgar, "In Situ Adaptive Tabulation for Real-time Control", *Proc. Amer. Cont. Conf.,* pp. 2222-2227, Boston, MA, 2004.

[122] J.B. Rawlings and T.F. Edgar, "Frontiers of Chemical Engineering: The Systems Approach", *DYCOPS Conf.,* paper no. 206, Boston, MA, 2004.

[123] J.D. Hedengren and T.F. Edgar, "Order Reduction of Large Scale DAE Models", *Texas A&M Symposium on Complex Processes,* 2004.

[124] T.F. Edgar, "Computing Through the Curriculum: An Integrated Approach for Engineering", *ASEE Annual Meeting*, Salt Lake City, UT, June, 2004.

[125] T.F. Edgar, "When Does Controllability Equal Profitability", *Process Systems Engineering Symposium*, Kunming, China, January, 2004.

[126] G. Farmer, T.F. Edgar and N.A. Peppas, "Modeling and Control of the Behavior of Glucose Sensing Devices", in *N.A. Peppas, K. Anseth, A.K. Dillow and C.E. Schmidt, eds., Advances in Biomaterials, Bionanotechnology, Biomimetic Systems and Tissue Engineering,* 231-234, AIChE, New York, NY, 2004.

[127] S.A. Harrison, T.F. Edgar, and G.S. Hwang, "Annihilation of Arsenic-Vacancy Complexes in Crystalline Silicon", *205th Electrochemical Society Conference*, San Antonio, TX, May, 2004.

[128] S.A. Harrison, T.F. Edgar, and G.S. Hwang, "Diffusion ofFluorine-Silicon Interstitial Complex in Crystalline Silicon," *Materials Research Society Spring Meeting*, San Francisco, CA, April 2005.

[129] S.A. Harrison, T.F. Edgar, and G.S. Hwang, "Role of Interstitials in As TED and Clustering in Crystalline Silicon," *Materials Research Society Spring Meeting*, San Francisco, CA, April, 2005.

[130] S.A. Harrison, T.A. Kirichenko, D. Yu, T.F. Edgar, S.K. Banerjee, and G.S. Hwang, "Origin of Vacancy and Interstitial Stabilization at the Amorphous-Crystalline Silicon Interface," *Materials Research Society Spring Meeting,* San Francisco, CA, April, 2005.

[131] T.F. Edgar, "Order Reduction of Large Scale DAE Models", *IFAC 16th World Congress,* Prague, Czechoslovakia, July, 2005.

[132] T.F. Edgar, B. Ogunnaike, J. Downs, B.W. Bequette and K.R. Muske, "Renovation of the Undergraduate Process Control Course", *Proceedings of Chemical Process Control VII (CPC7*), Lake Louise, Alberta, January, 2006.

[133] B. Ogunnaike, T.F. Edgar and K.R. Muske, "Graduate Process Control Education: A Global View", *Proceedings of Chemical Process Control VII (CPC7*), Lake Louise, Alberta, January, 2006.

[134] J. Hedengren, T.F. Edgar and J.B. Rawlings, "Moving Horizon Estimation – The Explicit Solution", *Proceedings of Chemical Process Control VII (CPC7*), Lake Louise, Alberta, January, 2006.

[135] L. Rueda and T.F. Edgar, "Experimental Validation of Model-Based Control Strategies for Multicomponent Azeotropic Distillation", *Proceedings of ADCHEM Symposium*, Gramado, Brazil, April, 2006.

[136] A. Prabhu, R. Chong, and T.F. Edgar, "Performance Assessment of Run-to-Run EWMA Controllers", *Proceedings of ADCHEM International Symposium on Advanced Control of Chemical Processes,* Gramado, Brazil, pp. 1127-1132, April 2-5, 2006.

[137] S.A. Harrison, T.F. Edgar, and G.S. Hwang, "Mechanisms for Interstitial-Mediated Transient Enhanced Diffusion of N-type Dopants in Crystalline Silicon", *Materials Research Society Spring Meeting*, San Francisco, CA, April, 2006.

[138] T.F. Edgar. "Chemical Process Control: Benchmarks, Technology Drivers, and Future Directions", The ConFab Meeting, Las Vegas, NV, May, 2006.

[139] A.V. Prabhu and T.F. Edgar. "A Novel Method for Performance Assessment of Run-to-Run EWMA Controllers", *AEC/APC Symposium XVIII*, Westminster, CO, October, 2006. Best Student Paper Award.

[140] Y. Zhang and T.F. Edgar. "Bio-reactor Monitoring with Multiway-PCA and Model based-PCA", *AIChE Meeting*, San Francisco, CA, 2006.

[141] Y. Zhang and T.F. Edgar. "On-line Batch Process Monitoring Using Modified Dynamic Batch PCA", *Proceedings of the 2007 ACC Conference*, pp. 2551-2556, New York City, NY, 2007.

[142] T.G. Farmer, N.A. Peppas, and T.F. Edgar. "Design of A Polymeric Insulin Infusion System for Blood Glucose Control", *Proceedings of the 2007 ACC Conference*, pp.607-612-New York City, NY, 2007.

[143] H. Lee, M. Funk and T.F. Edgar. "Advantages of Wafer-to-Wafer Feedback Control for High Volume Polysilicon Gate Etch Process Using Integrated Scatterometry", *AEC/APC XIX Symposium*, Indian Wells, CA, 2007.

[144] J. Wang, Q.P. He, and T.F. Edgar. "A General Framework for State Estimation in High-Mix Semiconductor Manufacturing', *Proceedings of the 2007 ACC Conference*, pp.3636-3641, New York City, NY, 2007.

[145] X. Liang, D.B.Weber, T.F. Edgar, L.W. Lake, M. Sayarpour, and A.A. Yousef. "Optimization of Oil Production in a Reservoir Based on Capacitance Model of Production and Injection Rates", *SPE 107713, SPE Hydrocarbon Economics and Evaluation Symposium*, Dallas, TX, 2007.

[146] W. Cho, J.T. Lee, and T.F. Edgar. "Nonlinear Model Identification for Temperature Control in a Single Wafer Rapid Thermal Processing", *AIChE Annual Meeting,* Salt Lake City, UT, November, 2007.

[147] Zhang, Y, and T.F. Edgar. "Generalized Model Based Design of Experiments (DOE) Criteria for DAE System Parameter Estimation", *AIChE Annual Meeting*, Salt Lake City, UT, November, 2007.

[148] J. Lee, C.H. Je, S.W. Sung, and T.F. Edgar. "Multiple Switching Relay for Identification of Frequency Responses", *17th IFAC World Congress, 2008.*

[149] A.V. Prabhu, T.F. Edgar, and R.P. Good. "Missing Data Estimation for Run-to-Run EWMA Controlled Processes, *Proceedings of the Foundations of Computer-Aided Process Operations (FOCAPO) Conference*, pp. 327-330, Cambridge, Massachusetts, June 2008.

[150] Y. Zhang, and T.F. Edgar. "A Robust Dynamic Time Warping Algorithm for BatchTrajectory Synchronization", *Proceedings of the 2008 ACC Conference,* pp. 2864-2869, Seattle, Washington, 2008.

[151] R. Dunia, T.F. Edgar, and F. Haugen. "A Complete Programming Framework for Process Control Education", *2008 IEEE Multi-Conference on Systems and Control*, 2008.

[152] H. Lee, et al., "Advanced Profile Control and the Impact of Sidewall Angle at Gate Etch for Critical Nodes", *SPIE,* San Jose, February, 2008.

[152] B.R. Parkinson, H.J. Lee, T.F. Edgar, D. Prager, and M. Funk. "Application of Multivariable Control Systems in Wafer-to-Wafer Control, *AEC/APC Symposium,* Salt Lake City, October 2008.

[153] K.H. Baek and T.F. Edgar. "Optimum Sensor Selection and Utilization Technique for Plasma Etching", *AEC/APC Symposium,* Salt Lake City, October 2008.

[154] M. Fowler and T.F. Edgar. "Control Precise Blending of Semiconductor Processing Solutions", *AEC/APC Symposium,* Salt Lake City, October 2008.

[155] J. Stuber, H. Lee and T.F. Edgar. "Dynamic Sampling in Automated Process Control", *AEC/APC Symposium,* Salt Lake City, October 2008.

[156] S.Z. Fashami, S. Cohen, G. T. Rochelle, T.F. Edgar, M. Webber. "Flexible Operation of Amine Scrubbing in Response to Electric Demand and Pricing", *GHG Symposium*, 2008.

[157] Y. Zhang and T.F. Edgar. "A Robust Derivative Dynamic Time Warping Algorithm for Batch Process Control", *Proceedings of the 2008 ACC Conference*, pp. 2864-2869, Seattle, WA 2008.

[158] T.F. Edgar. "Process Monitoring and Control of Plasma Etching", Vol. STS-2, pp. 65-77, *Semicon Korea*, Seoul, Korea, January 2008.

[159] T.F. Edgar. "Process Control: Batch to the Future", *Adconip Conference,* pp. 10-19, Jasper, Alberta, May, 2008.

[160] A.V. Prabhu, R.P. Good and T.F. Edgar. "Missing Data Estimation for Run-to-Run EWMA-Controlled Processes", *Proceedings of Foundations of Computer-Aided Process Operations, (FOCAPO 2008*), Boston, MA, June, 2008.

C. BOOK CHAPTERS

[1] J.J. McKetta and T.F. Edgar. Synthetics - A New Energy Frontier. In Social Issues Resources, Series 8. University of Texas, Austin, Texas, 1974.

[2] W.R. Kaiser and T.F. Edgar. In Situ Gasification of Texas Lignite, Chapter 8 in Geology of Alternate Energy Sources. Geological Society of America, Houston, Texas, 1977.

[3] T.F. Edgar. Underground Gasification of Coal. In J.J. McKetta, editor, Encyclopedia of Chemical Processing and Design, Vol. 9. Marcel Dekker, Inc., New York, 1977.

[4] T.F. Edgar. Processes and Representative Applications. In D.A. Mellichamp, editor, Real-Time Computing, Chapter 4. Van Nostrand, New York, 1982.

[5] T.F. Edgar. Advanced Control Strategies for Chemical Processes: A Review, Chapter 4 in Computer Applications to Chemical Engineering Process Design and Simulation American Chemical Society, Washington, D.C, 1980.

[6] D.W. Gregg and T.F. Edgar. Underground Coal Gasification. In M. Elliott, editor, Chemistry of Coal Utilization, Chapter 26. Wiley, New York, 1981.

[7] T.F. Edgar. Models for Dynamic Systems. In D.A. Mellichamp, editor, Real-Time Computing, Chapter 19. Van Nostrand Reinhold, New York, 1982.

[8] J.D. Wright and T.F. Edgar. Digital Computer Control and Signal Processing Algorithms. In D. A. Mellichamp, editor, Real-Time Computing, Chapter 20. Van Nostrand Reinhold, New York, 1982.

[9] W. R. Kaiser and T.F. Edgar. Resources, Properties and Utilization of Texas Lignite: A Review. Chapter 4 in Chemistry of Low-Rank Fuels, 1984.

[10] T.F. Edgar. Process Optimization. In J.J. McKetta, editor, Encyclopedia of Chemical Processing and Design, volume 31. Marcel Dekker, New York, 1989.

[11] J.B. Rawlings A.P. Fordyce and T.F. Edgar. Control Strategies for Fermentation Processes. In D.R. Omstead, editor, Computer Control of Fermentation Processes, Chapter 12. CRC Press, New York, 1989.

[12] D. T. Dalle Molle and T.F. Edgar. Qualitative Modeling of Chemical Reaction Systems. Chapter 1 in M. L. Mavrovuniotis, editor, AI Applications in Process Engineering. Academic Press, New York, 1989.

[13] J. B. Rawlings and T.F. Edgar. Process Dynamics and Control. In J. J. McKetta, editor, Encyclopedia of Chemical Processing and Design. Marcel Dekker, New York, 1990.

[14] C. Ling and T.F. Edgar. Process Control. In J. G. Williams, editor, Encyclopedia of Microcomputers. Marcel Dekker, New York, 1993.

[15] Y. Huang and T.F. Edgar. Knowledge-based Design Approach for the Simultaneous Minimization of Waste Generation and Energy Consumption in a Petroleum Refinery. Chapter 14 (pp. 181-196) in A. Rossiter, Waste Minimization Through Process Design, McGraw-Hill, New York, 1995.

[16] K.R. Muske and T.F. Edgar. Nonlinear State Estimation. In M. Henson and D. Seborg, co-editors, Nonlinear Process Control. Prentice Hall, New York, 1996.

[17] T.F. Edgar. Process Dynamics and Control, Section 18.3. The Electronics Handbook. CRC Press, 1996.

[18] J. Kantor and T.F. Edgar. Computing Skills in the Chemical Engineering Curriculum. Computers in Chemical Engineering Education, CACHE Corporation, Ann Arbor, MI 1997.

[19] T.F. Edgar et. al., "Process Control", Section 8, Perry's Handbook, 7th Edition (D.W. Green and J.O. Maloney, Eds), McGraw-Hill, New York, 1997.

[20] J.Hahn and T.F. Edgar. Process Control Systems. Encyclopedia of Physical Science and Technology, Vol. 13, pp. 111-126, 2002.

[21] J. Hahn and T.F. Edgar, "Process Dynamics and Control", *Electronics Handbook*, CRC Press, 2004.

[22] Y. Zhang and T.F. Edgar, Chapter 8, "Multivariate Statistical Process Control; in *New Directions in Bioprocess Modeling and Control* (G. McMillan and M. Boudreau), ISA, 2007.

[24] T.F. Edgar et al., Section 8: "Process Control", Perry's Chemical Engineering handbook, 8th Edition (in press), 2008.

[23] T.F. Edgar and J. Hahn. Section 4.1 "Process Automation", *Handbook of Automation*, Springer, New York, 2009.

D. BOOKS

[1] T.F. Edgar. Coal Processing and Pollution Control Technology. Gulf Publishing Company, Houston, Texas, 1983.

[2] T.F. Edgar, D.M. Himmelblau and L.S. Lasdon, Optimization of Chemical Processes. McGraw-Hill, New York, New York, First Edition, 1988; Second Edition, 2001.

[3] D.E. Seborg, D.A. Mellichamp, and T.F. Edgar. Process Dynamics and Control. Wiley, New York, First Edition, 1989; Second Edition, 2004, Third Edition, 2009.

E. MONOGRAPHS

[1] J.T. Richardson and T.F. Edgar. Resources and Utilization of Texas Lignite, Dec. 1974.

[2] M.J. Humenick, W.R. Kaiser, R.J. Charbeneau, and T.F. Edgar. Environmental Effects of In Situ Gasification of Texas Lignite, May 1981.

F. PUBLICATIONS EDITED

[1] T.F. Edgar. *In Situ*, a refereed journal published by Marcel Dekker devoted to In Situ, Conversion of Fossil Fuels, salt, Uranium, and Other Minerals, volumes 1-13.

[2] T.F. Edgar. AIChEMI Modular Instruction Series on Process Control, Series A, volumes 1-5.

[3] G. V. Reklaitis and T.F. Edgar. *Computers and Chemical Engineering*, Special Issue on Applications of Computer Graphics in Chemical Engineering.

[4] D. E. Seborg and T.F. Edgar. Proceedings of the Engineering Foundation Conference on Chemical Process Control, 1981.

G. PAPERS AND REPORTS

[1] T.F. Edgar. Optimal control of singular and bang-bang systems, Feb. 1972.

[2] J.B. Riggs and T.F. Edgar. Simplification of linear diffusion models, March 1973.

[3] J.M. Galland and T.F. Edgar. Analysis and modeling of underground coal gasification systems, Oct. 1973.

[4] J.A. Restrepo, V. Krishnamoorthy, E.H. Wissler, and T.F. Edgar. Identification and estimation of *z*-transform models for a distillation column, March 1974.

[5] T.F. Edgar. The potential of in situ gasification for the southwest united states, Sept. 1974.

[6] C.O. Schwanke, J.O. Hougen, and T.F. Edgar. Problems in the application of optimal multivariable control theory to distillation columns, Nov. 1976.

[7] J.M. Galland, B. Dinsmoor, T. Tsang, and T.F. Edgar. Analysis and modeling of underground coal gasification systems, Nov. 1976.

[8] T.W. Thompson, K.E. Gray, and T.F. Edgar. In situ gasification of Texas lignite, Sept. 1976.

[9] K. E. Gray, W. R. Kaiser, and T.F. Edgar. In situ conversion of Texas lignite to synthetic fuels, April 1975.

[10] K.E. Gray, W.R. Kaiser, and T.F. Edgar. In situ conversion of Texas lignite, Nov. 1976.

[11] T.W. Thompson, W.R. Kaiser, K.E. Gray, and T.F. Edgar. In situ conversion of Texas lignite to synthetic fuels, June 1976.

[12] T.W. Thompson, W.R. Kaiser, K.E. Gray, M.J. Humenick, and T.F. Edgar. In situ conversion of Texas lignite to synthetic fuels, Jan. 1977.

[13] T.W. Thompson, W.R. Kaiser, K.E. Gray, M.J. Humenick, and T.F. Edgar. In situ conversion of Texas lignite to synthetic fuels, July 1977.

[14] G.H. Dunn and T.F. Edgar. Solution of some mixed integer programming problems arising in natural gas production and distribution, Nov. 1977.

[15] T.F. Edgar. Particulate control technology, Report to EPA Jan. 1977.

[16] T.F. Edgar. Analysis of low btu coal gasification/combined cycle technology and costs to develop input data for the project independence evaluation system, Nov. 1976.

[17] T.F. Edgar. Analysis of the costs of control systems for total and find particulate matter, Sept. 1977.

[18] L.S. Tung and T.F. Edgar. A study of pole placement with incomplete state feedback for abinary distillation column, May 1978.

[19] P. Cukor, L. Smith, and T.F. Edgar. A simple correlating function for analysis of esp performance in coal fired power plants, June 1978.

[20] T.H. Tsang and T.F. Edgar. Modeling of pyrolysis and drying in underground coal gasification, April 1979.

[21] L.S. Tung and T.F. Edgar. Model development and reduction for a distillation column, April 1979.

[22] T.F. Edgar. Assessment of the use of process dynamics and control for influencing energy utilization in industrial processes, June 1979.

[23] M. Rabins, H.H. Richardson, J. Zaborszky, and T.F. Edgar. Process and systems dynamics and control: High priority research needs relevant to energy, Dec. 1979.

[24] V.L. Howell) H.B. Cooper. Impact of increased coal utilization on compliance with ozone ambient air standards in the Houston Galveston Metropolitan area, Oct. 1979.

[25] C.D. Rao and T.F. Edgar. Air quality impacts of underground lignite gasification in Texas, 1980.

[26] P.G. Christman and T.F. Edgar. Analysis of limestone-sulfur interactions for fluidized bed combustion, 1980.

[27] T.F. Edgar. Cache survey on computer graphics in chemical engineering education, Aug. 1980.

[28] P.G. Christman and T.F. Edgar. The kinetics and product distribution of the cao/so reaction, Nov. 1981.

[29] H.P. Tseng and T.F. Edgar. Effective diffusivity in char combustion reactions, Nov. 1981.

[30] E. Vogel and T.F. Edgar. An adaptive dead time compensator for process control, Nov. 1980.

[31] P. Christman and T.F. Edgar. Distributed pore size model for the sulfation of limestone, Nov. 1980.

[32] P. Christman and T.F. Edgar. The effect of temperature on sulfation of limestones, Nov. 1980.

[33] H.P. Tseng and T.F. Edgar. Combustion properties of Texas lignite, April 1981.

[34] E.F. Vogel and T.F. Edgar. An adaptive multivariable pole-zero placement controller for chemical processes with variable dead time, Nov. 1982.

[35] H.P. Tseng and T.F. Edgar. The change of the physical properties of coal char during reaction, Nov. 1982.

[36] R. Kochhar T. Westby and T.F. Edgar. Retention of sulfur by ash during fluidized bed combustion of Texas lignite, April 1983.

[37] E.F. Vogel J. Gerry and T.F. Edgar. Adaptive control of a pilot scale distillation column, April 1983.

[38] G.V. Reklaitis, R.S.H. Mah, and T.F. Edgar. Computer graphics in the che curriculum, 1983.

[39] E.J. Jones, E.P. Hamilton, and T.F. Edgar. Application of a sawdust gasifier to produce low btu gas from lignite at a Texas brick plant, December 1982.

[40] P. Pavlechko and T.F. Edgar. Pole placement adaptive control of processes described by discrete convolution models, June 1984.

[41] W. Min and T.F. Edgar. Combustion tube studies on the influence of water influx on steam-oxygen gasification of lignite, May 1984.

[42] D.E. Seborg, S.L. Shah, and T.F. Edgar. Adaptive control strategies for process control: A review, November 1983.

[43] T.F. Edgar. Support research on chemical, mechanical and environmental factors in underground gasification of Texas lignite, 1983.

[44] T.F. Edgar. Analysis of sulfur retention during fluidized bed combustion of Texas lignite, 1983.

[45] W. Min and T.F. Edgar. The dynamic behavior of a fixed-bed steam oxygen coal gasifier distrubed by water influx, Nov. 1984.

[46] B.W. Bequette and T.F. Edgar. Selections of process measurements in distillation column control to minimize multivariable interaction, Nov. 1984.

[47] P. Pavlechko, M. Wellons, and T.F. Edgar. Multivariable adaptive control with the generalized analytical predictor, Nov. 1986.

[48] W. Bequette, R. Horton, and T.F. Edgar. Multivariable control of a complex distillation unit,, April 1987.

[49] J. Rawlings, N. Bell, and T.F. Edgar. Control of a water gas shift reactor with dynamic inlet conditions, April 1987.

[50] T.F. Edgar. Nonlinear control of a high purity distillation column by the use of partial linearization, April 1987.

[51] P. D. Pavlechko and T.F. Edgar. Multivariable adaptive control with the generalized analytical predictor, November 1987.

[52] D. T. Dalle Molle, B. J. Kuipers, and T.F. Edgar. Qualitative modeling of dynamic systems, November 1987.

[53] G. Munkvold, I. Kim, J. Beaman, and T.F. Edgar. Analysis of radial gradients in pressure swing adsorption, August 1988.

[54] D. T. Dalle Molle, I. Trachtenberg, and T.F. Edgar. Qualitative modeling of a plasma etcher, 1988).

[55] S.W. Butler, I. Trachtenberg, and T.F. Edgar. Mechanisms and modeling of plasma polymerization, June 1990.

[56] D. T. Dalle Molle and T.F. Edgar. Building qualitative models of dynamic chemical systems, March 1990.

[57] T.F. Edgar. Will computers control the world?, 1990.

[58] J.C. Hoskins, K.J. McLaughlin, D.M. Himmelblau, and T.F. Edgar. Artificial neural network of plasma etching, August 1989.

[59] M.J. Liebman and T.F. Edgar. Data reconciliation for dynamic processes using nonlinear programming techniques, March 1990.

[60] S.W. Butler, K.J. McLaughlin, I. Trachtenberg and T.F. Edgar, SPIE Technical Symposium on Microelectronic Processing Integration, SPIE - The International Society for Optical Engineering, Santa Clara 1990.

[61] S.W. Butler, I. Trachtenberg, and T.F. Edgar. Modeling of selective etching of silicon dioxide over silicon in cf4/h2, June 1990.

[62] J. Bushman, I. Trachtenberg, and T.F. Edgar. Process control and modeling of plasma etching reactors, November 1992.

[63] S. Chatterjee, I. Trachtenberg, and T.F. Edgar. Surface energy estimation techniques applied to single wafer rapid thermal processing systems, November 1992.

[64] J. Choi, V. Manousiouthakis, and T.F. Edgar. On h0 simultaneously optimal decentralized controller design, November 1992.

[65] Y.L. Huang and T.F. Edgar. An artificial intelligence approach to the design of a process for waste minimization, September 1992.

[66] Y.L. Huang and T.F. Edgar. An artificial intelligence approach for integrated process design and control: Case study on synthesizing cost-effective and highly controllable heat-integrated reactor networks, November 1992.

[67] Y.L. Huang and T.F. Edgar. Simultaneous recovery of waste chemicals and energy in an oil refinery, September 1993.

[68] T. Soderstrom, T.F. Edgar, L. Russo and R. Young. Plantwide Dynamic Data Reconciliation Applied to Environmental Monitoring. *AIChE National Meeting,* April 1997.

[69] T. Soderstrom, L. Russo, R. Young, and T.F. Edgar. Practical Implementation Issues in the Large Scale Application of Nonlinear Dynamic Data Reconciliation. *AIChE Meeting*, March, 1999, Houston, Texas.

[70] W.J. Campbell, C. Reader, V. Wenner, and T.F. Edgar. Multivariate Run-to-Run Control of Arm-to-Arm Variations in Chemical Mechanical Planarization. *AIChE Annual Meeting*, 1998.

[71] T.F. Edgar. Vision 2020 and Distillation Modeling, Operations, and Control. *AIChE, 2000*, pp. 93-98, Atlanta, 2000.

[72] J. Hahn, S. Lextrait and T.F. Edgar. Nonlinear Balanced Model Residualization via Neural Networks. Presented at Annual *AIChE* Meeting, Los Angeles, November, 2000.

[73] C.A. Bode, A.J. Toprac, R..O. Edwards, and T.F. Edgar. Linear Model Predictive Control with Extensions for Lithography Overlay, *AEC/APC Symposium XII*, pp. 953-962, S. Lake Tahoe, CA, September, 2000.

[74] T.F. Edgar, "Process Modeling and Control in Semiconductor Manufacturing: Challenges and Opportunities", *Applied Materials*, Sunnyvale, CA, June, 2004.

[75] T.F. Edgar, "Chemical Engineering Education and the Role of Cyberinfrastructure", *AIChE Mtg.*, New Orleans, LA, April, 2004.

H. ORAL PRESENTATIONS

Over 400 presentations made, 1971 – present.

OTHER PUBLISHING ACTIVITIES

[1] A research plan for the Department of Energy in process dynamics and control, (1978)

[2] Author of DOE report "Research Needs in Energy Engineering: Systems, Instrumentation and Control" (1986).

[3] Editorial Board, *Chemical Engineering Reviews* (Freund Publishing) (1985-present).

[4] Editorial Board, *AIChE Journal* (1984-85), (2003 – present).

[5] Editorial Board, *Computers and Chemical Engineering* (1987-present).

[6] Founding General Editor, *In Situ,* (1977-90).

[7] Editorial Board: *Journal of Process Control* (1990-1999).

[8] Area Editor, *Chemical Engineering Education,* (1990-2004).

[9] Chemical Engineering Advisory Board, John Wiley and Sons, (1990-present).

[10] Encyclopedia of Science and Technology (Chemical Engineering Editor) 7^{th} Edition, (1995).

[11] Chemical Engineering Advisory Board, McGraw-Hill (1998-2004).

[12] Editorial Board, *Transactions Control, Automation and Systems Engr.* (Korea), (2000-present).

[13] Editorial Board, *Interactive Journal of Robust and Nonlinear Control* (2008-present)

STUDENT THESES AND DISSERTATIONS SUPERVISED

Master's Theses

[1] J. A. Restrepo, 12/72, Discrete and Continuous Dynamic Modeling of a Distillation column.

[2] J. B. Riggs, 5/73, A Survey of the Model Reduction Problem.

[3] J. M. Galland, 12/73, Analysis and Modeling of Underground Coal Gasification Systems.

[4] J. Schwartz, 5/74, Analytical and Computational Simplification of Linear Dynamic Models.

[5] D. R. Oakley, 5/75, Multivariable Control of a Distillation Column.

[6] D. A. Westbrook, 5/76, Design of a Combustion Tube for Experimentation on In Situ Gasification of Texas Lignite.

[7] J. E. Murray, 5/77, Two Methods for the Optimum Development of Petroleum Reservoirs.

[8] S. J. Hsia, 8/77, Oxidation Kinetics of Texas Lignites.

[9] G. Valeri, 8/77, Production of Methane and Other Chemicals from Texas Lignite.

[10] F. Ozturegen, 12/77, An Economic Study of In Situ Gasification of Texas Lignites.

[11] J. A. Cadwell, 12/78, Pyrolysis Properties of Texas Lignite Under Conditions of In Situ Gasification.

[12] D. W. Webb, 12/78, Multivariable Modeling and Decoupling Control of a Distillation Column.

[13] B. Dinsmoor, 12/79, The Modeling of Channel Systems in Underground Coal Gasification.

[14] S. M. Matteson, 12/79, Pyrolysis Kinetics of Texas Lignite.

[15] M. J. Singer, 12/79, A Mathematical Model for the Fluidized Bed Combustion of Texas Lignite.

[16] A. N. Dasgupta, 5/80, Analysis and Design of a Fluidized Bed Gasification System for Texas Lignite.

[17] W. C. Hunt, Jr., 5/80, Cracking of Low Heating Rate Pyrolysis Products Obtained from Texas Lignite.

[18] C. M. Johnson, 8/80, A Three-Dimensional Numerical Simulation for Underground Coal Gasification.

[19] R. C. Heeb, 8/80, Computer-Aided Multivariable Controller Design for Distillation Columns.

[20] S. M. Berg, 8/80, Stability of DDC Control Algorithms Subject to Process Control Inaccuracies.

[21] D. Grittman, 8/82, Application of On-line Closed-Loop Identification to a Pilot-Scale Distillation Column.

[22] G. H. Dunn, 12/80, Optimal Design of Gas Transmission Networks.

[23] T. A. Wellborn, 8/81, Linear Burning Rates of Texas Lignites.

[24] M. Athans, 12/80, The Fate of Sulfur During Pyrolysis of Texas Lignite.

[25] F. Zybert, 8/81, Energy Conservation in Distillation.

[26] H. Jimenez, 8/81, A Process Economics Model for In Situ Gasification of Texas Lignite.

[27] K. Y. Park, 5/82, Design of Surface Facilities for Underground Gasification of Texas Lignite.

[28] S. Joshi, 5/83, Fate of Sulfur in Underground Coal Gasification.

[29] J. K. Ponnamperuma, 12/82, The Design and Operation of Combustion Tube for Studying the In-Situ Gasification of Texas Lignite.

[30] J. Gerry, 12/82, Application of the Vogel-Edgar Controller to a Distillation Column.

[31] E. Bass, 8/83, Gasification Kinetics of Texas Lignite: A Study of the Steam-Char Reaction.

[32] M. Mai, 5/84, An Investigation of the Factors Governing Early Cavity Growth During In Situ Gasification of Texas Lignite.

[33] R. Cook, 8/84, Design and Operation of a Combustion Tube for Gasification of Texas Lignite

[34] M. Wellons, 5/85, A Generalized Analytical Predictor for Process Control.

[35] S. Poon, 8/85, Measurement and Analysis of Burning Rates for Lignite Cores.

[36] D. Little, 8/85, A New Computational Approach for Constrained Dynamic Matrix Control.

[37] E. Lopez, 12/84, Characteristics and Measurements of Two-Phase Slug Flow Through An Orifice Meter.

[38] S. Santivisat, 5/89, Boiler Simulation and Control on Fisher PROVOX.

[39] R. Ranly, 8/91, The Application of Quadratic Dynamic Matrix Control to a Pibt Scale Distillation Column

[40] H. Ouarti, 8/92, The Use of Approximate Models and Exact Linearization for Control of Nonlinear Processes

[41] A. Sabharwal, 6/95, Design and Controllability Analysis of Heat and Mass Exchanger Networks.

[42] B. Mull, 5/95, Digital Control of Rapid Thermal Processes.

[43] R. Chong, 8/05. Adaptive Run-to-run control of semiconductor processes.

Ph.D. Dissertations

[1] V. Krishnamoorthy, 12/76, On Line Identification and Multivariable Control of a Distillation Column.

[2] L. S. Tung, 8/79, Analysis and Control of Large Scale Processes with Limited Measurements.

[3] T. H. Tsang, 5/80, Modeling of Heat and Mass Transfer During Coal Block Gasification.

[4] P. Christman, 12/81, Analysis of Simultaneous Diffusion and Chemical Reaction in the Calcium Oxide-Sulfur Dioxide System.

[5] E. Vogel, 5/82, Adaptive Control of Chemical Processes with Variable Dead Time.

[6] H. P. Tseng, 12/82, Identification of the Combustion Behavior of Coal Char Between 350 C and 900 C.

[7] R. Kochhar, 5/84, Mechanisms of Sulfur Retention by Lignite Ash During Isothermal Sulfation.

[8] K. Park, 12/84, Investigation of Cavity Growth Mechanisms for Underground Gasification of Western Coals.

[9] H. Chang, 12/84, Process Analysis and Simulation of UndergroundCoal Gasification.

[10] T. Westby, 12/84, Carbon Combustion Efficiency and Sulfur Oxide Emissions During Fluidized Bed Combustion of Texas Lignite.

[11] W. Min, 5/85, Studies of the Influence of Water Influx on Steam-Oxygen Gasification of Lignite.

[12] T. Yount, 5/86, Simulation of the Performance of an Atmospheric Pressure Fluidized Bed Combustor.

[13] W. Bequette, 11/86, Measurement Selection and Control System Design for Multivariable Interacting Processes.

[14] A. Alsop, 4/87, Nonlinear Chemical Process Control by Means of Linearizing State and Input Variable Transformations.

[15] R. Horton, 5/87, Multivariable Control of an Energy Integrated Distillation Column.

[16] M. Mai, 1/87, Analysis of Simultaneous Calcination, Sintering, and Sulfation of Calcium Hydroxide under Furnace Sorbent Injection Conditions.

[17] P. Pavlechko, 5/87, An Adaptive Generalized Analytical Prediction for Process Control.

[18] K. McLaughlin, 5/89, Development of Techniques for Real-Time Monitoring and Control of Plasma Etching.

[19] D. Dalle Molle, 8/89, Qualitative Simulation of Dynamic Chemical Processes.

[20] In-Won Kim, 8/90, Robust Errors in Variables Estimation Using Nonlinear Programming Techniques.

[21] Noel Bell, 5/90, Steady-State and Dynamic Modeling of a Fixed Bed Water-Gas Shift Reactor.

[22] K. Allred, 8/91, Modeling, Optimization, and Control of Selective Plasma Etching of Silicon and Silicon Dioxide

[23] G. Munkvold, 12/90, A Multicomponent Predictive Model for Pressure Swing Adsorption Applied to Air Separation

[24] S. Butler, 5/91, Etching and Polymerization in Fluorocarbon-Hydrogen Plasmas: Mathematical Modeling and Experimental Investigation

[25] M. Liebman, 5/91, Reconciliation of Process Measurements Using Statistical and Nonlinear Programming Techniques

[26] A. Patwardhan, 5/91, Modeling and Control of a Packed Distillation Column

[27] A.Toprac, 8/92, Modeling and Experimentation in the Chemical Vapor Deposition of Silicon in a Single Wafer Rapid Thermal System

[28] G. T.Wright, 5/92, Modeling and Nonlinear Predictive Control of a Fixed-Bed Water-Gas Shift Reactor

[29] T. Badgwell, 12/92, Modeling and Optimization of Multiwafer Low Pressure Chemical Vapor Deposition Reactors

[30] S. Chatterjee, 12/93, Modeling and Parameter Estimation in a Single Wafer Rapid Thermal Reactor

[31] C. Ling, 12/93, A Study of New Model-based Fuzzy Control Techniques and their Verifications

[32] J. Bosley, 5/94, An Experimental Investigation of Modeling, Control, and Optimization

[33] T. Breedijk, 12/94, Model Identification and Nonlinear Predictive Control of Rapid Thermal Processing Systems.

[34] S. Bushman, 12/95, Process Monitoring, Modeling, and Control of Plasma Etch Systems.

[35] K. McBrayer, 2/96, Detection and Identification of Bias in Nonlinear Dynamic Processes.

[36] J. Stuber, 9/96, Modeling Control and Temperature Measurement in Rapid Thermal Processing.

[37] R. Dunia, 5/97. A Unified Geometric Approach for Process Monitoring and Control.

[38] K. Edwards, 12/97. Kinetic Model Reduction Utilizing Optimization and Variable Selection Techniques.

[39] S. Morrison, 5/98. Scheduling Methods for Batch Digestors, Batch Process Plants, and Job Shops with the Conveyor Algorithm.

[40] K. Balakrishnan, 5/98. Temperature and Process Uniformity Control in Rapid Thermal Processing.

[41] K. Teague, 5/99. Productive Dynamic Model of a Small Nonisothermal Pressure Swing Air Separation Process.

[42] J. Campbell, 8/99. Run-to-Run Control of Chemical Mechanical Planarization.

[43] C. Pfeiffer, 12/99. Analysis and Design of Heterogeneous Control Laws for Nonlinear Chemical Processes.

[44] B.S. Ko, 5/00. On Performance Assessment of Feedback Control Loops.

[45] T. Soderstrom, 5/01. Integration of On-Line Data Reconciliation and Bias Identification Techniques.

[45] C. Bode, 5/01. Run-to-Run Control of Overlay and Linewidth in Semiconductor Manufacturing.

[46] S. Alici, 8/01. Dynamic Data Reconciliation using Process Simulation Software and Model Identification Tools.

[47] A. Pasadyn, 10/01. Simultaneous Run-to-Run Control and Identification for Multiple Products and Process Environments.

[48] J. Hahn, 5/02. A Balancing Approach to Analysis and Reduction of Nonlinear Systems.

[49] S.B. Hwang, 5/02. Modeling of RTCVD of SiGe.

[50] J. Schell, 5/02. Modeling and Control of Reactive Distillation Column.

[51] S.K. Firth, 12/02. Just-in-Time Adaptive Disturbance Estimation for Run-to-Run Control in Semiconductor Processes.

[52] V.M. Martinez, 12/02. Adaptive Run-to-Run Control of Overlay in Semiconductor Manufacturing.

[53] J. Peng, 5/03. Modeling and Control of Packed Reactive Distillation Columns.

[54] S. Lextrait, 5/04. Packed Reactive Distillation Columns, Modeling, Simulation, and Control Analyses.

[55] J. Hedengren, 5/05. Real-time Estimation and Control of Large-scale Nonlinear DAE Systems.

[56] W. Cho, 5/05. Modeling and Control of Rapid Thermal Chemical Vapor Deposition Reactor.

[57] L. Rueda, 12/05. Modeling and Control of Multicomponent Distillation Systems Separating Highly Non-Ideal Mixtures.

[58] D. Castiniera, 5/06. Modeling of Flare Combustion Systems Using Computational Fluid Dynamics.

[59] S. Harrison, 5/06. First-principles Modeling of Arsenic and Fluorine Behavior Ultrashallow Junction Formation.

[60] K. Chamness, 12/06. Integrated Methods for Semiconductor Process Monitoring and Fault Detection.

[61] T. Farmer, 5/07. Intravenous Closed-Loop Glucose Control In Type I Diabetic Patients.

[62] A. Prabhu, 8/08. Performance Monitoring of Run-to-Run Control Systems used in Semiconductor Manufacturing.

[63] Y. Zhang, 8/08. Improved Methods in Statistical and First Principles Modeling for Batch Process Control and Monitoring.

[64] H. Lee, 8/08. Advanced Process Control and Optimal Sampling in Semiconductor Manufacturing.

PROFESSIONAL ACTIVITIES

Program Chairman, Symposium on Process Automation, 1971-72

Finance Chairman, 1974 Joint Automatic Control Conference, Austin

AIChE National Program Committee, Systems and Process Control Area, (Chairman), 1975-78

AIChE National Membership Committee, Vice-Chairman, 1973-77

Editor, Modules in Process Control, CACHE Corporation

Steering Committee, Minority Engineering Workshop, Dallas, 1975

Equal Opportunity in Engineering Program, Director, 1974-1976

Trustee, CACHE Corporation, 1975-

Vice-President, CACHE Corporation, 1980-1981

President, CACHE Corporation, 1981-1984

Co-organizer, Texas Workshop on Minorities in Engineering, Oct., 1975, Dallas

Director, American Automatic Control Council, 1978-80

Chairman, Computer Graphics Task Force, CACHE Corp., 1978-80

Program Chairman, 1979 Joint Automatic Control Meeting, Denver

Assistant Chairman, Ch.E. Department, 1978-1979

Graduate Advisor, Ch.E. Department, 1979-1985

Director, CAST Division of AIChE, 1979-83

Co-Chairman, Engineering Foundation Conference on Process Control, 1981

Finance Chairman, 1982 American Control Conference, Washington, D.C.

Coordinator of Computing Sessions, 1982, ASEE Summer School, Santa Barbara, California

Second Vice Chairman, CAST Division, AIChE, 1984

First Vice Chairman, CAST Division, AIChE, 1985

Chairman, CAST Division, AIChE, 1986

General Chairman, American Control Conference, 1987

Vice-Chairman, Applications Committee, International Federation of Automatic Control, 1981-1985

Chairman, Awards Committee, American Automatic Control Council, 198485

Chairman, Research Panel for U.S. Dept. of Energy, Systems (Instrumentation and Control, 1985

Accreditation Visitor, AIChE/ABET, 1984-present

Steering Committee, "Chemical Process Control" Conference, 1986, 1991

Board of Judges, 1987 Kirkpatrick Chemical Engineering Achievement Award

Session Chairman at 20 technical meetings (AIChE, ASEE, SPE, IEEE, JACC, ACC)

Director, AIChE, 1989-92

Director, AIChE Foundation, 1990-94, 1997-2001

President: American Automatic Control Council, 1989-91

Advisory Committee, Department of Chem. Engr. – University of Maryland

Advisory Committee, Technology Based Engineering Education Consortium

Advisory Committee, Department of Chemical Engineering, MIT

Advisory Committee, Department of Chemical Engineering, University of Kansas

Advisory Committee, Department of Chemical Engineering, UCLA

Advisory Panel, U. S. Department of Energy Basic Energy Engineering, 1989-90

Governing Board and Executive Committee, Council for Chemical Research, 1989-92

Vice Chair, Council for Chemical Research, 1991-92

Managing Board, AIChE Center for Waste Reduction Technology, 1992

Program Chair, CCR Annual Meeting, 1992

Chair, Council for Chemical Research, 1992-93

Academic Advisory Board, Dow Chemical Company, 1992-

National Research Council Committee Impact of Critical Technologies in Chemistry/Chemical Engineering, 1992.

Vice President, AIChE, 1996

President, AIChE, 1997

Executive Officer, CACHE Corporation, 2000 - present

Chair, Board of Trustees, AIChE Foundation, 2004-2005

Commisioner, ABET Educational Advisory Committee, 2005-2011

College of Engineering Committees:

- College of Engineering - Computer (Chair, 1981-84)
- Equal Opportunity in Engineering
- Engineering Advisory Council
- Graduate Studies
- Word Processing
- AIChE Student Chapter Advisor
- Omega Chi Epsilon Sponsor
- Dean Search Committee
- Information Technology

University Committees:

- Housing
- Faculty Senate
- University Council
- Faculty Computing
- Project QUEST (personal computers)
- Calendar
- Athletics Advisory
- Multimedia Instruction Committee (Chair, 1995-)
- Technology Enhanced Learning (1999-2000)
- Graduate Assembly

CONTINUING EDUCATION

1973-74	Participated in lecture series, "Introduction to Chemical Engineering" for DuPont de Nemours Co., Inc. plant at Victoria, Texas.
May 1974	Organized short course, "Computer Process Modeling and Control" and presented lectures
May 1976	Organized short course, "Computer Process Modeling and Control," and presented lectures
May 1977	Organized short course, "Computer Process Modeling and Control," and presented lectures
Jun 1978	Participated in short course, "In Situ Energy Recovery Technology" at University of New Mexico
Mar 1979	Participated in a short course, "Underground Coal Gasification" at University of California, Los Angeles
May 1979	Was course moderator and instructor for short course "Combustion Evaluation in Air Pollution Control"
Jul 1979	Helped teach a course on "Process Control" at University of California, Santa Barbara
Oct 1979	Presented lectures on pipeline optimization to visiting Egyptian students
Jan 1980	Course Director of 3-day short course "Automatic Process Control" in Houston
May 1980	Participated in short course "Distillation Control" at Lehigh University
July 1980 July 1981	Helped teach a course "Process Control" at University of California, Santa Barbara
Sept 1982	Course Director of 3-day short course "Automatic Process Control" in Houston
Apr 1983	Organized and helped teach short course "Automatic Process Control", Amsterdam, Netherlands
May 1983	Helped teach course (same title), Kuwait Petroleum Co, Kuwait.
May 1983	Helped teach course (same title), College Park, MD
Dec 1983	Gave program on "The Inquiring Mind," KUT-FM & Texas Radio Network, Austin, TX.
Nov 1983	Prepared six hours of videotapes on digital control, Univ. of Maryland, automatic process control, College Park, MD.
Mar 1984	Lectured in short course, "Advanced Process Control," Wilmington, DE (DuPont).
Jun 1984	Lectured in short course, "Advanced Process Control," Cincinnati, OH (Proctor & Gamble).
Sept 1984	Short course, "Automatic Process Control," E. I. DuPont de Nemours, Parkersburg, WV 1984.
Oct 1984	Short course, "Automatic Process Control," E. I. DuPont de Nemours, Orange, TX.
Nov 1984	Short course, "Advanced Process Control," E. I. DuPont de Nemours, Parkersburg, WV.
Dec 1984	Short course, "Advanced Process Control," E. I. DuPont de Nemours, Orange, TX.
May 1985	Short course, "Application of Advanced Control in the Chemical Process Industries, University of Maryland, College Park, MD.
Sept 1985	Short course, "Advanced Process Control," E.I. DuPont de Nemours, Wilmington, DE.

May 1987	Short course, "Application of Advanced Control in the Chemical Process Industries, University of Maryland, College Park, MD.
Sept 1988	Short course, "Adaptive Control," American Cyanamid, Pensacola, FL
July 1988	Short course, "Introduction to Coal Utilization," Energy Course for Science Teachers, Austin, TX
Jan 1989	Short Course, "Optimization of Chemical Processes," University of Texas at Austin, Austin, TX.
May 1989	Short Course, "Digital Control," University of Maryland, College Park, MD.
July 1989	Short Course, "Introduction to Coal Utilization," Energy Course for Science Teachers, Austin, TX.
June 1990	Short Course, "Introduction to Coal Utilization," Energy Course for Science Teachers, Austin, TX.
Jan 1990	Short Course, "Optimization of Chemical Processes," University of Texas, Austin, TX.
Jan 1991	Short Course, "Optimization of Chemical Processes," University of Texas, Austin, TX.
May 1989	Short Course, "Advances in Digital Control Algorithms," University of Maryland, College Park, MD.
Jan 1992	Short Course, "Optimization of Chemical Processes," University of Texas, Austin, TX.
May 1993	Short Course, "Digital Process Control," University of Maryland, College Park, MD.
Mar 1993	Short Course, "Process Control," Monterrey Autonoma University., Monterrey, Mexico.
Jan 1994	Short Course, "Optimization of Chemical Processes," University of Texas, Austin, TX.
Nov 1995	Short Course, "Advanced Process Control I," Advanced Micro Devices, Austin, TX
Jan 1996	Short Course, "Advanced Process Control II," Advanced Micro Devices, Austin, TX
April 1996	Short Course, "Advanced Process Control II," Advanced Micro Devices, Austin, TX
Feb 1996	Short Course, "Advanced Process Control III," Advanced Micro Devices, Austin, TX
May 1996	Short Course, "Advanced Process Control III," Advanced Micro Devices, Austin, TX
Sept, 2000	Short Course, "Run-to-Run Process Control, AEC/APC Symposium, Reno, NV
Oct, 2000	Short Course, "Run-to-Run Process Control, Applied Materials, Salt Lake City, UT
Oct 2004	Short Course, "Run-to-Run Process Control and Monitoring", AEC/APC Symposium, Westminster, CO.
May, 2006	Short Course, "Run-to-Run Process Control and Monitoring", Renesas Co., Landshut, Germany.

SUMMARY OF RESEARCH AND OTHER FUNDING

Project Title and Associate Investigators	Agency	Beginning and Ending Dates	Total Grant
Selection of Process Measurements for Control of Mass Transfer Processes	NSF	7/73-3/75	$ 17,000
Real-Time Computing of Chemical Engineering Processes (with E.H. Wissler, J.O. Hougen, and Project C-BE	NSF	1/73-6/75	$ 6,058
Modeling and Control of Physical Processes (with J.O. Hougen)	Bur. of Engr. Res.	9/72-9/73	$ 5,000
Energy Research/Optimization Research	DuPont	9/72-9/73	$10,000
The Optimum Scheduling of Drilling and Production for Gas Production	Bur. of Engr. Res.	9/73-8/74	$ 2,340
Analysis and Modeling of Underground Gasification of Texas Lignite	Bur. of Engr. Res.	9/74-8/75	$ 2,225
Gasification and Liquefaction of Texas Lignite--Governor's EnergyAdvisory Council	NSF/RANN	5/74-5/75	$ 12,100
In Situ Conversion of Texas Lignite to Synthetic Fuels (with K.E. Gray, C.G. Groat)	NSF/RANN	9/74-3/76	$ 59,800
In Situ Gasification of Texas Lignite	Various Donors	9/74-3/76	$ 35,000
In Situ Conversion of Texas Lignite to Synthetic Fuels (with K.E. Gray, W.R. Kaiser)	NSF/RANN	9/75-7/78	$231,000
Travel Grant from Ofc. of International Programs to visit the Univ. of Technical Sciences, Budapest, Hungary, to explore potential for cooperative research in aeration of biological waste	NSF	2/74	$ 2,000
Lignite Gasification	Various Donors	9/75-8/78	$ 35,000
In Situ Gasification of Texas Lignite (with T.W. Thompson, K.E. Gray, M.J. Humenick)	Texas Utilities	9/75-8/80	$ 125,000
The Generation of Hydrocarbons by Pyrolysis During In Situ Lignite Gasification	Texas Petroleum Research Committee	9/77-8/78	$ 10,000
Lignite Gasification	Various Donors	9/77-8/78	$ 50,000

Fluidized Bed Combustion	Tex. Energy Dev. Fund	4/78-12/79	$ 44,000
Underground Coal Gasification (with T.W. Thompson, M.J. Humenick)	DOE	4/78-9/80	$220,000
Fluidized Bed Combustion	Bur. Engr. Research	9/77-8/78	$ 3,000
Lignite Gasification	Various Donors	9/77-8/79	$ 65,000
Mining and Mineral Resources Fellowships (with R.S. Schechter and M.M. Backus)	HEW	9/78-8/79	$148,000
Associated Western Universities Fellow	DOE	10/78-8/79	$ 9,000
Environmental Effects of In Situ Coal Gasification (with M.J. Humenick and W.R. Kaiser)	EPA	10/78-3/80	$ 52,950
Lignite Gasification and Combustion	Various Donors	9/79-8/80	$ 84,000
Mining and Mineral Resources Fellowships (with R.S. Schecter and M.M. Backus)	HEW	9/79-8/80	$ 90,000
Assoc. Western Universities Fellowships	DOE	9/79-8/80	$ 10,000
Mining and Mineral Resources Fellowships	DOI	9/79-4/80	$ 9,000
Analysis of Sulfur Retention in Ash During Fluidized Bed Combustion of Texas Lignite	TENRAC	9/80-9/81	$ 30,000
Mining and Mineral Resources Fellowships (with R.S. Schechter and M.M. Backus)	HEW	9/80-8/81	$150,000
Lignite Gasification and Combustion	Various Donors	9/80-9/81	$ 85,000
Underground Coal Gasification (with T.W. Thompson, M.J. Humenick)	U.S. DOE	4/78-9/81	$220,000
Mining and Mineral Resources Fellowships (with R.S. Schechter and M.M. Backus)	U.S. Dept. Education	9/80-9/81	$ 90,000
Assoc. Western Universities Fellowships	U.S. DOE	9/80-9/81	$ 10,000
Environmental Effects of In Situ Coal Gasification (with M.J. Humenick)	U.S. EPA	10/80-9/81	$ 46,272
Mining and Mineral Resources Research Fellowships	U.S. DOI	9/80-9/81	$ 5,000

Analysis of Sulfur Retention in Ash During Fluidized Bed Combustion of Texas Lignite	TENRAC	6/80-9/81	$ 46,382
Analysis of Sulfur Retention in Fluidized Bed Combustion of Texas Lignite	U.S. DOE	8/80-8/82	$ 58,900
Engr. Fdn. Conference on Chemical Process Control (with D.E. Seborg)	NSF	11/80-5/81	$ 18,000
Lignite Gasification and Combustion	Various Donors	9/31-9/82	$ 75,000
Underground Coal Gasification (with T. W. Thompson, M. J. Humenick)	U.S. DOE	9/81-1/84	$311,904
Underground Coal Gasification (with T. W. Thompson, M. J. Humenick)	TENRAC	9/81-9/83	$ 59,050
Assoc. Western Universities Fellowships	U.S. DOE	9/81-9/83	$ 21,000
Analysis of Sulfur Retention in Fluidized Bed Combustion of Texas Lignite	TENRAC	9/81-9/83	$ 91,250
Advanced Control Strategies for Distillation	NSF	12/81-5/85	$152,941
Lignite Gasification and Combustion	Various Donors	9/82-9/85	$ 52,000
Lignite Fellowships	Texas Mining & Mineral Resources Research Institute	9/84-6/86	$ 20,000
Process Control	Various Donors	9/83-9/85	$ 30,000
Research on Chemical Factors in Underground Coal Gasification	U.S. DOE	8/84-8/85	$ 77,845
Algorithm Development for Computer Control of Chemical Processes	NSF	6/85-6/88	$204,176
Process Control	Various Donors	9/85-9/89	$ 97,000
Lignite Gasification and Combustion	Shell Development	9/85-8/88	$ 30,000
Performance Modeling of Molecular Sieves in an On Board Oxygen Generation System (with J. Beaman)	U.S. Army U.S. Air Force McDonnell-Douglas	9/85-12/86	$ 91,000
Development of New Etch Processing Technologies (with I. Trachtenberg, J.R. Brock, A.J. Bard)	Texas Advanced Technology Research Program	11/85-8/87	$560,000

Novel Approaches to the Growth of Refractory Metal Silicides (with J.M. White, R. Bene, D.M. Kwong, I. Trachtenberg, J.W. Lagowski)	Texas Advanced Technology Research Program	11/85-8/87	$350,000
Shell Modernization Grant (with D.R. Paul, I. Trachtenberg, J.G. Ekerdt, W. Koros)	Shell Companies Foundation	9/87-8/89	$296,800
Process Control Laboratory Endowment	Dow Chemical Co.	9/86-8/88	$ 50,000
Process Control Research	Shell, E. I. DuPont de Nemours, Exxon	9/86 - 9/88	$ 64,000
On Board Oxygen Generation System (J. Beaman)	U. S. Air Force, McDonnell-Douglas	9/85 - 9/89	$138,000
Advanced Control Strategies for Distillation Columns	NSF	7/85 - 7/88	$ 171,000
Development of Mathematical Models and Control Strategies for Solid State Device Processing (I. Trachtenberg)	NSF	7/88-7/91	$ 299,864
Etching Technologies for Microelectronics Manufacturing and Other Fine Line Applications (J. R. Brock, I Trachtenberg)	Texas Advanced Technology Program		$ 331,025
Understanding and Modeling of Unit Operations (A. Tasch,I. Trachtenberg, et al.)	SEMATECH Center of Excellence	9/1/88-9/1/93	$4,060,000
Intelligent Control of Microelectronics manufacturing (I. Trachtenberg, K. Astrom)	Texas Advanced Technology Program	1/1/90-8/31/92	$ 349,880
Process Control Research (D. M. Himmelblau, J. B. Rawlings)	E.I. DuPont de Nemours, Exxon Chemical, Shell Development, Rhone Poulenc, International Paper, Mobil Oil	9/1/88- 9/1/93	$ 288,000
Intelligent Control of Microelectronics Manufacturing	Texas Instruments	1/1/91- 1/1/93	$ 19,000
Generic Equipment Models for Process Control of Microelectronics Manufacturing (with I. Trachtenberg)	Texas Advanced Technology Program	1/1/92- 1/1/94	$ 295,880
Modeling and Control of Single Wafer Microelectronics Processes (with I. Trachtenberg)	National Science Foundation		$ 272,613

Process Control Research (with J.B. Rawlings and D.M. Himmelblau)	Weyerhauser, Intevep, Mobil, Exxon, Amoco, Union Carbide	9/1/93- 9/1/94	$ 129,000
Gain Scheduled Control for Rapid Thermal Processors (with I. Trachtenberg)	SEMATECH	9/1/94-8/31/95	$ 61,000
Development of a Design Methodology for Waste Minimization	Environmental Protection Agency	6/1/94-5/31/95	$ 44,800
International Travel Grant for PSE'94 (Kyongju, Korea) and ADCHEM'94 (Kyoto, Japan)	NSF Travel	10/1/93-9/30/94	$ 22,000
Advanced Control of Rapid Thermal Processing (with I. Trachtenberg)`	SEMATECH	9/1/95-3/31/96	$ 28,000
Process Control Research (with J. Qin and D.M. Himmelblau)	Exxon, Amoco, DMC, Matrix Integrated Systems, Air Products, Texas Instruments, AMD, DuPont	9/1/95-8/31/96	$167,000
Process Control Research (with J. Qin)	Exxon, Amoco, Simulation Sciences, DuPont, AMD, Motorola, Union Carbide, Yield Dynamics, Texas Instruments, Aspentech, Condea-Vista, Tokyo Electron	9/1/96-9/1/01	$500,000
Model-based Control of Microelectronics Processing (with I. Trachtenberg)	NSF	9/1/96-9/1/00	$291,000
Cross-Training of Technicians and Engineers in Microelectronics Manufacturing	NSF/University of New Mexico subcontract	7/1/98-4/1/01	$95,000
Process Control Research	Exxon, AMD, Texas Instruments, SensArray, Emerson Process Management, Chemstations, Tokyo Electron, Samsung	9/1/01 – 9/1/08	$710,000
Flare Combustion Emission Modeling and Control	EPA	9/1/05 – 9/30/06	$60,000
State Partnerships to Save Energy Now Through Training, Landfill Gas Feasibility	Department of Energy (CEER)	7/31/06 – 7/31/08	$50,000

Legal Cases Involving

Thomas F. Edgar as Expert Witness

1. AMAT vs. INSYST
   (Superior Court – California, 2007-2008)

2. Fisher Rosemount Systems vs. Control Systems International
   (U.S. District Court 2006-2007)

EDGAR
EXHIBIT B

Proceedings of the

1993 American Control Conference

The Westin St. Francis Hotel, San Francisco, California
June 2-4, 1993

Sponsoring Organization

The American Automatic Control Council

U.S. National Member Organization of the

International Federation of Automatic Control (IFAC)

MEMBER ORGANIZATIONS

American Institute of Aeronautics and Astronautics
American Institute of Chemical Engineers
Association of Iron and Steel Engineers
American Society of Mechanical Engineers
Institute of Electrical and Electronic Engineers
Instrument Society of America
Society of Computer Simulation

The 1993 ACC is held in cooperation with *IFAC*

Volume 3 of 3

Cover photo courtesy of the San Francisco Convention and Visitors Bureau, by Kerrick James.

American Automatic Control Council
c/o Department of EECS
Northwestern University
2145 Sheridan Road
Evanston IL 60208-3118
(708) 491-3641

These conference proceedings will be distributed through the

IEEE Service Center
445 Hoes Lane
PO Box 1331
Piscataway NJ, 08855-1331
(908) 981-0060 or (800) 678-4333

IEEE Catalog number 93CH3225-0

Library of Congress number 92-54779

ISBN 0-7803-0860-3 (Softbound)
ISBN 0-7803-0861-1 (Casebound)
ISBN 0-7803-0862-X (Microfiche)

Proceedings of the
American Control Conference
San Francisco, California • June 1993

Application of Predictor Corrector Control to Polysilicon Gate Etching

Stephanie Watts Butler and Jerry Stefani
Semiconductor Process and Design Center
MS 944
Texas Instruments
Dallas, TX 75265

Abstract

A modification of Internal Model Control (IMC) was developed which produces excellent response when a process drift is present. The new controller, termed Predictor Corrector Control (PCC), employs a double exponential forecasting filter. Simulations were used to demonstrate that the PCC controller is quicker to respond to step changes and better tracks drifts than traditional controllers (which utilize single exponential filters). Thus, PCC is ideal for supervisory control of microelectronics manufacturing processes, which are known to suffer from machine aging. PCC was demonstrated on a polysilicon gate etch process with encouraging results. For this process, a single wavelength ellipsometer monitored the etch rate at the center of the wafer, and models were employed to relate the etch rate at other sites on the wafer with process conditions and the measured etch rate at the center. The supervisory controller produced setpoints (settings) for the equipment regulatory controllers which achieved a high etch rate process with a maximum specified nonuniformity.

1. Introduction

Polycrystalline silicon (polysilicon) gate etch is a critical step in manufacturing MOS devices. It determines the tolerance limits on MOS circuit performance. The polysilicon gate etch process used in the Microelectronics Manufacturing Science and Technology (MMST) program is comprised of three steps (Figure 1).

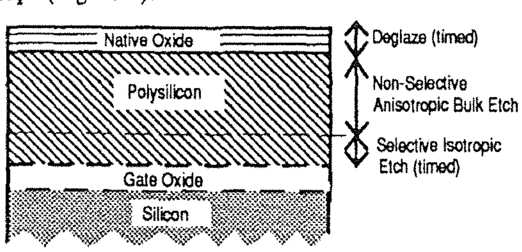

Figure 1: Films and Sequence of Steps
(not drawn to scale)

The first step removes the native oxide. The bulk of the polysilicon is etched in the reactive ion etch (RIE) second step. It is anisotropic so as to maintain straight sidewalls, but has low polysilicon to oxide selectivity. Therefore, the second step is stopped prior to etching through to the underlying oxide. The final step of the process, which removes the remaining polysilicon, is selective to oxide. However, it is slow and isotropic.

The overall objective of this process is to produce a desired critical dimension without damaging the underlying gate oxide. The key step in the polysilicon gate etch process is the second step. The bulk of the polysilicon is removed in this step while sustaining straight sidewalls so that undercutting is avoided during the isotropic third step. Due to lithography considerations, growth of the line must be kept minimal. In addition, the line profile must be maintained uniformly across the wafer. The etch rate must also be uniform across the wafer. Otherwise, too much polysilicon may be left at some points on the wafer, while at other points the polysilicon will be completely removed and the underlying oxide damaged. In order to maximize factory throughput, a high etch rate is also beneficial. This process is known to drift due to aging of the reactor. Therefore, performing the bulk etch for the same time with fixed process setpoints for all wafers would produce unsatisfactory results.

In order to achieve better control of this process, a single wavelength *in situ* ellipsometer, the STE 70 manufactured by Sofie Instruments (1), is used for robust automated endpointing. The ellipsometer is also an element of an intelligent model-based control system. Such a system is composed of many components, which are presented in Figure 2.

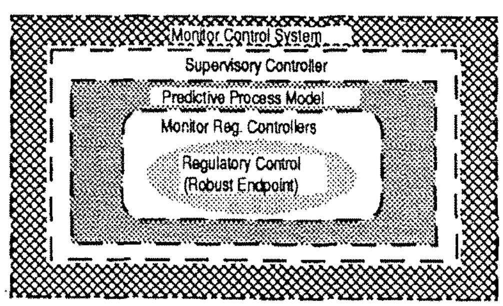

Figure 2:
Intelligent Model-Based Control System

The fundamental component is the control of the machine, termed regulatory control. These controllers include the pressure controller, as well as the mechanism for shutting off the machine at the end of the process (endpointing). For robustness, these controllers must be monitored to determine if they are functioning correctly and whether maintenance is required. The information obtained from the machine, including that from the endpointing algorithm, is used to create models which predict future process performance. Such models are utilized by a supervisory control system which determines the setpoints for the regulatory controllers. These setpoints are commonly referred to as *settings* or *the recipe*. Supervisory control in microelectronics manufacturing is commonly called *run-by-run control* (2). Finally, the entire control system is observed to decide if its performance is satisfactory. Communication can flow in both directions between any two components of the system. This paper will concentrate on the supervisory controller.

2. Supervisory Control System Design

A good controller must meet the following objectives:

1. The ability to track the target without lag.
2. The ability to prevent disturbances from influencing the output.
3. The ability to reject noise, i.e., to not respond to spurious fluctuations.

It is known that objectives 1 and 3 are somewhat mutually exclusive. Thus, a controller that improves the speed of response with better noise rejection is difficult to achieve. Traditional run-by-run controllers utilize a Response Surface Model, whose offset (constant) is estimated ("tuned") when a Statistical Quality Control (SQC) failure is detected (2,3). The "tuned" model is then optimized to generate the new recipe. A single exponential filter is used to estimate the model offset, which causes a corresponding lag in the controller driving the output to target. The filter is required to remove the impact of spurious process fluctuations (noise) upon parameter estimation. However, because the model is not tuned until a SQC failure is detected, the amount of filtering required is not as large as would be necessary if the models were continuously tuned.

This filtered offset controller is equivalent to Internal Model Control (IMC) with a static model and a single exponential filter, as shown in Figure 3. This controller's name is based upon its structure which has a process model block internal to its block diagram (4). IMC has been used recently for supervisory control of the exposure step in a lithography process (5). When a single exponential filter is used to estimate the model offset, the resulting controller reduces to a pure integral controller (2). An IMC controller with a single exponential filter can not produce the target setpoint if the process suffers from a drift. As described earlier, the polysilicon gate etch process is known to drift as the reactor ages. Thus, a supervisory controller was developed that would account for process drift.

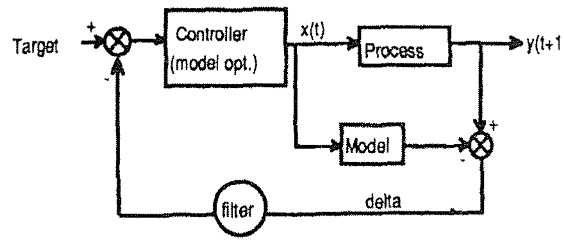

Figure 3
Internal Model Control

2.1 Double Exponential Forecasting Filter

A forecasting filter is one which provides a forecast (prediction), rather than merely smoothing the current data. A double exponential forecasting filter consists of a filter to estimate the true output, as well as a filter to estimate the trend. The forecast is equal to the smoothed value plus the smoothed trend:

Current Smoothed Value =

$(1-\alpha)$(Data at time t) + α(Best previous estimate) [1]

Current Smoothed Trend =

$(1-\beta)$(Estimate of Trend at t) + β(Previous trend)

Forecast =

Current Smoothed Value + Current Smoothed Trend

where α, β are the tuning constants

The single exponential filter traditionally used in IMC was replaced with a double exponential filter in order to create a controller which could compensate for a drifting process. This resulting modified IMC controller has been termed Predictor Corrector Control (PCC). In the case of the PCC, the data to be filtered is the model error (Delta_t):

$$\text{Delta}_t = Y_t - \text{Model0 Prediction}_t \quad [2]$$

where Model0 is the original Response Surface Model. The current smoothed value is the filtered model error (called FDelta). The current smoothed trend is termed the filtered prediction error (FPE). The estimate of the trend is the Prediction Error (PE). Holt's filter is synonymous with double exponential forecasting filter (6). Holt's forecasting filter is used predominately in financial planning, rather than in process control. However, Holt developed his filter for the exact reasons that PCC was developed. We have investigated several possible variations of double exponential filtering by considering different calculations for the trend (PE) and the value used for the best previous estimate in the calculation of the current smoothed value (FDelta). We preferred one particular variation of the filter based upon tuning considerations. The resulting controller with this filter is termed PCC(b(t)) and is depicted in Figure 4.

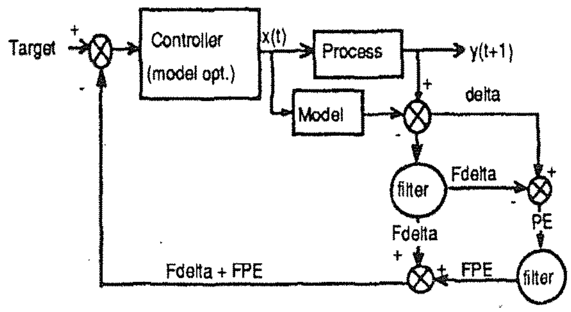

Figure 4
Predictor Corrector Control (PCC)

The filter equations are:

PCC(b(t))

$$\begin{aligned} FDelta_t &= (1-\alpha)Delta_t + \alpha * FDelta_{t-1} \\ PE_t &= Delta_t - FDelta_{t-1} \\ FPE_t &= (1-\beta)PE_t + \beta * FPE_{t-1} \end{aligned} \quad [3]$$

The following equations for FDelta and PE would produce equivalent results for the same tuning values:

$$\begin{aligned} FDelta_t &= (1-\alpha)Delta_t + \alpha(FPE_{t-1} + FDelta_{t-1}) \quad [4] \\ PE_t &= Delta_t - Delta_{t-1} \end{aligned}$$

One variation of the filter was produced to reduce lag. It will not achieve target if a process drift is present. However, it will achieve an output that is offset by exactly the drift rate, while IMC will produce an offset equal to the drift rate divided by the filter factor. The controller with this filter has been termed PCC(b(t+1)). The equations for this modified double exponential filter are:

PCC(b(t+1))

$$\begin{aligned} FDelta_t &= (1-\alpha)Delta_t + \alpha * FDelta_{t-1} \\ PE_t &= Delta_t - FDelta_t \\ FPE_t &= (1-\beta)PE_t + \beta * FPE_{t-1} \end{aligned} \quad [5]$$

2.2 Simulations

Extensive simulations were performed to analyze the controller and compare its performance to traditional IMC. A linear single input-single output (SISO) system was selected for testing the controller. A single input-single output system is a system that has one manipulated variable (x) and one measured/controlled variable (y). The true process model for this process is:

$$y = atrue*x + btrue$$

The following process control model was used:

$$model0 = a*x$$

where

btrue — the true value of the model offset (includes disturbance)
for drift, btrue(t) = btrue(t-1) + drift value

Figure 5 shows the controllers' responses to a sudden shift followed by a rapid drift whose rate is slowed after several wafers are processed. This situation might arise due to a machine maintenance, which causes a shift, followed by machine aging. Machine aging occurs rapidly at first but then slows as more wafers are processed. The filters have been tuned equivalently with respect to integral action. Table I gives the common process control system performance metrics, Integral Square Error (ISE) and Integral Absolute Error (IAE) (4). Both PCC controllers perform better than IMC. PCC(b(t)) eliminates the offset due to drift, but suffers more overshoot than does PCC(b(t+1)) when the drift rate changes. Additional simulations found PCC to be robust to both noise and model mismatch.

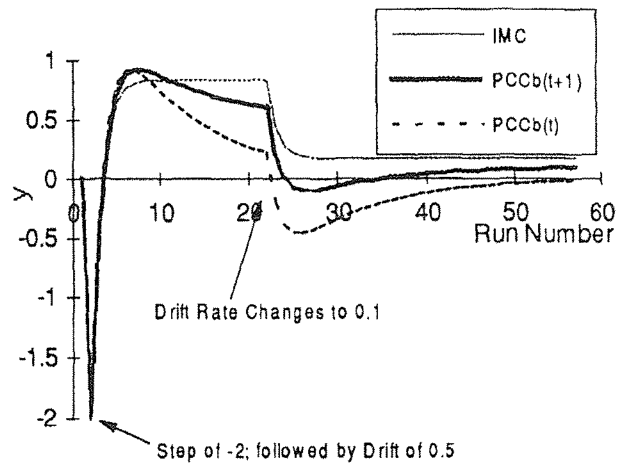

Figure 5: Controller Response to Step and Drifts
Tuning: PCC(b(t+1)) and PCC(b(t)) $\alpha=0.5$ and $\beta=0.9$; IMC $\alpha=0.4$

Table I: Performance Measures

Controller	ISE	IAE
IMC	17.5	24.0
PCC(b(t+1))	14.9	18.8
PCC(b(t))	12.5	18.6

2.3 Implementation

NPSOL was incorporated into the controller for optimization purposes. A controller action is generated for each wafer, i.e., the models are continuously "tuned"[6] and optimized. Heavier filtering is used than would be used if controller actions were based upon SQC failures. To prevent wandering around the operating space[7] the controller selects the closest solution to the current operating point. To prevent small insignificant changes in the controller action, a deadband is employed; the setpoints for the last wafer are used if they will produce a process which is within 1-sigma of the target and meets all the constraints. If no solution is possible, the operator has the option to process with the setpoints for the last wafer. Because we are trying to control a process which drifts with time, the PCC(b(t)) controller was used with tuning of α=0.5 and β=0.9. These tuning values were selected based upon simulations with noise estimated from actual data.

3. Process Models

A necessary component of a run-by-run process control strategy is a model which relates the measurable variables to the manipulated variables. The models are often empirical (low-order polynomial expressions), derived using statistically designed experiments. In order to be beneficial, the *in situ* sensors must provide information that is related to the process goals (7). An ellipsometer measures in real time the thickness of the polysilicon at a small spot near the center of the wafer. Obviously, endpointing the bulk etch step will guarantee that this spot will have neither too much nor too little polysilicon remaining at the end of the bulk etch step. Unfortunately, the ellipsometer is only measuring one small area on the wafer. If the uniformity of the process is not maintained, other locations on the wafer may have too much or too little polysilicon remaining. Therefore, only controlling the response at the center of the wafer does not achieve all the objectives for this process. Consequently, a novel modeling scheme is utilized to try to relate the results at the center with process performance elsewhere on the wafer (8). Using off-line measurements, as well as the in situ sensor data, we have modeled the responses at various sites across the wafer. The important distinction of our modeling technique is that these site models are functions of the process factors as well as the behavior at the center of the wafer measured by the ellipsometer. Details about creating the models are given elsewhere (8). The uniformity of the etch process for any wafer may be inferred using the etch rate measured by the ellipsometer and these models. Consequently, run-by-run control of the uniformity becomes feasible.

4. Controller Performance

In order to use an optimizer with the models, the goals stated in the introduction must be expressed mathematically. A target was set for the etch rate measured by the ellipsometer. In addition, when the ellipsometer stopped the bulk etch step with a target value of polysilicon remaining, the constraint on the remaining polysilicon at site i, $thickness_i$, was:

$$|thickness_i - \text{thickness at center}| \leq 300 \text{ Å}$$

An additional constraint was set for the line growth at the wafer center. A response surface model for line growth was derived using off-line measurements. Since there was no *in situ* sensor, the model was not updated during the experiment.

4.1 Experimental Results

The samples were 6-inch diameter P<100> silicon wafers with doped polysilicon on top of 500 Å undoped thermal gate oxide. The wafers were patterned with a benchmark gate reticle. The etcher is an single wafer Advanced Vacuum Processor (AVP) manufactured by Texas Instruments. Figure 6 is a plot of Ln Data/Ln Target versus run number. The data is presented in the Log space because the initial modeling results indicated that a Ln transformation was necessary. Thus, feedback and SQC must be performed in the Log space. The three lines correspond to the observed etch rate, filtered model predictions, and model0 (original Response Surface Model). The difference between the model prediction and model0 in Figure 6 represents the amount of model tuning that has occurred since the controller was initialized (in this case prior to start of this experiment). There were many delays and hardware and software problems during the experiment which caused erratic behavior. However, overall, the controller did a good job of satisfying the constraints on remaining polysilicon thickness and achieving the target etch rate. For the 43 wafers etched, the etch rate deviated less than 4.5 Å/sec from the target. The change in predicted etch rate away from the target was partly due to the need to meet the constraints on etch uniformity and linewidth gain. Only three wafers had uniformities which violated the constraints These results are satisfactory considering that in this experiment the optimization was not necessarily global. That is, global optimization was sacrificed for local

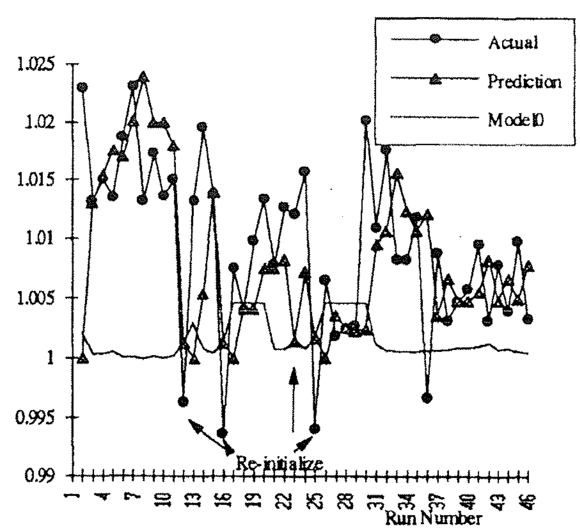

Figure 6: LN Data/LN Target; LN Model/LN Target

optimization to prevent bouncing around the operating space which would preclude the filter from stabilizing.

5. Conclusion

A modification of IMC control is developed which produces excellent response when a process drift is present, making PCC ideal for supervisory control of microelectronic manufacturing processes. Simulations were used to show that PCC provides superior performance compared to IMC when process drift is present. PCC was demonstrated on a polysilicon gate etch process with encouraging results. For this process, a single wavelength ellipsometer monitors etch rate at the center of the wafer, and models are employed to relate the etch rate at sites on the wafer with process conditions and the measured etch rate at the center. The supervisory controller produced setpoints (settings) for the equipment regulatory controllers which would achieve a high etch rate process with a maximum specified nonuniformity.

Acknowledgments

We wish to thank Gabe Barna for helping organize the experiment, Steve Henck for *in situ* ellipsometry support, and Daty Rogers for assisting in running the experiment and making measurements. Special thanks to Bill Pu and Sonny Maung for software integration. Mike Sullivan, Judy Hirsch, Jason Wang also provided software support. This work was sponsored in part by the Air Force Wright Laboratory and the DARPA Microelectronics Technology Office under contract F33615-88-C-5448.

References

1 S. A. Henck, J. Vac. Sci. Technol. A, 10, Jul/Aug (1992) (Accepted for publication).

2 E. Sachs, A. Hu, and A. Ingolfsson, "Run by Run Process Control: Combining SPC and Feedback Control," Submitted to *IEEE Transactions on Semiconductor Manufacturing* (Oct 1991).

3 Ling, Z.-M., S. Leang, and C. J. Spanos, "In-line supervisory control in a photolithographic workcell," SRC publication C91008, also *SPIE Proceedings of Advanced Techniques for Integrated Circuit Processing*, J. Bondur and T. R. Turner, Eds., **Vol. 1392**, 660 (1991).

4 D. E. Seborg, T. F. Edgar, and D. A. Mellichamp, Process Dynamics and Control, Wiley Series in Chemical Engineering, Wiley, New York: (1989).

5. Crisalle, O. D., R. A. Soper, D. A. Mellichamp, and D. E. Seborg, "Adaptive Control of Photolithography," *AICHE Journal*, **38**(1), 1 (1992).

6 C. C. Holt, "Forecasting Seasonal and Trends by Exponentially Weighted Moving Averages," Office of Naval Research, Research Memorandum No. 52 (1957).

7. S. W. Butler, K. J. McLaughlin, T. F. Edgar and I. Trachtenberg, "Development of Techniques for Real-Time Monitoring and Control in Plasma Etching: II. Multivariable Control System Analysis of Manipulated, Measured, and Performance Variables," *J. Electrochem. Soc.*, **138**(9), 2727 (1991).

8. J. Stefani and S. W. Butler, "Real-Time Inference of Plasma Etch Uniformity Using *In Situ* Ellipsometry," Symposium on Highly Selective Dry Etching and Damage, Spring Electrochemical Society Meeting, Honolulu, Hawii (May 1992).