A WEB-BASED COURSE ON THE FUNDAMENTALS AND DESIGN OF MICRO- AND NANO-ELECTRONIC PROCESSES: CHALLENGES, INNOVATIONS AND BENEFITS

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Abstract *--- 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 a course on the fundamentals and design of micro- and nano-electronics engineering that was offered for the first time on the Web in Spring 2000. It was offered for a second time in Spring 2001. To our knowledge, this is the first chemical engineering (ChE) micro- and nano-electronics course ever to be offered on the Web. Through this web-based dual-level ChE course, we present related innovations and discuss our experiences on the impact the Internet is having in the field of engineering education, new technologies in engineering education, and preparing students for the challenges of nano-engineering in the 21st century. 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.*

Index Terms -— Novel web-based simulation tools, Micro- and nano-electronic processes, New technologies in engineering education, Web-based instruction

INTRODUCTION

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 nanometer length scale dielectric materials, passivation of silicon and silicon germanium, surface and gas phase reaction chemistry in microfabrication, impurity diffusion through the films, and process-structure-function relationships in the processing of micro- and nanometer scale electronic materials are some representative example-systems [1-7]. 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 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., [8]).

We started a dual-level class (offered to graduate and advanced undergraduate students) entitled 'Fundamentals and Design of Microelectronics Processing' in Spring 1997. The objective of this course is to provide participants and students the basic principles and practical aspects of the most advanced state of micro- and nano-electronic materials processing as well as MEMS processing. 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 relationships in electronic materials and microfabrication. In 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 [9]: ThermoEMP and TSuprem-4. Table I shows the outline of the course on the Web that consisted of 43 lectures and extensive external links.

TABLE I
OUTLINE OF WEB-BASED COURSE

Introduction	(3 Lectures)
Crystal Growth	(4 Lectures)
Thin Film Deposition	(14 Lectures)
ThermoEMP as a Simulation Tool	(1 Lecture)
Passivation of Electronic Materials	(4 Lectures)
TSUPREM-4 as a Simulation Tool	(1 Lecture)
Ion Implantation	(3 Lectures)
Advanced Lithography	(5 Lectures)
Dry Etching	(4 Lectures)
Wet Etching	(2 Lectures)
Design of Experiments	(2 Lectures)

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INNOVATIONS OF THE WEB-BASED INSTRUCTION OF THE COURSE

In order to design effective class material for all students, we needed to take into account different ways of learning that included visual, audio, reading and writing, and interactive modes. Therefore, material had to be prepared 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. On the web, there were several effective ways to communicate and interact 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 in the class could substantially interact with the instructor and fellow classmates in Spring 2000 and 2001.

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. In our course, an electronic set of extensive written notes were included as the core reference material. Several references and relevant journal articles as well as other reading assignments were utilized every 3-5 lectures. HTML also helped us to incorporate rich media such as photos, drawings, audio, interaction and, more importantly, hyperlinks. 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 and enhanced 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 substantial 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. Figure 1 shows an actual web page of our class that contains lecture material prepared using text with audio, hyperlinks, and additional explanations.

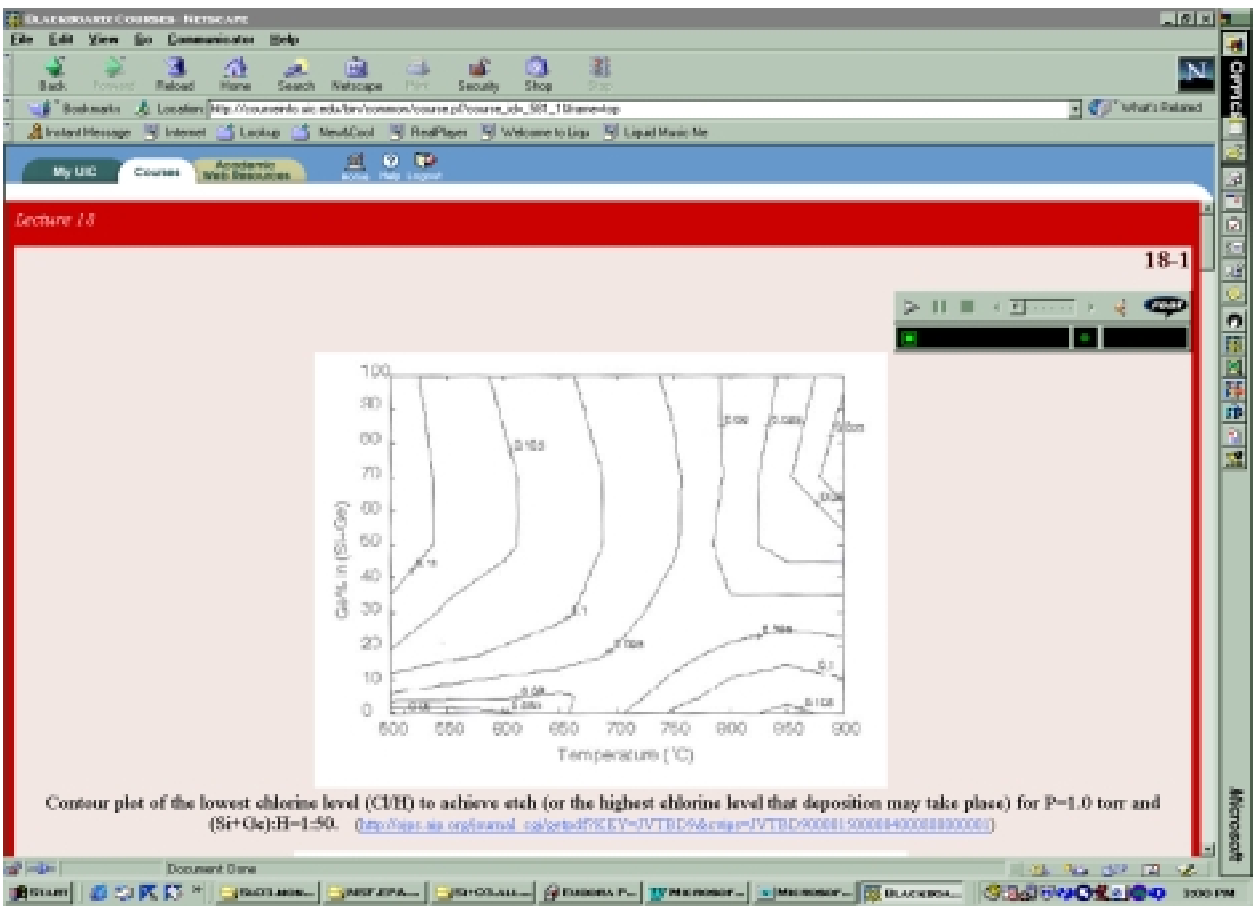

FIGURE. 1

EXAMPLE OF AN ACTUAL WEB PAGE OF THE CLASS; IT DEMONSTRATES THE USE OF DIFFERENT MEDIA

Two effective examples in this ChE course were the simulation tools ThermoEMP and TSuprem-4 [9]. ThermoEMP is a computer program which calculates the chemical equilibrium compositions of microelectronic materials processing; results are generated through a methodology that minimizes the Gibbs free energy of the system via a rigorous thermodynamic analysis [10]. The minimum temperature above which oxide-free silicon growth (a very important requirement in the electronics industry) can take place or the effects of dichlorosilane flow rate and temperature on the selective epitaxial growth of silicon can, therefore, be effectively studied apriori and very quickly. Figure 2 shows this basic three-step web-based simulation tool. TSuprem-4 (licensed from Technology Modeling Associates (TMA), Inc.) is a computer program for simulating the processing steps involved in the manufacture of silicon integrated circuits, discrete devices and MEMS [11].

BENEFITS OF THE WEB-BASED COURSE AND ASSESSMENT OF STUDENTS' PROGRESS

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. 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" at the end of semester. Another advantage was accessibility. Instructional material was available 24 hours a day. Because the instructional material was always available, learning was self-paced. From the instructor's point of view, the preparation, editing and publishing of all material on the web for the first time was a huge undertaking. Once the class material was in electronic format, it was easier to modify/update it.

Assessing the progress of students in the Web-based ChE course was superior to that in the conventional classroom. Each lecture had an essay type quiz, which was graded electronically by the instructor/teaching assistant. This system of quizzes was found to be extremely effective and challenging to the students. Homework was posted on the web and had to be turned in electronically. 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: in the classroom and on the Web.

A direct comparison of the averages on the mid-semester and final exams in the Web (Spring 2000, and 2001) 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. Yet, 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 was a good one. However, the latter assumption is very difficult to check.

CHALLENGES FOR THE STUDENTS AND THE INSTRUCTOR

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 [9,12]: it was easy to figure out how to use the simulation tools, the overall class experience was enhanced by the use of the software, and it was convenient to have universal access to programs via the web.

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 (i) the convenience of taking a lecture at any time, any place and pace they wished; (ii) the effectiveness of learning through the use of several multi-media approaches; (iii) the use of one quiz for each lecture; (iv) the availability of hyperlinks to several web sites of interest and reference; (v) 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 the first time. The live help sessions in the classroom before each exam as well as the weekly classroom meetings were praised as 'extremely helpful.'

Further insight that was gained from our experience as to how to improve attempts at true 'distance' education included: unavailability of effective means for proctoring tests and exams outside the classroom, substantial benefit from video-conferencing, need for more thinking about minimizing students' tardiness with the class material, and 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.

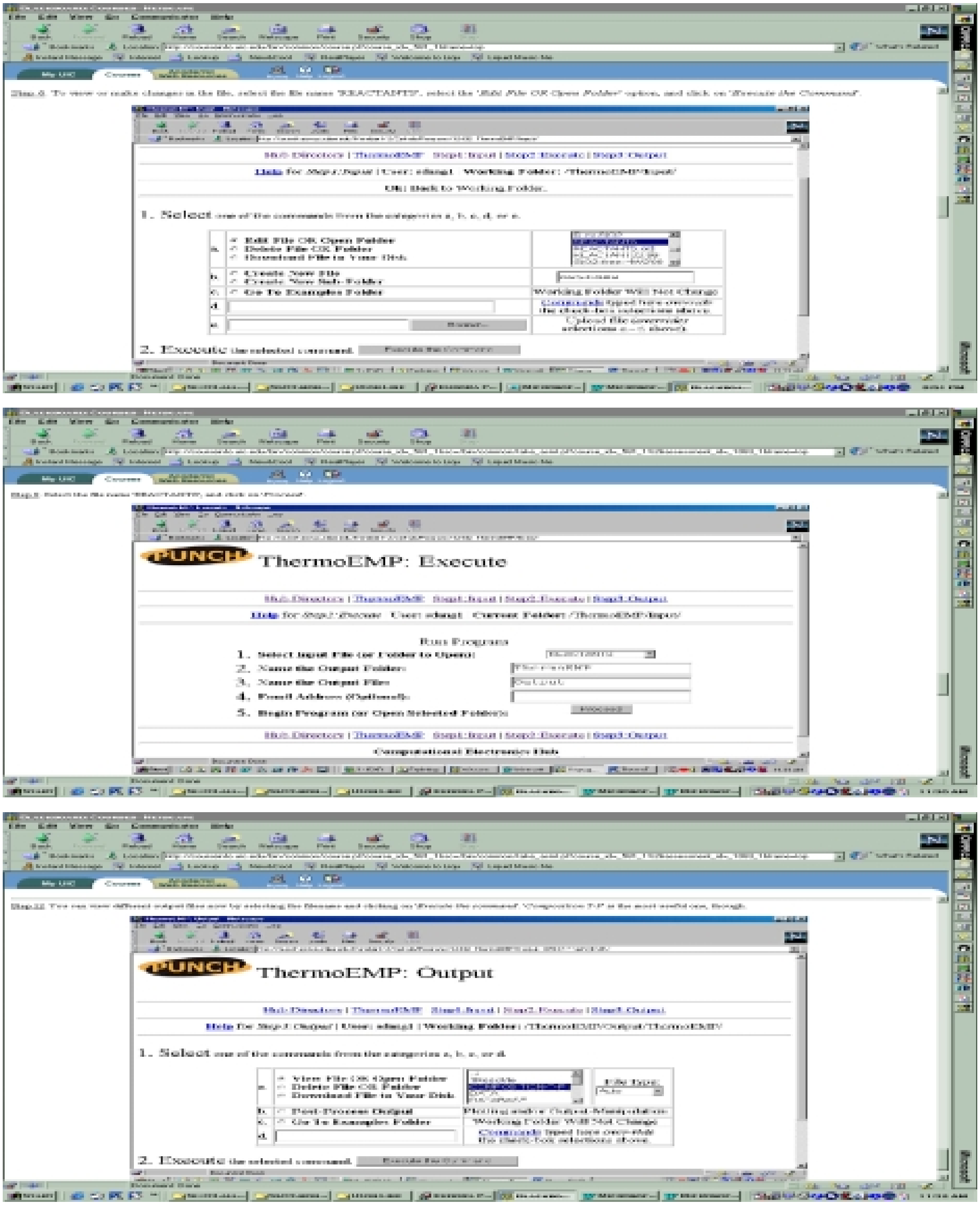

FIGURE. 2

THE THREE-STEPS OF THE WEB-BASED SIMULATION TOOL "THERMOEMP": PREPARATION OF INPUT FILE (TOP), EXECUTION OF THE SIMULATIONS (MIDDLE), AND ACQUIRING OF THE OUTPUT FILES (BOTTOM)

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