

The Start-Up Company Approach to Teaching Semiconductor Processing

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Abstract

An interdisciplinary course in semiconductor processing has been developed and successfully introduced into the chemical, materials, and electrical engineering curriculums that blends new and traditional teaching techniques. A start-up company culture is created in which teams of “employees” composed of students from a range of disciplines and having varied industrial experiences work side-by-side on a long-term (semester) project threaded with short-term (two week) open-ended design components. The long-term laboratory project is to build integrated circuit devices on a 4" silicon wafer using a 5-mask pmos metal gate process. The short-term design experiments improve upon the existing IC process or develop a next generation process. In the lecture portion of the course both the unit operations needed for device building and the electrical principles required for device testing are discussed. The cooperative learning environment that is created provides the knowledge content of semiconductor processing and strengthens the oral and written communication skills necessary for success in industry.

I. Introduction

Microelectronic device fabrication is inherently interdisciplinary. The microelectronic circuits that have found their way into so many parts of our daily activities are built by combining basic types of processes or unit operations. These basic processes include diffusion, thin film deposition, ion implantation, photolithography, and etching. Each of these basic processes in turn draws upon knowledge that is traditionally in the domain of physics, chemistry, and chemical, materials, and electrical engineering. For example, the gate dielectric (SiO_2) in a transistor which is the workhorse of microelectronic devices is formed using a diffusion process. The skill set needed to properly understand and control this process is drawn from solid-state physics, crystallography, chemical kinetics, heat, mass, and fluid transfer, process control, and surface analytical techniques, to name a few. Understanding and controlling the other basic processes requires a different skill set, but one that is again drawn from several disciplines. The basic function and performance of the resulting device are tested using principles drawn from solid-state electronics. Since device fabrication is highly interdisciplinary there are advantages to teaching it that way in a single course.

The interdisciplinary nature of microelectronic device fabrication also provides an opportunity to improve communication, teamwork, and lateral thinking skills. It is just not possible throughout

a single 15 week semester for each student in the course to master every unit process and electrical testing procedure in enough depth to use them successfully in the laboratory. The students are majoring in chemical, materials, electrical, and information engineering as well as physics and chemistry. Moreover, they have a range of industrial work experiences. Each student consequently comes in with a different set of skills that is strong in some areas of device fabrication and weak in others. This situation lends itself well to completing the device fabrication and testing work in small teams composed of students with as broad a distribution of backgrounds as possible based on knowledge and experience. Each student in the team will, in principle, have or be able to readily acquire the skill necessary for a part of the overall effort needed to build and test the devices during the semester. No single student has all of the talent but by pooling skills and working together each team can complete a larger goal. The opportunity to work with people from other majors broadens the students' educational experience and promotes lateral thinking. The team-based work unit creates a more cooperative learning environment that encourages interdependence. Moreover, the common goals of the team promote oral communication both inside and outside of the laboratory. Lateral thinking, teamwork, and oral communication are part of a list of skills that have been singled out for improvement in engineering curricula.^{1,2}

The setting for the course is a fictitious start-up company called Spartan Semiconductor Services, Inc. An effort is made to simulate a working microelectronic device fabrication facility in large part to give a sense of the risks and rewards available in such an atmosphere. The professional work environment that is created encourages student ownership of their work. The unifying project and primary goal of the course is to make working microelectronic devices. Threaded in with this larger goal are short-term design projects. All of the laboratory work is completed in teams. These ingredients are what we call the entrepreneurial approach to teaching and learning since both the instructors and students own, launch, manage, and assume the risks of the educational enterprise. This paper describes this approach applied to a microelectronic device fabrication course.

II. Course Structure

The prerequisites required of students entering the course mirror the interdisciplinary nature of microelectronic device fabrication and establish a broad "employee" knowledge base. ChE/MatE/EE 129 is a 3 unit undergraduate elective course that meets 2 hours per week for lecture and 3 hours per week for laboratory. All students except EE's are required to have taken the lower division Introduction to Materials (MatE 25) course; EE's are required to have taken MatE 153. Chemical engineering majors are required to have taken Transport Phenomena (ChE 190). Materials engineering majors are required to have taken Electronic, Optical and, Magnetic Properties of Solids (Mat 153). Electrical engineers are required to be taking Semiconductor Device Physics (EE 128) as a co-requisite. Physics, chemistry, and mechanical and industrial engineering majors are required to be in their last year of study. Although the students may not have specific knowledge of microelectronic device processing, they are assumed to bring a skill set in chemical kinetics or structure and properties of electronic materials or electronic devices or be mature in their own discipline.

The lecture course covers the fundamentals of integrated circuit fabrication, including silicon oxidation, impurity diffusion, physical and chemical vapor deposition of thin films, surface preparation, photolithography, and etching. During the parallel 15-week laboratory section,

student teams process device wafers using a five-mask, metal gate pmos process, as well as design and perform a series of experiments in process development.

Much effort is made to create a class culture as exciting as a start-up company. All class handouts are labeled “Spartan Semiconductor Services, Inc.” along with our logo, rather than with the course name. Grade points are given for innovative ideas, through the Employee Incentive Program. We are contemplating whether to encourage students to start their own “start-up companies” with “venture capital” from the parent company and contract work from them. Guest speakers are brought in to lecture once or twice each semester on issues covered only peripherally in class such as packaging, environmental, health, and safety, or process integration. The simulated corporate atmosphere compels students to take ownership of their learning and to recognize the mutual dependence between themselves and their team to get the job done.

III. Team Structure

Teams of students are assembled for both the lecture and the laboratory sessions. In the lecture, cooperative learning techniques³ are used with students randomly arranged in two or three-member groups when needed. There they work on open-ended problems and discuss their results in class. Often they must better define the question posed before they can develop an answer. These exercises reinforce the notion of group learning and illustrate that there is often more than one “right” answer to a problem. All students attend the same lecture session. In the laboratory, students are arranged in four or five-member teams by the instructors on the first day of class on the basis of a survey that the students fill out. The teams are made as heterogeneous as possible based on GPA (above or below 3.0), work experience (relevant or not), and major. Each team is given a color either red or blue and asked to choose a team name. Fab Five, Red Monday, and Blue Angels are some of the creations. The members of the laboratory teams are the same for the entire semester.

Two teams meet at the same laboratory session each week. After an introductory session, the semester is divided into a sequence of six 2-week periods for the processing part of the laboratory. The final two weeks of the semester are devoted to testing the devices made. During each of the 2-week device processing sessions, one team is assigned to build integrated circuit devices and the other is involved in a process development experiment. The teams switch roles every two weeks. The Fabrication and Test team (the FATs) are the device builders. Their objective each week is to take the wafers through a section of the pmos process which consists of approximately 150 total steps. They communicate the status of the batch of device wafers at the end of the two weeks in an Oral Status Report before passing this job on to the other team in their session. The pmos process sequence that the FATs follow is contained in a traveler. The FATs are also responsible for documenting the actual processing sequence used and possible alternatives that were considered. The other team in the lab session is involved in Process Development (the PROs). This team is assigned to investigate one of the process steps and to either characterize it or try to improve it. At the end of the two-week period, the PROs report their results in poster form. Each poster is then displayed in the foyer of the laboratory so that the entire class can evaluate it.

Group grades are assigned on the basis of the oral status reports and the posters. The objective of the reports is clear, concise and effective presentations from which the new team gets enough information to carry out the next step in the process. There is only one set of device wafers for

the entire section, so they get passed back and forth between the teams every two weeks. Thus the final product of the course (working microelectronic devices) depends critically on each team keeping accurate and complete records of their contributions to the process during each session.

IV. Entrepreneurial Approach

The primary goal of building functional microelectronic devices during the semester long course inspires a passionate effort on the part of both the students and the instructors. The allure of learning just how microelectronic devices are made is a strong motivational factor in carrying out this long term project. "Sure everyone uses computers, but I know how the brains of a computer are made," is typical of the sentiments of students having completed the course. The Fat teams follow a process traveler to build the devices. Initially they treat the traveler like a recipe for cookies in which a proven series of steps leads to a predictable result. They quickly find out that in contrast to a cookie recipe, the steps detailed in the traveler are anything but predictable. This teaches them that they need to monitor the process at intermediate points using test wafers in order to achieve a desired outcome. Moreover, in order to accomplish all of the steps necessary to reach a desired point in the processing during a given lab session, each student within the Fat team has to have a clearly defined role. One person can not possibly carry an entire team, and each individual member has individual accountability to complete a given task.

Most students find the responsibility of thinking about how an individual processing step fits into the larger whole daunting at first, but gain confidence in their abilities, albeit at different rates, with experience. For some, carrying out a well-defined procedure in a set time is a relatively new experience. The majority in the middle tier expend the enormous effort required to gain command over the approximately 150 step process used to build the pmos transistors and assume ownership of their work. These students ask the other team in their section about the device wafers when they are involved in a Pro experiment and are clearly concerned when problems arise. The handful in the top tier are able to take the effort expended and conceptualize it. One instructor works closely with a Fat team each session instructing students on the use of equipment, searching for explanations of test and device wafer results, and asking how a processing step will alter the device cross-section. Both the students and the instructors assume multiple roles that change as the process evolves. There is a sense of urgency in this enterprise because a relatively large number of processing steps must be completed in each 3 hour lab session to produce functioning device wafers by the end of the semester. The Fat team duties emphasize interdependence both within an individual team to accomplish a given sequence of processes and between the teams that handle the same device wafers since information transfer is essential to the quality of the final product. The multiple roles, urgency, and interdependence needed to complete a long-term objective are typical of start-up companies and are one aspect of the entrepreneurial approach to learning and teaching.

Integrated with the building of microelectronic devices are multiple open-ended design projects. The Pro teams complete these short-term (2 week) experiments. Ostensibly the experiments are done to improve "profitability," but often the chance to deepen an understanding of one aspect of microelectronic device fabrication is a sufficient driving force to evoke considerable effort. Both the students and the instructors must learn to balance risk with reward, however, since only two weeks are available to design and carry out a given experiment. The Fab Five in the Spring 1996 semester chose to investigate the effect of surface preparation on the growth of silicon oxide in the surface reaction limited regime by a thermal oxidation process. Surface preparation or

cleaning was discussed in lecture the previous week so the students had some familiarity with the chemistries used. They did not know whether the aqueous solutions used to clean wafers would effect the oxidation kinetics, but they reasoned that each cleaning sequence produces a different surface termination which should influence the oxidation reaction at the surface in this regime. This reasoning paid off in a statistically significant difference in the oxidation kinetics depending on which of three cleaning procedures was used. The Pro team concept creates competition but between teams not individuals. The teams try to up one another which spurs novel ideas. Threading short-term projects that are open-ended in nature with a long-term goal is another aspect of the entrepreneurial approach.

A professional work environment is organizationally intensive but an important element of the course. It consists of preparing an employee handbook, fostering team communication skills, demanding excellence of each student, creating a World Wide Web page, and choosing a logo. A Spartan Semiconductor "Employee Handbook" contains most of the documents needed to work for the "company." The handbook is divided into five sections: (1) *Employee Handbook* which contains administrative documents such as the syllabus, lab schedules, and lecture schedules; (2) *Continuing Education* which contains the lecture notes used in class and supplementary reading materials not covered in the textbook; (3) *Process Handbook* which contains the traveler and other supplementary information on safety, etc.; (4) *Problem Solving Exercises* which contain both the homework and the in-class problem solving exercises; (5) *Executive Memos* which contain memorandums from the company officers detailing important information not covered elsewhere. Team communication skills are built using cooperative learning techniques⁴ which are applied at the start of the course to non-content specific exercises, such as a desert survival problem which demonstrates the utility of teamwork and the different roles that are necessary. Content specific exercises are introduced during the lectures. These skills are essential for effective team performance and for creation of a noncompetitive, interdependent work environment.

Another element to creating a professional work ethic is demanding excellence of the students. A significant effort is expected on the part of each student, not only the team. Each student is held individually accountable by constant questioning during all aspects of the lecture and lab sessions, by submitting a final report describing the fabrication of the device wafers, and by taking a final examination. A World Wide Web page for the "company" is in the process of being created which contains an introduction to the course and a portion of the "Employee Handbook." The web page fits in with the company atmosphere, helps to disseminate the teaching technique, and acts as a reference source via the computer in the fabrication lab. It will also serve the important purpose of documenting changes to the process traveler by the Fat teams and archiving the results of the experiments done by the Pro teams. The logo of the company appears on all documents. "Sparky" as it is commonly called is a warrior standing atop an integrated circuit device ready to do battle.

The last aspect of the entrepreneurial approach is to make efficient use of the local talent pool. SJSU educates an engineering work force for the microelectronic, aerospace, biotechnology, and environmental industries in the San Francisco Bay Area. The undergraduate engineers at SJSU are ethnically diverse and often work at companies both big and small in Silicon Valley while attending school. The ethnic diversity means that communication skills need improvement which raises a barrier to effective teamwork. Their work ethic, however, is already well developed as

many students support their families. Moreover, the tasks that many of them are involved in at work find resonance in some part of the course which provides another avenue for students to make a contribution to the course.

The mix of all of these elements makes for a challenging course to teach and to take since so many activities are happening in parallel. Device building, experimentation, team building, and content specific knowledge, in this case microelectronic device processing, are the key activities that the glue of the start-up company and professional work environment hold together. Both students and faculty bring a unique skill set to the course and all depart having that skill set extended. We have found this approach allows faculty and students to jointly own, launch, manage, and assume the risks of the educational enterprise.

The course has proven to be portable. It has been successfully implemented at the Department of Materials Engineering at California Polytechnic University, San Luis Obispo, CA.

Summary

The elements of an approach to education that contains many aspects of the entrepreneurial process have been combined to teach a course in microelectronic device fabrication. The essential parts of this approach are:

- Alluring long-term project threaded with short-term open-ended experiments.
- Start-up company culture.
- Professional work environment.
- Team based work units combined with individual accountability.
- Efficient use of the local talent pool.

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