June, 2002

A Course Assessment Of The Microelectronics Process Engineering Program At SJSU

Gregory Young, *San Jose State University*
Stacy Gleixner, *San Jose State University*
David W Parent, *San Jose State University*
Yasser Dessouky, *San Jose State University*
Emily Allen, *San Jose State University*, et al.

Course Assessment of the Microelectronics Process Engineering Program at SJSU

Gregory Young[1], Stacy Gleixner[1], David Parent[1], Yasser Dessouky[1], Emily Allen[1], and Linda Vanasupa[2].

San Jose State University[1],California Polytechnic State University, San Luis Obispo[2]

Abstract

The program assessment strategy of San Jose State University's new interdisciplinary curriculum in Microelectronics Process Engineering is described. Vertical integration of specific class and program learning objectives allows for a clear and efficient method to evaluate the continued growth and improvement of the program. The program assessment process relies on clearly defined and detailed program and course learning objectives that are linked vertically to ABET outcomes. In addition, we discuss briefly the structure of the program and the "hands-on" experience that we provide the students.

Introduction

Semiconductor manufacturing companies utilize thin film processing methods to fabricate electronic components, communication devices and micromechanical devices. Process engineers are needed to develop, operate and improve these thin film processes. The concepts that are applied in manufacturing the various "high-tech" devices require a process engineer with an interdisciplinary engineering background. This modern process engineer is required to understand electrical engineering design rules, electronic material properties, and the physics that describe mass, momentum and energy transport. In addition to the multidisciplinary engineering aspects of microelectronics curricula, a 1991 Semiconductor Research Corporation (SRC) report suggests that more emphasis should be placed on statistical process control (SPC), design of experiments (DOE), yield management and total quality management (TQM) [1].

In response to the microelectronics industry needs, San Jose State University has designed a Microelectronics Process Engineering Program (μProE) to educate engineers in microelectronics fabrication as well as to address the missing manufacturing statistical analysis missing in traditional curricula. The goal is to produce graduates with the technical background to understand both the devices being produced and the processes by which they are manufactured. This bachelor's degree program includes coursework from the traditional disciplines of electrical, chemical, materials and industrial and systems engineering, as well as a laboratory course sequence in which integration of the disciplines is explicitly achieved. A detailed description of

San Jose State University's µProE program can be found elsewhere [2]. The course requirements for the program are shown in Table 1.

FALL	SPRING
1st Year	
Calculus I	Calculus II
General Chemistry I	General Chemistry II
Introduction to Engineering (E10)	Physics I – Mechanics
General Education	
English Composition IA	English Composition IB
2nd Year	
Calculus III	Differential Equations
Physics II - Electricity & Magnetism	Introduction to Circuits (EE98)
American Studies IA	American Studies IB
Introduction to Materials (MatE 25)	Statics (CE99)
	Oral Communication
3rd Year	
Physical Chem. (Chem161A)	Matls Characterization (MatE141)
Systems/Structures Matls (MatE115)	Safety & Ethics in Engr. (ChE 161)
Electronic Props Matls (MatE 153)	Design of Experiments (ISE 135)
Engineering Statistics (ISE 130)	Semicond. Device Physics (EE128)
Technical Writing (E100)	**Basic IC Fab/Desgn (MatE/EE 129)**
Mass & Heat Transport (ChE 190)	Chemical Thermodynamics (ChE151)
4th Year	
Advanced Thin Film Processes (MatE/ChE 166)	**Microel. Manufacturing Methods (MatE/EE 167)**
Senior Design Project (E198A)	Senior Design Project (E198B)
Reactor Design/Kinetics (ChE158)	Solid St. Transformations (MatE152)
Technical Elective	Technical Elective
Advanced General Ed.	Advanced General Ed.

Table 1: Course Requirements for the µProE Program

Program Design

The design of this program features three new courses developed specifically for the µProE program. The three new courses, highlighted in Table 1, function as three separate divisions of a fictitious semiconductor processing company, Spartan Semiconductor Services (S^3i) and are the cornerstone of the program. The courses/divisions are MatE/EE129: Introduction to IC Fabrication (Digital NMOS division), MatE/ChE 166: Advanced Thin Films (Thin Film Research Division), and MatE/EE 167: Microelectronics Manufacturing Methods (CMOS Division and SPC task force). MatE/EE129 is an existing course that has been improved upon to address the requirements of the program. An extensive description of MatE129 can be found elsewhere [3], [4].

These three courses are lecture and lab courses. The lecture portion of each course focuses on the fundamental science that is applied in the fabrication of integrated circuits and memory storage devices. In addition to the technical aspects of integrated circuit process engineering, the lecture also discusses "best practices" of quality control and design of experiments. The laboratory portion of the courses reinforces the lecture concepts with practical applications. In both the MatE/EE129 and MatE/EE167 labs, the students fabricate actual working devices. MATE/CHE166 lab experience focuses on the characterization and statistical analysis of the thin films.

Developing this new program, we had the unique opportunity to build in an assessment mechanism from the "ground-up". The µProE faculty established 42 program learning objectives (PLOs) (Table 2). Each objective was written using active verbs as defined by Bloom's taxonomy [5]. Table 3 lists active verbs that corresponded to a specific level of understanding as defined by Bloom (Table 3). Note that we have combined two levels of Bloom's taxonomy into one level to facilitate the assessment process. This contraction of Bloom's original levels will be discussed in more detail.

ABET Outcomes	**Program Objectives: Specific Assessable Attributes for µProE Program**
1. Apply knowledge of mathematics, science and engineering	1.1 Make all required calculations for predicting and designing process steps relative to microelectronics. 1.2 Make effective estimations and assumptions where necessary and can document reasoning. 1.3 Locate required data. 1.4 Compare analytical calculations with simulated results and tabulated data.
2. Design and conduct experiments and analyze/interpret data	2.1 Use statistical design of experiments and response surface methodology to characterize and optimize a process. 2.2 Design a metrology procedure to characterize a process or device. 2.3 Appropriately select measurement technique needed to characterize a process. 2.4 Evaluate limitations of measurement tools and associated error ranges.
3. Design system, component or process to meet desired needs	3.1 Develop a process flow and a detailed traveler to produce a desired physical device. 3.2 Apply design rules and create mask designs 3.3 Design process specs for defect/particle/metrology control 3.4 Forecast process integration issues when modular process steps are put together. 3.5 Evaluate trade-offs between module processes. 3.6 Draw cross-section of components from mask view
4. Function on multidisciplinary teams	4.1 Designate team roles and assign and monitor specific tasks of team members. 4.2 Function within an assigned role. 4.3 Resolve conflict within team.
5. Identify, formulate and solve engineering problems	5.1 Measure and document the effect of processes on device and component performance and physical characteristics. 5.2 Determine where uncertainties or problems occur in process flow and correct. Can perform analysis of process integration issues. 5.3 Identify relationships between unit processes and device characteristics.
6. Understanding of professional and ethical responsibility	6.1 Work safely in the lab environment and is able to train others on safe practices. 6.2 Takes responsibility for assigned tasks in laboratory setting.
7. Communicate effectively	7.1 Write an engineering report 7.2 Make an effective oral presentation. 7.3 Document laboratory tasks and results. 7.4 Summarize project objectives and results in textual and graphical formats.

8. Understand the impact of engineering solutions in a global/societal context	8.1 Is aware of environmental impacts of chemicals and processes used in laboratory. 8.2 Document the life cycle/disposal requirements of toxic chemicals used in lab.
9. Recognition of the need for and an ability to engage in lifelong learning	9.1 Conduct an information search through library and Internet. 9.2 Recognizes when further knowledge in a subject area is required for personal goals 9.3 Demonstrate resourcefulness, alternative ways of locating information
10. Knowledge of contemporary issues	10.1 Is aware of global business environment 10.2 Document limits of current technology 10.3 Discuss product cycle in computer and electronics industry
11. Use the techniques, skills, and modern tools necessary for engineering practice	11.1 Use statistical, modeling and simulation software 11.2 Operates available characterization, analysis and electrical test tools. 11.3 Use common software such as spreadsheets and word processors 11.4 Analyze the yield of a process and find problem areas. 11.5 Identify critical points for statistical process control of a process. 11.6 Engage in and document TQM principles 11.7 Use industry -common process simulation software tools to predict/validate experimental results. 11.8 Demonstrate supportive laboratory use of basic electronic measurement equipment.

Table 2: μProE Program Objectives

Bloom's Taxonomy	Active Description Verbs	Level of Learning
Knowledge	list, define, tell, describe, identify, show, label, collect, examine, tabulate, quote, name, who, when, where, etc.	1
Comprehension	summarize, describe, interpret, contrast, predict, associate, distinguish, estimate, differentiate, discuss, extend	
Application	apply, demonstrate, calculate, complete, illustrate, show, solve, examine, modify, relate, change, classify, experiment, discover	2
Analysis	analyze, separate, order, explain, connect, classify, arrange, divide, compare, select, explain, infer	
Synthesis	combine, integrate, modify, rearrange, substitute, plan, create, design, invent, what [illegible]	3
Evaluation	assess, decide, rank, grade, test, measure, recommend, convince, select, judge, explain, discriminate, support, conclude, compare	

Table 3: Bloom's Taxonomy

The objectives describe the desired attributes that faculty believe a µProE graduate should possess. The development of these PLOs was a collaborative effort between the faculty and industrial partners of the µProE program. In addition to establishing the PLOs, a link was made between each PLO and a specific ABET outcome. Developing the linkage between program objectives and ABET outcomes when initially creating a new program facilitates any subsequent changes to the program objectives due to technology and societal needs. Developing this linkage at the beginning of the program development ensure that all ABET outcomes are addressed.

Course Design

The µProE program utilizes many existing courses from other engineering disciplines. This paper discusses the course design of the three cornerstone courses within the major: MatE/EE129, MatE/CHE166 and MatE/EE167. Each course focuses on a different aspect of integrated circuit design and manufacturing. The development of each course involves writing specific course learning objectives (LOs). The learning objectives for each course address technical topics, written and oral communication, and work on interdisciplinary teams. Using Bloom's taxonomy, these LOs clearly identify what PLOs are being address in each course. In addition to defining the course material, the learning objectives define the depth of understanding that each topic is to be covered. These learning objectives provide the students with a comprehensive study guide for each course. Table 4 lists a few of the LOs for CHE/MatE166. The right hand column of Table 4 identifies the linkage between course and program objectives. The left hand column of Table 4 identifies the specific level of learning that is expected from each course learning objective. This level of learning corresponds to the levels defined in Table 3.

Prog. Link	**Specific Learning Objective**	**Level of Learning**
2.2	Detail different ways of measuring surface roughness and identify the best measurement technique for different situations.	2
1.1	Calculate the diffusional flux of material in a PVD process.	3
11.1, 11.2	Calculate the precision of a measurement technique.	3
2.1, 11.1	Design an experiment using proper replication, randomization, and control of variables.	3
1.1	Calculate etching rate as a function of directionality and selectivity.	2
1.1	Describe the oxidation/reduction reactions that occurs in electrolytic plating	2
1.1	Define electromigration and explain its impact on IC reliability.	2
1.1	Calculate the evaporation rate of a pure metal.	2
2.4	Describe the difference between accuracy and precision of a measurement technique.	2
2.3, 2.4	Quantify the variation between users for a given piece of equipment.	2
2.4, 11.1	Calculate the variation between levels using a sum of squares method.	2
1.1	Calculate the mass balance of an etch process for endpoint detection.	2
1.1	Identify the rate limiting step during different stages of CVD.	2
1.1	Identify the variables that effect plating rate and film quality.	2

Table 4: Examples of Specific Course Learning Objectives

This vertical integration from specific course learning objectives to ABET outcomes is the basis for our program assessment strategy (Figure 1).

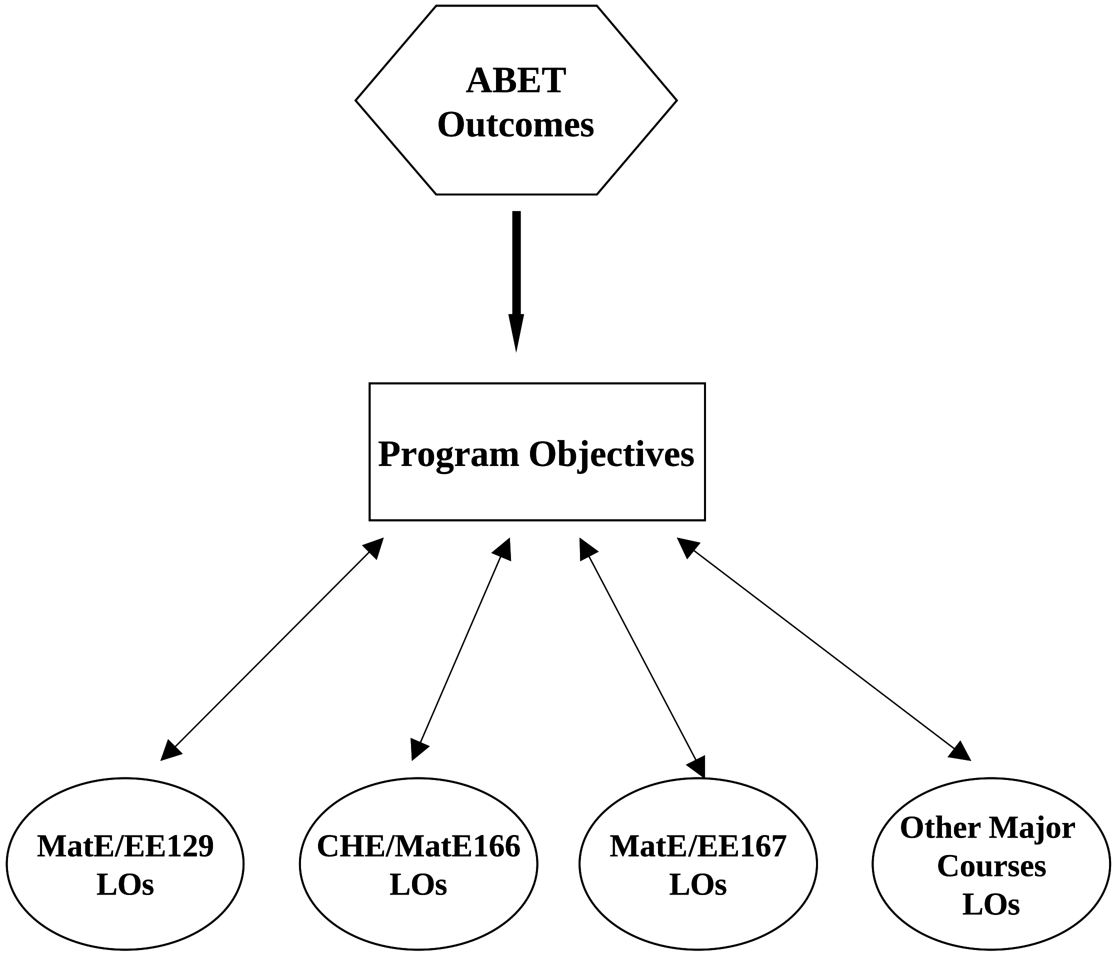

Figure 1: Vertical Integration of Program Assessment

Note that information and changes flow in both directions between program and course learning objectives. This open flow allows for continual growth and improvement of both the program and specific courses.

Assessment Strategy

The key to a successful assessment strategy is the cooperation of all the faculty members involved with the program. Since the formal assessment of the program and individual courses translates to more work, every attempt was made to develop an effective assessment process that requires the minimal amount of work from the faculty.

The proposed assessment strategy requires faculty members to assess the courses that they teach. The advantage of faculty assessing their own courses is that the instructor is familiar with the course content and how it integrates with the program. A standard course assessment template was created for the faculty to follow. The template that lists the nine major sections is shown in Figure 2. The background information of this template is based upon a course description template developed by the University of California [6].

Course Assessment Template:

(all items in italics should be part of your course syllabus)

Semester/Year ____________ *Instructor:* ______________________

Course Title:

Course Number(s):

Catalog Description:

Class Level: (Include all programs that require this course)

Text

Title:

Author(s):

Publisher:

A. ABET and Program Objectives Satisfied (Include all programs that require this course)

B. Prerequisites and Post requisites (Include all programs that require this course)

C1. Primary Specific Learning Objectives (Must know. Must be assessed)

C2. Secondary Specific Learning Objectives (Optional. All 2nd objectives may not be assessed)

D. Assessment Actions (List of actions implemented as a result of the assessment)

E. Assessment of Prerequisites (Optional) Assessment method to be determined by the instructor)

F1. Assessment of Primary Learning Objectives (Tools for assessment are decided upon by the instructor. Exams/HW/Class Observations/Team Projects…)

F2. Assessment of Secondary Learning Objectives

G. Student Assessment of Course Structure

H. Evaluation/Interpretation of Assessment Data (Review of assessment results. Compare to previous assessment results.)

Figure 2: Course Assessment Template

The information listed in the italic sections can probably be extracted from existing course syllabi with little or no modification. Only the underlined sections constitute additional work for the faculty. Using this template for the first time in the Fall 2000 semester, I spent approximately 6 hours completing the underlined sections. Two hours were spent prior to the start of the semester deciding what work I needed to collect for assessment purposes. Virtually no time was spent during the semester on assessment. I continually collect work for assessment during the semester, but I normally collected the work for grading purposes. Four hours were spent after the semester processing all the data that I collected and writing my evaluations. The metrics to evaluate each course LO are currently being discussed and developed.

Course assessment is only one part of the overall program assessment. Each course will be evaluated as a portion of the curriculum for program assessment. Additionally, the information linking specific course LOs to PLOs is processed by the assessment coordinator (the author) and integrated into a course assessment matrix (CAM). The CAM is used to determine where the PLOs are addressed in the program. A portion of the CAM is shown in Table 5. From the completed CAM one can assess if all the PLOs are met and if each PLO is met at the desired level. It should be noted that is not necessary to meet all PLOs at the highest level.

The proposed assessment strategy requires that course learning objectives be evaluated on a regular basis. Modifications of these course objectives are based upon changes to the overall program objectives or change in course content. Teaching styles and methods will be constantly modified to ensure that students master the courses learning objectives.

Class assignments such as exams, lab reports, homework, and in-class exercises are all designed to address specific course learning objectives. Student performance on these assignments is evaluated to determine the level of competency that students achieve. Additionally, the learning objectives themselves are evaluated for relevance to the overall program objectives. This iterative process of assessment is designed to continually improve the course and the entire microelectronics process engineering program.

	Program Objectives: Specific Assessable Attributes for µProE Program	MatE129/EE129	CHE166/MatE166	MatE167/EE167
1.1	Make all required calculations for predicting and designing process steps relative to microelectronics.	**2**	**3**	**3**
2.1	Use statistical design of experiments and response surface methodology to characterize and optimize a process.	**N/A**	**3**	**3**
2.2	Design a metrology procedure to characterize a process or device.	**2**	**2**	**2**
3.1	Develop a process flow and a detailed traveler to produce a desired physical device.	**1**	**2**	**2**
3.2	Apply design rules and create mask designs	**N/A**	**N/A**	**2**
3.6	Draw cross-section of components from mask view	**1**	**2**	**2**
4.1	Designate team roles and assign and monitor specific tasks of team members.	**1**	**2**	**2**
4.2	Function within an assigned role.	**2**	**2**	**2**
5.1	Measure and document the effect of processes on device and component performance and physical characteristics.	**1**	**2**	**2**
7.2	Make an effective oral presentation.	**2**	**2**	**2**
7.4	Summarize project objectives and results in textual and graphical formats.	**2**	**2**	**2**
8.1	Is aware of environmental impacts of chemicals and processes used in laboratory.	**2**	**2**	**2**
9.1	Conduct an information search through library and Internet.	**2**	**2**	**2**
10.2	Document limits of current technology	**2**	**2**	**2**
11.6	Engage in and document TQM principles	**N/A**	**N/A**	**3**
11.8	Demonstrate supportive laboratory use of basic electronic measurement equipment.	**2**	**N/A**	**3**

Table 5: A Section of Course Assessment Matrix

Assigning a faculty member one course per semester to assess, a complete assessment of all major courses will be completed in approximately three years. During this time individual courses will by modified and to improve the quality of the overall program. Upon completion of an entire assessment cycle the program will be assessed. Tools to assess the program would be the individual course assessments, input from industrial partners reviewing program objectives, and the completion of the program objective/course objective matrix (CAM). Figure 3 illustrates the program assessment cycle.

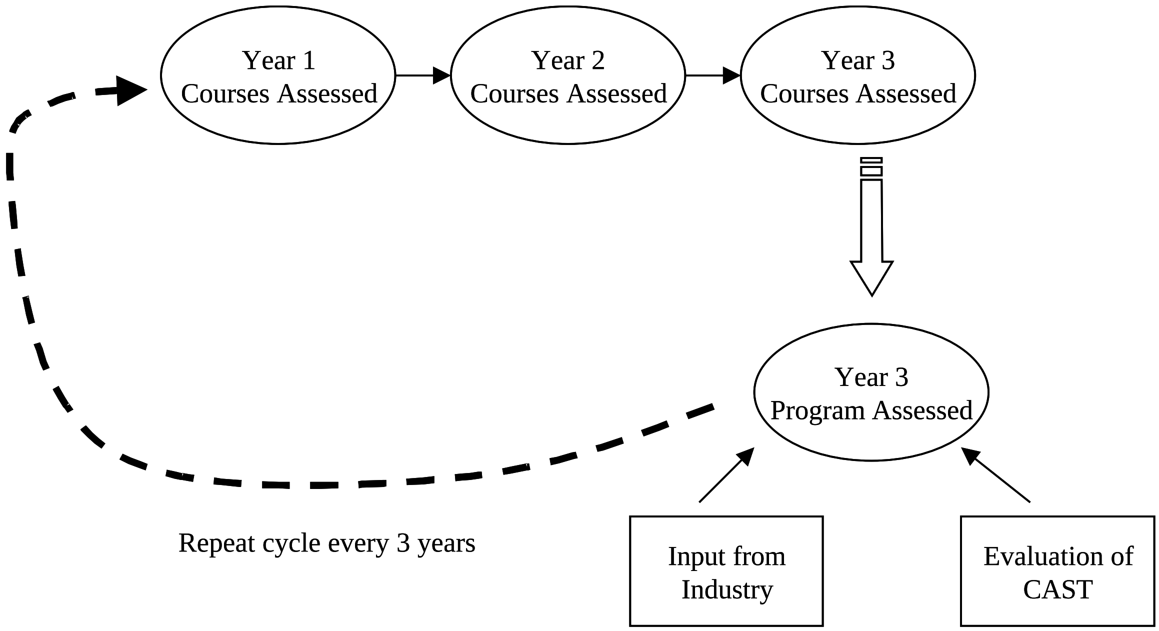

Figure 3: Program Assessment Cycle

Current Progress

The μProE program has a completed list of PLOs that define the program. An initial draft of course LOs have been defined for the three cornerstone courses of the program. The linkage between PLOs and LOs for these courses is currently under review. A complete course assessment for CHE/MatE166 and MatE/EE129 should be completed by the end of the academic year. Course assessments of Chemical and Materials Engineering courses that support the program have been completed. However, the assessment of these support courses has been based upon Chemical Engineering and Materials Engineering PLOs. Thet are currently being analyzed from the perspective of the μProE PLOs

Future Work

The assessment process is a continually evolving improvement cycle. There needs to be a better understanding of how to evaluate learning objectives, and also continual improvement on writing the learning objectives. As the cycle continues the metrics that are used to assess the courses and program need to be defined in a clear manner. Currently the metrics are very subjective and some without merit.

Conclusions

The implementation of this assessment strategy in both the Chemical and Materials Engineering programs has been well received by the faculty. We are currently in the beginning of the first course assessment cycle for each program. The information and comments that have resulted in the first course assessments have been very positive. Faculty have instituted changes in teaching styles to present material more effectively. Course content has been modified to accurately reflect the overall program objectives. Finally, students indicate that the detailed course learning objectives are beneficial to studying and provide a clear guidance to critical course concepts.

Acknowledgements

Much of this work has been accomplished with the support of the National Science Foundation (DUE#9952707). The laboratory has been enhanced by a Challenge Grant from the Society of Manufacturing Engineers, as well as financial and in-kind support from Intel Corporation, Applied Materials, Novellus Systems, Cypress Semiconductor, Advanced MicroDevices, Project Consultants and Quintel Corporation.

Bibliography

1. SRC Competitiveness Foundation Workshop on Microelectronics Manufacturing Engineering Education, Semiconductor Research Corporation, Research Triangle Park, NC (1991).

2. E. Allen, S. Gleixner, G. Young, D. Parent, Y. Dessouky and L. Vanasupa, "Microelectronics Process Engineering: A Non-Traditional Approach to MS&E," Procs. Materials Research Society, ***684E****, GG5.1 (2001).*

3. D. Parent, E. Allen, S. Gleixner, and G.L. Young "Microelectronics Process Engineering Program at SJSU". UGIM Proceedings, July 2001

4. A.J. Muscat, E.L. Allen, E.D.H. Green and L.S. Vanasupa, "Interdisciplinary Teaching and Learning in a Semiconductor Processing Course," J. Eng. Educ. ***87,*** *413 (1998).*

5. B. Bloom, ed. Taxonomy of Educational Objectives in the Cognitive Domain, University of Chicago Press, Chicago, IL (1955).

6. http://www.ucop.edu/sas/publish/cc_2001/docs/course_instructions.pdf

Biographies

Greg Young is Assistant Professor in the Department of Chemical and Materials Engineering at SJSU. He received his PhD in Chemical Engineering from the University of California at Davis in 1990. He teaches transport and semiconductor processing courses and conducts research on electroplating of copper. He can be reached at glyoung@email.sjsu.edu.

Stacy Gleixner is an Assistant Professor in the Department of Chemical and Materials Engineering at San Jose State University. She teaches courses on electronic materials, solid state kinetics and thin film deposition. Her research focuses on development and processing of microelectromechanical devices. She received her PhD in Materials Science and Engineering from Stanford University in 1998. She can be reached at gleixner@email.sjsu.edu.

David Parent is an Assistant Professor in the Electrical Engineering Department at SJSU. He teaches CMOS processing and device physics and conducts solar cell research. He received his PhD in Electrical Engineering in 1999 from the University of Connecticut. He can be reached at dparent@email.sjsu.edu.

Yasser Dessouky is an Associate Professor in the Department of Industrial and Systems Engineering at SJSU. He received his PhD in Industrial and Management Systems Engineering from Arizona State University in 1993. He *teaches statistical process control and conducts research on operations management. He can be reached at ydessouk@email.sjsu.edu.*

Emily Allen is Chair of the Department of Chemical and Materials Engineering at San Jose State University. She teaches courses on electronic materials, IC processing and solid state kinetics, and conducts research on magnetic thin films and semiconductor processing. She received her PhD in Materials Science and Engineering from Stanford University in 1992. She can be reached at elallen@sjsu.edu.

Linda Vanasupa is a Professor of Materials Engineering at California Polytechnic University at San Luis Obispo, and teaches electronic materials and processing. Her research is on characterization of metal film deposition. She received her PhD from Stanford University in Materials Science and Engineering in 1990. She can be reached at lvanasup@tuba.calpoly.edu.