# A Web-Based Course in Chemical Engineering:
# "Fundamentals and Design of Microelectronics Processing"

**(http://www.uic.edu/eng/meng/che_494.htm)**

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The ability to instantly communicate and exchange information with anyone at anytime, anywhere in the world, i.e., the Internet, has eliminated distances that once kept people apart. Here, we focus on the course "Fundamentals and Design of Microelectronics Processing," which was offered *for the first time* on the Web in Spring 2000. In fact, this is the first course ever to be offered on the Web from the Chemical Engineering Department at UIC; to our knowledge, this is also the first chemical engineering (ChE) microelectronics course ever to be offered on the Web. Through this web-based dual-level ChE course, we present and discuss our experiences on the impact the Internet is having in the field of engineering education. We also examine the Internet's potential benefits to learning and what it means to teach a graduate/advanced undergraduate engineering course on the Web.

## The Dual Level Graduate/Undergraduate Course

Increasingly more chemical engineers are entering the field of microelectronic materials and processing, in part because basic knowledge of this fast growing field lies in chemical engineering. Novel ultra-thin dielectric materials, passivation of silicon and silicon germanium, surface and gas phase reaction chemistry in microfabrication techniques, diffusion of impurities through the films, and process-structure-function relationships in micro- and nano-electronics processing are some representative example-systems [1-11]. Chemical, electrical and material engineering principles in the fundamental understanding and design of microelectronics processing are bringing about great changes in integrated circuits, micro-electro-mechanical systems (MEMS), and other fields in which data acquisition, computation, or controls are necessary. Several chemical engineering departments (worldwide) have been either offering courses in microelectronic materials and processing or incorporating several examples and case studies in core curriculum chemical engineering courses (e.g., [12-14]).

In Spring 1997, UIC started a dual-level class (offered to graduate and advanced undergraduate students) entitled ‘Fundamentals and Design of Microelectronics Processing.' The objective of this course is to provide participants and students the basic principles and practical aspects of the most advanced state of electronics and MEMS processing. The emphasis of this course is on basic aspects of thin film growth, substrate doping and passivation, ion implantation, lithography and etching coupled with chemical kinetics, reactor design, thermodynamics, optimization and other engineering concepts as they apply to fundamental processes useful for feature sizes down to the order of about 0.01 - 1 μm. Therefore, the principles and philosophy underlying the selection of topics and their ordering focus mainly on fundamental notions of transport, reaction kinetics, thermodynamics, and reactor design along with process-structure-function relationships in electronic materials and microfabrication. In the Spring semester of 1998, the scope and effectiveness of this course was substantially enhanced and augmented with the introduction and implementation of two web-based semiconductor simulation tools [15-16]: ThermoEMP and TSuprem-4. Table 1 shows the outline of the course on the Web that consisted of 41 lectures; the number of lectures listed for each heading in the course outline is not meant to be related, however, to the number of bulleted subjects underneath. Further, in the Course Information section of the class there are several additional items including: (i) two lectures introducing those two web-based simulation tools along with step-by-step instructions and working examples, and (ii) extensive external links.

## Web-Based Instruction of the ChE Course

Instead of attending classes in a centralized institution or location, Students can sit in front of a computer monitor anywhere in the world, to viewing, listening and interacting with class materials that have been designed for that purpose on the Internet. In order to design effective class material for all students, we needed to take into account different learning styles. They included different ways of learning: visual, audio, reading and writing, and interactive (examples are provided at http://www.uic.edu/eng/meng). Therefore, we had to prepare materials with the different learning styles in mind.

Various components were incorporated into the ChE class materials so as to mimic and enhance the real live experience of a classroom. Extensive audio segments of the professor lecturing, for example, discussed specific issues and topics in depth, during this first offering of the course on the Web. In a classroom, when a student has a question, (s)he raises his(er) hand and immediately attracts the professor's attention. On the web, there were several effective ways to communicate with the professor, teaching assistant, and classmates. By means of "asynchronous and synchronous" communication tools such as email, bulletin boards and chat rooms, the students and participants in the ChE class last Spring could maintain contact with the instructor and fellow classmates. Bulletin boards and email turned out to be the main communication tools.

Text is the easiest material to prepare for computer-based learning. Text on a computer could be easily improved by taking advantage, for example, of HyperText Markup Language (HTML) and hyperlinks. It could be prepared to look like a book or a set of slides. Further, any document already existing in electronic format could be easily published on the Web. In our course, an electronic set of extensive written notes were included as the core reference material. This was in no way a substitute to the traditional textbook(s) and/or other references. In fact, several references and relevant journal articles as well as other reading assignments were utilized every 3-5 lectures. The entire set of electronic notes was created with an HTML editor. HTML also helped us to incorporate rich media such as photos, drawings, audio, interaction and, more importantly, hyperlinks. Hyperlinks allowed students to click on an area of the document and immediately be transported to the previous or following chapter, to additional references published worldwide on the internet, bookmarked pages, an audio explanation by the professor, a graphical representation of the problem being discussed, or to other relevant sites.

We did not have to learn HTML because any current text-editor (Word, etc.) has the capability to translate to HTML for us. HTML could be considered as an encoder, a universal container in which you put your information. It is the universal language of the web so that anybody has the ability to see any information of interest with a simple web browser without requiring specialized tools. Such electronic sets of written notes can be updated and published on the web immediately. This is a significant benefit since current research and development would require material to be updated frequently. Yet, the overall preparation of the first electronic set of written notes coupled with photos, audio, interaction, hyperlinks and drawings turned out to be a substantially higher than anticipated commitment of time, effort and resources. It was estimated that our course took about three times more time and effort for its initial preparation on the Web compared to the preparation for a well-run traditional course. The lead time needed to get this course set up was about 6-8 months, while financial and personnel resources from the university were critically important and extremely helpful. Figure 1 shows an actual web page of our class that contains lecture material prepared using text with audio, hyperlinks, and additional explanations.

"Interactive/interaction" refers to learning by doing something. For engineering classes, it is becoming more frequent to use interactive programs to show various kinds of results. Examples could include the behavior of a chemical plant (students define the characteristics of the plant and observe its performance), fabrication of a micro-electro-mechanical system (students design/define sequential processes and understand the characteristics and performance of the system that is created), etc. Whenever one such interactive tool is available on the web, it can easily be linked to the class notes, for the benefit of the students.

Two effective examples in this ChE course were the simulation tools ThermoEMP and TSuprem-4 [15,16]. ThermoEMP (e.g., http://www.uic.edu/classes/che/che494/) is a computer program which calculates (1) the chemical equilibrium compositions of microelectronic materials processing and (2) the thermodynamic and transport properties of the equilibrium mixture (formed after reaction); results are generated through a methodology that minimizes the Gibbs free energy of the system via a rigorous thermodynamic analysis [17]. The minimum temperature above which oxide-free silicon growth (a very important requirement in the microelectronics industry) can take place, oxide-free silicon carbide growth in a variety of reaction environments, or the effects of dichlorosilane flow rate and temperature on the selective epitaxial growth of silicon can, therefore, be effectively studied with ThermoEMP; a remarkable aspect of these case studies is that students experience key issues in real life problems and they have the opportunity to see that solutions may be obtained, in some cases at least, within a very short period of time without doing any experiments (e.g., from fundamental knowledge-driven simulation tools) [15]. TSuprem-4 (licensed from Technology Modeling Associates (TMA), Inc.; http://www.uic.edu/classes/che/che494/) is a computer program for simulating the processing steps involved in the manufacture of silicon integrated circuits, discrete devices and MEMS [18]; in fact, a highly wide range of processing steps can be modeled by this program. Several examples demonstrating the effectiveness of TSuprem-4 have been presented and discussed in [15].

***Some Advantages***

Web-based learning was beneficial for those students who could not attend classrooms because of their personal or professional commitments, limited financial resources, or physical limitations. As a whole, all participants in the class, including the professor/teaching assistant, had something to learn. The instructors and students received immediate feedback. It was also useful for those students who perhaps were shy and afraid to ask questions in public, based on the students' "instructor and course evaluations" for this course at the end of semester. Another advantage was accessibility. Instructional material was available 24 hours a day, eliminating conflicts with one’s schedule. Because the instructional material was always available, learning was self-paced. From the point of view of the instructor, the preparation, editing and publishing all the material on the web for the first time was a huge undertaking that was made possible with the help of an internet-expert teaching assistant (Sanjit S. Dang), an expert multimedia professional (Raymond A. Matthes), and financial resources from the University of Illinois at Chicago. Our expectation is that once the class material is in electronic format, it may be easier to modify it and keep it up to date.

***Assessment of Students' Progress***

Assessing the progress of students in the Web-based ChE course was similar to the conventional classroom. Each lecture had a quiz, which was graded electronically by the instructor/teaching assistant. Although some of the Web management tools let you create simple multiple choice quizzes that are automatically graded by the system when the student submits the quiz, we decided against the use of multiple-choice quizzes in our course. This resulted in substantially greater effort in preparing and grading them; yet, this system of quizzes was found to be much more effective and challenging to the students. However, more sophisticated kinds of assessments could be prepared using Mallard, for example, a web-based interactive quizzing tool (http://www.ews.uiuc.edu/Mallard/Overview). Homework was posted on the web and had to be returned electronically to the instructor/teaching assistant. Since in Spring 2000 this course was on the Web for the first time ever, homework was accepted in paper format too. Exam assessment might be done electronically, but with the present technology it was deemed safer to do it the old fashioned way: in a classroom. Before each exam, there was one help session offered in both formats this time: in the classroom (extensive version) and on the Web (abbreviated version). Overall, in the learning expectations and the grading of problems and tests, there was some differentiation between advanced undergraduates and graduate students taking this class. All students had to do the same amount of core work; however, undergraduates were not required to do extra work and case studies.

A direct comparison of the averages on the mid-semester and final exams in the Web (Spring 2000) and traditional formats (Spring 1997, 1998, and 1999) of the course showed that students in the Web format scored about 15% higher than those in the traditional one. However, in such comparisons, two apparent assumptions have to be considered: (i) the exams had comparable difficulties, and (ii) the average caliber and background of the students who took the course during the last four spring semesters were the same. We believe that the former assumption is a good one. However, the latter assumption is very difficult to check.

### *Students' Feedback and Evaluations*

The feedback and written evaluations of the students on the scope and instruction effectiveness of the two web-based semiconductor simulation tools, ThermoEMP and TSuprem-4, were overwhelmingly positive: (i) students strongly agreed that it was easy to figure out how to use the simulation tools; (ii) they strongly agreed that the overall class experience was enhanced by the use of the software; (iii) they strongly agreed that it was convenient to have universal access to programs via the web; and (iv) they would like/have liked to use the simulation tools in other classes too.

The feedback and written evaluations of the students on the scope and instruction effectiveness of their first ever web-based course included several useful points. The students were strongly positive about

- the convenience of taking a lecture at any time, any place and pace they wished;
- the effectiveness of learning through the use of several multi-media approaches;
- the use of one quiz for each lecture;
- the availability of hyperlinks to several web sites of interest and reference;
- the help session(s) before each exam; and, perhaps, above all

- the half an hour long weekly meetings we had in the classroom throughout the semester. These meetings turned out to be very important in the trouble-shooting of many aspects of the implementation of this course on the Web for the first time.

The help session(s) before each exam in the classroom format were offered as extra help during this first year of the implementation of the course on the Web; we anticipate that starting next year, the help sessions, if any, will be totally on the Web. The live help sessions in the classroom before each exam as well as the weekly classroom meetings were praised as 'extremely helpful.'

The students had a variety of comments for other aspects of the web-based course experience:

- it was difficult to 'stay on task,' that is, quite a few students indicated they would most likely go through the lectures, quizzes and homeworks of this course as late as possible, since they did not have to go to the classroom at certain times, on specific days;
- there were a few difficulties early on, during the implementation of the course; they were related with the timing and 'error-free' posting of the course material as well as the fact that this was the first web-based course for everybody involved, students and instructors. However, problems were taken care of as soon as possible.
- More ways of student-student and student-instructor interactions (like increased participation in live chat rooms among students, live video-conferencing, etc.) could have been used.

Possible suggestions/solutions to the issues mentioned above could include enforced deadlines for quizzes, increased use of chat rooms and in particular video-conferencing, and continuous improvements of and additions to the posted material on the Web. We anticipate to implement such solutions by the time the course is offered in Spring 2001.

A direct comparison of the scores of the "instructor and course evaluations" for this course at the end of each of the last four spring semesters, 1997-1999 with the traditional format of the course and 2000 with the Web one, revealed that the "instructor's overall effectiveness" (one of the two required items in all evaluations at UIC) was the same every year, while the "overall quality of the course" (the other required item in the evaluations) had a slightly higher score in the Web format. These should be viewed, however, in the context that all course evaluation scores were already close to the highest possible one. Also, each time, the course had a comparable number of students.

Further insight that was gained from our experience as to how to improve attempts at true 'distance' education included: (i) unavailability of effective means for proctoring tests and exams outside the classroom, (ii) substantial benefit from video-conferencing, (iii) need for more thinking about minimizing students' tardiness with the class material (typically up to the time a test or homework problem set is due), and (iv) partial lack of ideas on how to handle students who may be willing to finish the course material (and everything else) at a fast pace, say, in 8 weeks instead of 16 weeks, although we did not have to deal with such a case in the spring semester of 2000.

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## TABLE 1

### Outline of the Course on the Web

***Introduction*** ***(3 Lectures)***

Introduction to Microelectronics Processing, Yield
Overview of Electronic Materials

***Crystal Growth*** ***(4 Lectures)***

Fundamentals of Crystal Growth Processes
Energy and Mass Transfer, Modeling

Doping, Design of Crystal Growth Processes,
Modeling and Simulation, Examples

***Thin Film Deposition*** ***(14 Lectures)***

Chemical Vapor Deposition (CVD)
Silicon Epitaxy, Thermodynamics

ThermoEMP as a Simulation Tool
(*Thermo*dynamics of *E*lectronic *M*aterials *P*rocessing)

A Priori Process - Property Relationships
Surface and Gas Phase Chemical Kinetics
Kinetics and Mass Transfer of Epitaxial Growth
Transport Phenomena, Reactor Design, Modeling
Silicon Germanium, Silicon Carbide
Metal Organic CVD (MOCVD)
Doping of Epilayers, Autodoping, Diffusion

Three-Dimensional Integration
A Priori Process - Property Relationships, Reactor
Analysis and Design, Selective Epitaxial Growth
Three-Dimensional Integration and Microfabrication, Examples

Epitaxial Evaluation, Thin Film Characterization,
Physical Vapor Deposition, Molecular Beam Epitaxy

Plasma - Assisted/Enhanced CVD (PACVD or PECVD)
Design of Plasma CVD Reactors, Modeling, Examples

CVD of Polysilicon, Amorphous Silicon, $SiO_2$ and $Si_3N_4$

***Passivation of Electronic Materials*** ***(4 Lectures)***

Thermal Oxidation of Silicon
Kinetics, Reactor Design, Modeling

TSUPREM-4 as a Simulation Tool

Oxynitridation of Silicon

Kinetics, Reactor Design, Modeling, Simulation, Examples
Degradation and Characterization of Dielectric Thin Films

Redistribution of Impurities during Thermal Oxidation

***Ion Implantation*** ***(3 Lectures)***

Fundamentals, Kinetics
Design and Process Considerations
Analysis and Design of Masking Films for Ion Implantation
Mathematical Modeling, Examples

***Advanced Lithography*** ***(5 Lectures)***

Chemistry and Physics of Lithographic Materials
Fundamentals of Surface Preparation
Positive and Negative Resists, Multi-Level Resists
Design and Control of Lithographic Materials
Advanced Lift-off Techniques, Problem Areas, Examples

***Dry Etching*** ***(4 Lectures)***

Low-Pressure Discharges, Physical and Chemical Phenomena
Selectivity - Feature and Pattern Size Control
Fundamentals of Dry Etching
Design and Process Considerations
Modeling - Simulation, Examples

***Wet Etching*** ***(2 Lectures)***

Chemistry - Physics, Thermodynamic and Kinetic Considerations
Analysis and Design of Wet Etching Processes
Characterization of Etched Substrate Surfaces, Modeling - Examples

***Design of Experiments*** ***(2 Lectures)***

How to Use Statistical Techniques, General Factorial Design
Factorial Design at Two Levels, Interaction Effects, Example
Analysis of Data, Minimum Significant Factor and Curvature Effects
Example

## FIGURE CAPTION

Figure 1.  Example of an actual web page of the class; it demonstrates the use of different media.