Curriculum Innovation and Integration in Electronic Materials Processing and Engineering

Jane P. Chang
Department of Chemical Engineering, University of California, Los Angeles, CA 90095, USA
(310) 206-7980, jpchang@ucla.edu

Abstract: The semiconductor manufacturing industry is undoubtedly the largest chemical engineering industry since the once-dominated petroleum industry, and is revolutionizing the chemical engineering industry and taking it into the next summit. Chemical engineers are needed to design, operate and control the sophisticated chemical processes that fabricate the chips, and continuously research and develop new processes for the next generation integrated circuits. These individuals require knowledge of mathematics, physics, chemistry, and engineering that is essential for engineering materials at nanometer dimensions. The traditional engineering education training is often inadequate in preparing the students for the challenges presented by this industry's dynamic environment, and insufficient to meet the employer's criteria in hiring new engineers. Clearly, significant effort is required to change the way materials processing and engineering was taught. It is critically important to train the students in the scientific and technological areas that are pertinent to the microelectronics industries, and allow them to practice engineering principles in a laboratory environment. This paper describes a new multidisciplinary curriculum and training program at UCLA that provides knowledge and skills in semiconductor manufacturing through a series of courses that emphasize on the application of fundamental engineering disciplines in solid-state physics, materials science of semiconductors, and chemical processing. The curriculum comprises three major components: (1) a comprehensive course curriculum in semiconductor manufacturing; (2) a laboratory for hands-on training in semiconductor device fabrication; (3) an interactive learning website that provides access to students outside UCLA and industrial mentors. The capstone laboratory course is designed to strengthen students' training in "unit operations" used in semiconductor manufacturing. The laboratory course comprises the most comprehensive training (seven photolithographic steps and numerous chemical processes) in fabricating and testing complementary metal-oxide-semiconductor (CMOS) devices. Students form teams with electrical engineers and material scientists to practice engineering principles using the state-of-the-art experimental setup.

Keywords: Chemical engineering, semiconductor manufacturing, electronic materials.

1. Introduction

The advances in microelectronic technology and telecommunication have undoubtedly changed the way people and nations interact and will continue to impact our daily lives. The heart of this industry is the computer chip and the tiny solid-state transistors and capacitors that comprise it. By constantly shrinking the device dimensions, integrated circuits have become more and more powerful, while the cost per function has continued to decrease. For example, memory cells at dimensions below 0.18 micrometers can store gigabits of information in computers, and quantum electronic devices made from compound semiconductors can provide signal switching and amplification at speeds in excess of 150 gigahertz. All technological advances hinge on developing sophisticated chemical processes for depositing, patterning, and etching thin-film circuits onto semiconductor surfaces. To maintain the speed at which innovations and inventions are generated, there is an unprecedented demand of highly educated and trained engineers in semiconductor manufacturing industry in the United States, and throughout the world. The demand for experienced engineers has intensified with the development of revolutionary new products for the internet, computers, and for communication technologies. Engineering education innovation is needed to meet the dynamic changes in employment.

Chemical Engineering is a discipline with a broad science and technology base, and its practice has led to numerous technological innovations in energy, environment, medicine, biotechnology, and most recently, microelectronics.

Chemical engineers have an important role to play in microelectronics technology. They are needed to design, operate and control the sophisticated chemical processes that fabricate the chips, and continuously research and develop new processes capable of making the next generation of denser and denser integrated circuits. These individuals require knowledge of mathematics, physics and chemistry that is essential for engineering materials at dimensions between 10 and 1000 angstroms.

Engineers with at least four-year college degree accounted for one-third of the workers in this industry, and students with specialized training in semiconductor manufacturing are highly sought after by government laboratories, industries, and academia. However, the traditional engineering education training is often inadequate in preparing the students for the challenges presented by this industry's dynamic environment, and insufficient to meet the employer's criteria in hiring new engineers.

Clearly, the University should provide additional resources to change the way engineering of materials was taught. It is critically important to train the students in the various scientific and technological areas that are pertinent to microelectronics and nano-fabrication industries, and allow them to practice engineering principles in a laboratory environment with the state-of-the-art experimental setup. This paper presents a new multidisciplinary curriculum and training program to provide a systematic education for engineering students in Semiconductor Manufacturing and Nanotechnology. The knowledge and skills will be provided through a series of courses that emphasize on the application of fundamental chemical engineering disciplines in solid-state physics, materials science of semiconductors, and chemical process engineering. The curriculum has three major components: (1) a comprehensive curriculum in semiconductor manufacturing; (2) one laboratory for hands-on training in semiconductor device fabrication; (3) an interactive website learning format that provides access to students outside UCLA and industrial mentors.

The curriculum contains specialty courses on various technologies used to fabricate microelectronic devices, including, for example, chemical vapor deposition, plasma processing, photolithography, wet-chemical cleaning, ion implantation, silicon oxidation, and contamination control. The instruction culminates in the laboratory course: Semiconductor Processing Laboratory. The laboratory hours provide students with hands-on training on IC fabrication, and give them an opportunity to investigate new manufacturing technologies. Moreover, the course materials and lab experiments will be posted on the website to allow interactive learning outside the classroom.

2. Curriculum

The Chemical Engineering Department at UCLA offers a wide selection of undergraduate courses and five options – general chemical engineering, semiconductor manufacturing, environmental engineering, bioengineering, and biomedical engineering. Many undergraduate students also take advantage of numerous graduate-level subjects and research topics in their senior years. This type of exposure is invaluable in preparing them for work as chemical engineers for graduate school, industry, or government in chemical engineering.

2.1 Core Course Requirements

The Department of Chemical Engineering at UCLA offers students a comprehensive curriculum in solid-state physics, materials characterization, semiconductor processing, and the principles of IC manufacturing. The new semiconductor manufacturing option is designed to provide in-depth knowledge of the field such as Surface and Interface Engineering, Electrochemical Processing, Plasma Processing of Materials, and Physical and Chemical Vapor Deposition.

Students majoring in the Semiconductor Manufacturing Option start to take specialty courses as early as the last quarter in their sophomore year. The course on Science of Engineering Materials introduces the students to various materials used in engineering design. The next specialty course on Physics of Materials teaches the students the electronic, optical, and magnetic properties of solid materials. One additional course on the Physical Principles of Semiconductor Devices prepares the students on the fundamentals of semiconductor materials, p-n junctions, and based semiconductor devices. These prerequisite courses prepare the students for the capstone laboratory course on Semiconductor Manufacturing.

Table 1. The Curriculum in Semiconductor Manufacturing

Course Requirements (47 courses, 199 units)	
Chemical Engineering	14 courses
Chemistry & Biochemistry	8 courses
Mathematics	6 courses
Physics	3 courses
Material Science & Engineering	2 courses
Electrical Engineering	2 courses
Computer programming	1 course
English	1 course
Elective courses	
- General Education	6 courses
- Semiconductor Manufacturing	2 courses
- Chemistry	2 courses

2.2 Specialty Course Requirements

In addition to the core courses, two elective courses in the semiconductor manufacturing area are required from the course listing below.

Table 2. Specialty courses

Fundamental Subjects	Advanced Topics
Physics of Semiconductor Devices	Principles of ULSI Fabrication Processes
Materials Science of Semiconductors	Semiconductor Surface Science
Chemical Process Science	Chemical Vapor Deposition
Mechanical Design and Robotics	Reaction Kinetics of Semiconductor Processes
Semiconductor Equipment Laboratory	Principles in Plasma Processing
Semiconductor Device Processing Laboratory	Semiconductor Process Simulation and Modeling
	Electronic Packaging and Interconnection
	Flat Panel Display Technologies

The UCLA School of Engineering is world renowned for its scholarship in semiconductor physics, chemistry, and engineering, through its multidisciplinary approach towards the education and training for our undergraduate students. In addition, prominent semiconductor companies sponsor student research and training, and there are ample opportunities for interaction with the sponsors, including industry internships.

3. Laboratory Course

This course comprises of lectures and laboratory hours to provide both knowledge and training in semiconductor manufacturing. The lectures are organized into modules, including silicon crystal growth, diffusion, oxidation, chemical vapor deposition, ion implantation, photolithography, etching, metallization, fundamentals of semiconductors, p-n junction and MOS devices, and electrical characterization. In the laboratory, students form teams with electrical engineers and material scientist in carrying out the entire process flow in making solid sate devices, including capacitors, PN junctions, and CMOS transistors. Students are required to synthesize and apply the knowledge they have learned to the engineering of semiconductor manufacturing processes.

3.1 Example of Lectures

Ion implantation is one important process step in microelectronics fabrication. Students are trained to use a Monte Carlo based software (TRIM) which allows the students to learn the dynamics during ion implantation process. This topic ties very nicely to the mass-transfer problems in dopant diffusion that the students also learned in the class. TRIM is an experimental and research software ("The Stopping and Range of Ions in Solids", IBM software (1985)

ISBN-0-08-021603-X) developed by IBM for non-commercial and experimental use by researchers and students. Using Monte Carlo simulation, ion implantation is simulated by tracking the history of an ion through successive collisions with target atoms using the binary collision assumption detailed above. The trajectory of each ion as a function of its energy, position, and direction is determined. A large number of ion trajectory are calculated to yield statistically meaningful results [1]. An example of students' homework simulation results on ion distribution is shown below.

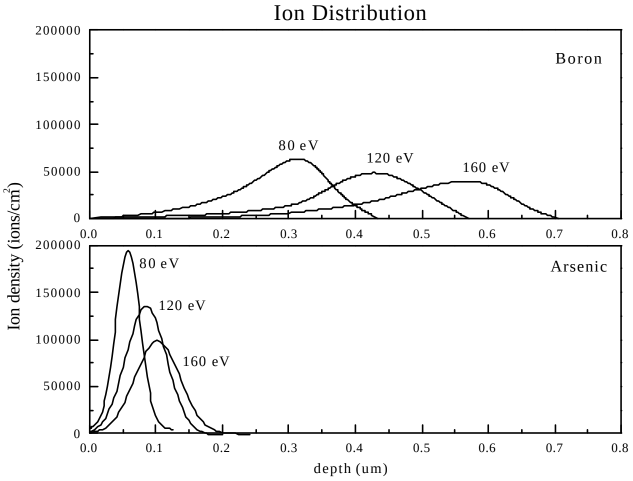

Figure 1. Ion implantation simulation.

Figure 2. Lectures given in the laboratory.

3.2 CMOS Fabrication in the Semiconductor Manufacturing Laboratory

A dedicated student micro-fabrication laboratory, ~700ft^2, is located inside the Nanoelectronics Research Facility at UCLA. It is a class 1000 HEPA filtered clean room where students conduct photolithography, wet cleaning, wet etching, and all metrology measurements. The advanced material processing steps are carried out in the Nanoelectronic research lab. The available equipment for the undergraduate teaching laboratory are listed below:

Table 3. Available laboratory equipment for students majoring in Semiconductor Manufacturing option

Lithography tools	Quintel 2001 contact aligner, photoresist coater, developer, and baking station.
Wet processing tools	Wet chemical cleaning bench for RCA and HF cleans. Spin-rinse dryers. Wet chemical etching bench for dielectrics and Al patterning.
Metrology tools	Nanospec AFT for measuring thin semitransparent films. Gaertner L116B automatic ellipsometer with variable angle of incidence. Miscellaneous optical microscopes with variable magnification. Tencor Alpha Step 200 profilometer. Omnimap 4 point probe for mapping sheet resistances. HP probe stations for I-V measurements.
Thermal processing tools	Thermal oxidation and annealing furnace. Metal sintering furnace.
Thin film processing tools	Low pressure chemical vapor deposition furnace. Three-target metal sputtering deposition system. Plasma enhanced chemical vapor deposition. Reactive ion etcher.

3.3 Integration of Lectures and Laboratory

The laboratory is currently capable of training 15 students per quarter. Students learn how to use state-of-the-art equipment to fabricate solid-state electronic devices and characterize the electronic device performance. Each team has to turn in a comprehensive team report at the end of the quarter summarizing the processing details and electrical characterization. Shown below are students learning how to operate process systems, the SEM image of a CMOS device made by the students, and the device characterization measured by the students.

Figure 3. Students learning oxidation process.

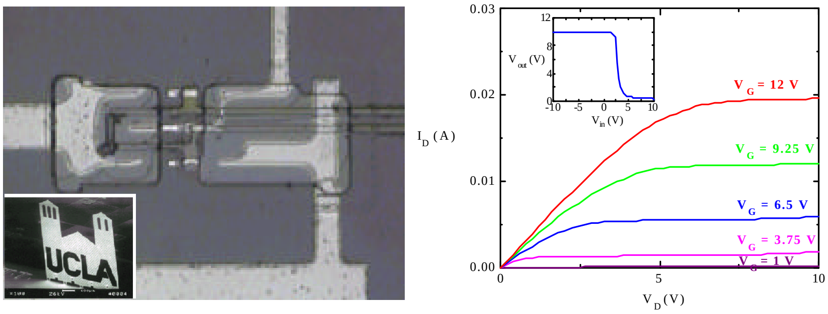

Figure 4. CMOS device fabricated at UCLA and device results.

4. Interactive Website

An interactive website is designed to serve the students in the UC systems and the Semiconductor Industry with information and assistance in technology development and human resources. The purpose of this website is to provide students with up-to-date information on technological innovation and an “up-to-minute” resume submission. All the Nanolab users and senior undergraduate students who are taking CMOS processing course can submit their resumes to this website and update their resumes regularly. This website also provides "one-stop shopping" for companies who want to (1) learn about UC research in this field, and (2) access students who are graduating with formal training in semiconductor manufacturing. Additional links are provided to UC faculty and companies currently participating in this program.

http://www.semi.ucla.edu

Figure 5. The University of California Multi-campus Semiconductor Manufacturing Program Home Page.

5. Conclusions

Curriculum innovation and integration in electronic materials processing and engineering is needed for training chemical engineering students for the 21st century. This new multidisciplinary curriculum is an ambitious program that aims at the education and training, in Semiconductor Manufacturing, of engineering students from a variety of disciplines. This is a technologically advanced area of manufacturing that faces significant labor shortages. Students who have successfully completed this option are highly sought after by industrial recruiters and academic graduate programs nationwide.

6. References

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