

**AC 2005-1356: DEVELOPMENT AND DISSEMINATION OF A  
MICROELECTRONICS LABORATORY CURRICULUM USING ON-LINE  
TECHNOLOGY**

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## DEVELOPMENT AND DISSEMINATION OF A MICROELECTRONICS LABORATORY CURRICULUM USING ON-LINE TECHNOLOGY

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### ABSTRACT

The Arizona State University (ASU) campus at Mesa, Arizona received an Advanced Technology Education (ATE) grant from the National Science Foundation to develop a series of six laboratory curriculum modules in the area of microelectronics. The partner institutions of the ATE grant are Central Arizona College, Chandler Gilbert Community College, Mesa Community College and the Maricopa Advanced Technology Education Center (MATEC). MATEC is a NSF funded center for Advanced Technology Education. The laboratory curriculum development efforts include both lower and upper division courses, which have laboratory activities integrated into the course. The instructional materials developed utilize the Microelectronics Teaching Factory (MTF) as the laboratory of choice. The MTF is located on the ASU campus at Mesa, Arizona. The curriculum uses a modular design, and is competency based, and industry validated with the goal of producing work ready graduates.

The intent of this paper is to cover the underpinning philosophy of the module development effort designed to maximize the effectiveness of the development and delivery of a laboratory curriculum for Microelectronics. The paper describes the in depth process involved in this effort by taking one module as an example to illustrate the salient features of this approach. In addition, a distinctive delivery tool that is developed under this project will be discussed to explain how remotely situated students in two-year institutions will get access to the material prior to their arrival to the MTF at ASU campus in Mesa, Arizona. Based on the learning that has taken place so far, the paper will cover in detail the effectiveness of development process and dissemination of the microelectronics laboratory curriculum material.

### INTRODUCTION

ASU East Campus and Central Arizona College, Chandler Gilbert Community College, Maricopa Advanced Technology Education Center (MATEC) and Mesa Community College were awarded an Advanced Technology Education (ATE) grant from the National Science Foundation to develop a series of laboratory curriculum modules for the Associate of Applied Science and Baccalaureate degree levels.\* The instructional materials developed are utilized as

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laboratory modules by faculty and students enrolled in the Microelectronics curriculum. Community college instructors supported by industry mentors and university faculty instruct the community college students on tool operation and maintenance, microelectronics manufacturing process, and workplace effectiveness. Six laboratory modules have been integrated into existing Baccalaureate and Associate Degree offerings in the Microelectronics and Electronics programs at the ASU East Campus and its partner community colleges. Associate degree-seeking students enrolled at the community college travel to the MTF for a scheduled laboratory period and co-share the Microelectronics Teaching Factory with baccalaureate and masters degree-seeking students enrolled at ASU.

## **BACKGROUND**

ASU relocated the College of Technology and Applied Sciences (CTAS) and its programs, laboratories, faculty, and students from the Tempe Campus to a new campus site, ASU East Campus. The College of Technology and Applied Sciences has rapidly evolved as the cornerstone of this technology rich environment. Several new laboratories, including the Microelectronics Teaching Factory, have been constructed to accommodate the technology degree programs offered within the College.

### **Microelectronics Teaching Factory: Background, Rationale, and Benefits**

Arizona continues to rank as one of the leading states in the number of workers employed in the semiconductor manufacturing industry. To meet these demands, national and local semiconductor companies have launched an aggressive campaign to attract students into programs that prepare them for the future workforce.<sup>1</sup> The goal of students in technology programs is to be hired by a high-tech employer or to advance to higher pay level if currently employed. Many of the students enrolled in technology programs within the CTAS are currently employed in the local high tech industry. As a result, local semiconductor companies have sought to collaborate with the higher education institutions, such as their neighboring universities and community colleges, to implement this workforce initiative. The College of Technology and Applied Sciences at ASU East Campus is leading the way by developing a state-of-the-art teaching factory in response to the high technology workforce demands both locally and nationally. A one-of-a-kind Microelectronics Teaching Factory (MTF) has been developed in partnership with Intel, Motorola (Freescale) and other local partners in the semiconductor industry by donating equipment, financial resources and human capital.<sup>2</sup> The facility provides a unique learning environment for the students from ASU East, ASU Tempe, and community colleges statewide that represent the future semiconductor workforce.

A major dilemma facing technology programs is the expense of building and maintaining realistic lab facilities. Even in states with generous education resources, costs are making it ever harder to maintain Microelectronics and Semiconductor Manufacturing Technology (SMT) programs and lab capability on multiple campuses. Arizona is typical in this regard. Three of the state's community colleges have well regarded SMT programs, but full-scale demonstration labs have been unaffordable. The absence of realistic lab training opens a steadily widening gap between the basic science and engineering taught in the academic world and the complex,

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expensive, and interactive technology used in the industry. By collaborating via the Teaching Factory, the partners in this project have begun to transform microelectronics education in Arizona into a truly integrated regional enterprise, one that takes advantage of the unique resources of each partnering institution.

### **Curriculum Development Project Goals:**

- ◆ Develop, pilot test, and refine six on-line laboratory modules for lower division courses for use in the Teaching Factory by associate degree-seeking students.
- ◆ Develop, pilot test and refine an additional six on-line laboratory modules with emphasis on data analysis and interpretation for use in the Teaching Factory by B.S. degree-seeking students.
- ◆ Construct the laboratory curriculum using production equipment and process technology located in the MTF.

This paper will focus on the Associate degree curriculum developed and delivered during the project. A series of laboratory curriculum modules have been developed over the duration of the multi-year project for both the Bachelors and Associate degree programs. They include Environmental Health and Safety, Etch, Photolithography, Metallization and Microchip Device Fabrication. All are common process areas found within a microchip fabrication facility and serve a key laboratory focus for microelectronics and semiconductor manufacturing degree programs.

Each module focused on selected microchip fabrication process within the Teaching Factory and corresponds with an existing electronics or microelectronics courses at a partner community college or ASU East. The term “module” refers to a package of instructional material that is available to faculty and students online and serves as a vehicle for an instructor led methodology and/or student self-paced learning activity. Each module contains student/faculty lab preparation materials and instructions, learner oriented lab manuals, laboratory exercises, and assessment instruments for both degree levels. The modules produced for the Teaching Factory also include “*teaching and learning tips*” known as Teaching Assistants (TA). The Teaching Assistants are embedded hyperlinks that contain summaries and examples designed to facilitate understanding and retention of technical subject matter. In addition they provide practice on applying new knowledge to technical tasks and problems; promote skill development; and provide information that students need for reference purposes such as on-line links and resources.

### **Oxidation Module Development Process**

The Oxidation Module has been selected as an example for this paper that highlights the salient features of the curriculum development process and approach. The Oxidation module was selected to provide a sense of the development effort, due to the nature of this particular process area within the cleanroom, beyond the base equipment several metrology tools were integrated

into this module as laboratory activities. A substantial number of development hours were required by the faculty to complete this module.

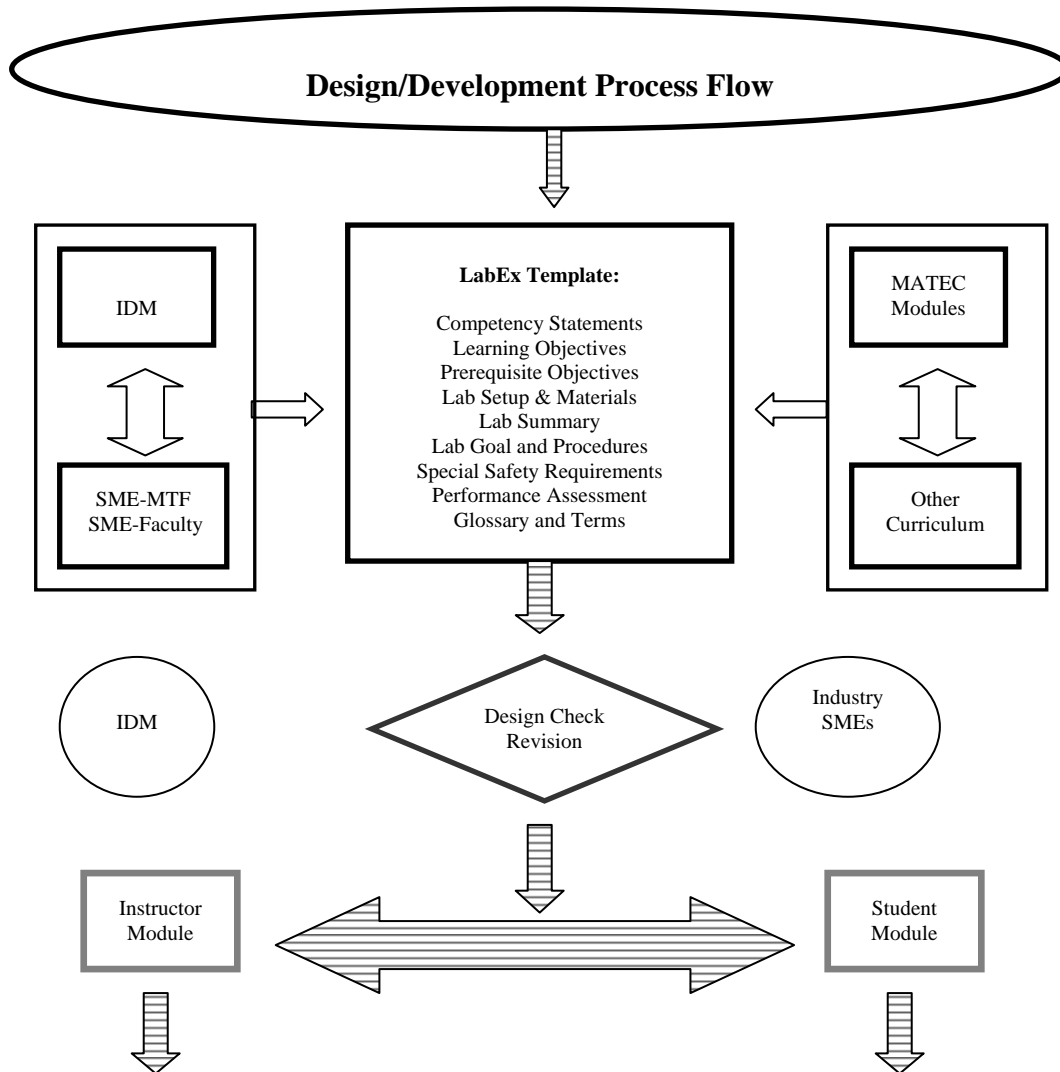
The semiconductor/ microelectronics manufacturing equipment and process technology presented a daunting task for the development teams. The equipment was designed for high volume microchip manufacturing setting. The industrial oriented equipment and Class 100 cleanroom environment is a very complex by design and not particularly friendly for faculty and student laboratory use. The learning curve required for operating and understanding the equipment; process technology and environment posed a real challenge for the faculty developers. In order to overcome this challenge, several faculty development workshops were scheduled to familiarize the developers on the equipment characteristics, capabilities and operation. Original equipment manufacturers manuals were made available to all developers and provided critical sources of information such as equipment operating procedures, schematics, and safety issues. In addition industry subject matter experts and the MTF management team played a key role in identifying the competencies and provided professional development and training for community college faculty on the tools and technology housed within the MTF.

At the onset of the project the faculty self selected his or her team assignments based on their content knowledge applicable to that module or area of interest. The Oxidation Module Development Team consisted of three community college and university faculty, two industry subject matter experts (SME), an instructional design manager and a project manager. An instructional design manager (IDM) worked closely with the faculty developers to design and adopt a standardized development process template that each member used to produce the modules. The on-line templates and checklist provide a virtual authoring and development space that enables ease and consistency during each development phase.<sup>3</sup> Figure 1 highlights the components contained within the templates.

A project management plan was put in place to as the first order of business. Project management resources and software were used to coordinate and track the development activity and progress. Project planning tools such as Gantt charts, task assignments and deliverables were commonplace during all phases of the development process. Each development team began a module by identifying the competency statements, prerequisite objectives and module learning objectives. The prerequisite learning objectives were selected from the MATEC modules. MATEC produced a comprehensive set of background and lecture oriented semiconductor-manufacturing modules as a deliverable for their NSF Center grant. Selected modules, individual components and features were leveraged in this project and incorporated into the Teaching Factory materials as prerequisite and background information. Team members then selected a component of the Oxidation module based on his or her subject matter knowledge or area of interest by partitioning themselves into multiple roles with associated tasks and capabilities in order to construct the components contained on the template. Regularly scheduled face-to-face meetings were held at the MTF to compile drafts; share ideas assume new assignments and try out the laboratory materials associated with a particular piece of equipment or infrastructure. The developers operated in a virtual authoring space throughout the project. The faculty and SMEs completed the bulk of the development work electronically by uploading and downloading files through the on-line authoring system. The on-line authoring system:

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minimized the need for face-to-face meetings, fostered a timely turn-around for materials submission, and overcame the constraints of developers located at geographic distributed campuses. The instructional design and project managers received the incoming drafts from all development teams; where they edited, formatted and uploaded the files to the on-line delivery system. Figure 1 below shows the overall module design and development process flow:



**Figure 1: Module Design and Development Process Flow**

### Module Delivery and Application

The delivery of the curriculum was constrained by four overriding issues:

1. The community college faculty and students could not access the curriculum via the university owned distance delivery system, considering they are not ASU students or staff.
2. Multiple faculty teaching different courses at multiple campuses.

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3. The need to navigate through a large number of documents.
4. Provide the capability to control the frequent revisions of documents.

The solution was to design a customized delivery system or purchase a commercial software package. The decision was made after much consideration and research on commercial software packages of this type, the team opted to design and program customized version that clearly met the needs of the project. A development server that is maintained and administered by the Microelectronics Teaching Factory hosts the delivery system. A programming team was formed by a group graduate students, university and community college faculty that have expertise in database development, web applications and JAVA Programming. The delivery system was designed based on the following specifications:

- Provide multiple user access capable of issuing unique usernames and passwords (faculty vs. student and full vs. partial).
- Program in client side technology (JAVA script) to accommodate portability among servers.
- Format as *pdf* non-modifiable documents to prevent derivative works.
- Create a consistent appearance of the documents independent of input and output medium.

The faculty member conducts the lecture portion of the course on his or her own campus and schedules the use of the MTF laboratory for their students prior to the semester start. A class roster containing student names with pre-assigned numbers is sent by the community college member to the MTF web administrator. The server administrator issues usernames and the student chooses a self-selected password that enables the student to logon for a pre-determined length of time and level of access. All students must demonstrate competency in Environment Health and Safety (EHS) by passing the EHS appraisal. Partial access is given for the EHS Module in order to gain access to the cleanroom and additional modules. At logon the student or faculty member is presented with a screen that highlights the modules and their sub-components. All of the modules contain a standardized set of components (highlighted by italics in Figure 2). The class is assigned a specific laboratory module or component, which can be downloaded as a print ready *pdf* file. The instructional materials are accessed by the clicking a user-friendly pull down menu. Each module contains both student and instructor materials and an on-demand glossary. The modules or sub-components can be assembled together as a laboratory workbook or serve as a series of discrete laboratory activities that can be selected by the faculty member based on the laboratory content focus and allocated time available. A typical laboratory activity can require 3-5 hours for completion as shown in figure 3. The faculty simply assigns the desired material prior to attending the scheduled laboratory at the Microelectronics Teaching Factory. As a matter of convenience and to accommodate the paperless cleanroom protocol: the faculty or student can also access the material on-line from the MTF cleanroom during their scheduled laboratory. The students and faculty members travel the ASU campus for the scheduled laboratory period using their own personal vehicles or the ASU shuttle, which serves two of the community college campuses involved in this project. The curricular resources described in this paper can be found at [www.east.asu.edu/mtf](http://www.east.asu.edu/mtf).

- **Module Overview**
- **Prerequisite Appraisal and Answer Key.**
- **Performance Assessment and Answer Key.**
- **Laboratory Activities**
  1. Silicon Wafer Cleaning
  2. Growing Oxide Layers
  3. Measuring Oxide Thickness
- **Equipment Demonstrations.**
  1. Heated Wet Bench Operation
  2. Horizontal Furnace Operation.
  3. Spectra-Map Oxide Measurement
  4. Surface Scanning-Particle Count Measurement

**Figure 2:  
Oxidation Module Components**

Module: Oxidation

**GROW AN OXIDE LAYER**

**Summary of Activity:** This activity uses the horizontal furnace to grow an oxide layer on clean wafers. Wafers are transported from the cabinet and transferred to a quartz boat. The quartz boat is placed in the furnace and the recipe is compiled (loaded), verified, and started. During the recipe, screens and the operator control panel are used to determine the recipe status. Wafers are removed after the process is completed and returned to the desiccant cabinet. Wafers can be inspected before and after the process to ensure cleanliness. The wafers will be used in the next lab activity to measure the thickness and determine if the process has produced the proper oxide thickness.

**Target Competency:** Grow an oxide layer of 100 to 1000 Angstroms (Å) on a wafer.

**MTF Lab Goal:** Produce a wafer(s) with an oxide thickness from 100 to 1000 Angstroms (Å) using the MTF horizontal furnace.

**Prerequisites:** Score of 80% or higher on Oxidation Prerequisite Appraisal plus successful completion of ESH, Oxidation Equipment, and MTF Clean lab exercises.

**Learning Objectives:** The following objectives pertain to the use of the MTF horizontal furnace to grow an oxide layer.

1. Compile the appropriate recipe for the MTF horizontal furnace using the keypad interface.
2. Verify process parameters for proper temperature and gas flow profile while oxidizing a wafer.
3. Load or unload a horizontal furnace wafer boat.
4. Demonstrate 100% compliance with the stated safety procedures for the horizontal furnace oxidation process.

**Conditions:** Perform all preparation and oxidation procedures with "buddy" (a fellow student). Both students demonstrate competency for all prerequisite knowledge and skill objectives prior to beginning the activity within the MTF.

**Criteria:** Produce an oxide thickness from 100 to 1000 Angstroms on one or more wafers.

**Time:** Classroom preparation time: 0.5 hours; MTF lab time: 4.5 hours  
Lab Activity: Grow an Oxide Layer 1 Instructor Material

**Figure 3: Oxidation Module-Sample Learning Sample**



## Conclusions

Through this project, the partners have developed a rich set of curriculum and electronic educational materials for use in the Teaching Factory for both A.A.S. and B.S. degree levels. The project has been successful by most measures, as evidenced by the module completion targets and the overall quality curricular products and delivery system.. Over 150 community college students used the materials during the 2004 fall semester at the MTF.

The development approach was designed to maximize the development and delivery process for multiple developers by providing structured platform designed to construct leading edge curriculum that has a built-in revision and quality control loop as part of the workflow process. Preliminary successes indicate that the development model can easily adapted to a wide range of non-related curriculum development activities.

The challenge is to keep the partnership in place, fold in new participants and continue to use and refine the materials. As with any curriculum development project, the technical materials must be enhanced and updated to stay current with industry changes. Plans are underway to institutionalize the curriculum at the partner institutions by signing inter-institutional agreements to formalize the use of the MTF as a laboratory of choice and to formalize a process for materials revision after the grant project has ended.

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## Biographical Information

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