Design of a Course in Semiconductor Device that Emphasizes Integration of Knowledge

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Abstract- A new approach to teaching a traditionally engineering science oriented, required senior level course in semiconductor devices was used in our Department of Electrical and Computer Engineering. The new approach is called *Integration of Knowledge*, which is also one of our campus principles of undergraduate learning. Utilizing SUPREM IV software the course also integrates contents from electromagnetics, solid-state physics, electronics, and circuit analysis into the design and analysis of three- and four-terminal semiconductor devices starting with the basic pn junction. The course was also designed with ABET EC2000 in mind. The new approach was offered in Fall 2000 semester with 22 students, and an assessment of student satisfaction with the course and with their learning is reported.

1. Introduction

This report describes the redesign of a required, senior course in semiconductor devices where students are asked to assimilate a diversity of knowledge types. That is, instead of teaching the course as a traditional engineering science course with fundamental engineering principles with problem solving, the new course asks students to integrate the following knowledge types: engineering science, solid-state physics, manufacturing, and computer-aided design. A course of this kind supports one of out campus general education principles—*the Integration of Knowledge* [1]. The benefits of asking students to integrate knowledge are (1) to show students that knowledge is not bounded by traditional course boundaries, (2) to promote understanding through multifaceted approach to learning, and (3) to bring in experts from different disciplines to provide students with different views and experiences that will enhance their understanding of the course materials. The integration of knowledge will be facilitated by assigning students a significant project that will require them to apply knowledge from all aspects of the diverse approaches covered by the faculty and guest lectures. This course design principle has been used successfully in the development of another senior course, an elective in the design of electronics for electric and hybrid-electric vehicles {2,3].

2.0 Types of Knowledge Being Integrated

In the old ABET nomenclature, our old course in semiconductor devises was considered to be an engineering science course. While this orientation might be perfectly suitable for a program that sends a large number of its students to graduate programs, it is not a good fit for our program. Thus, we decided to redesign the course by including a semiconductor design-oriented component that introduces the student to related aspects such as solid-state physics, fabrication, computer-aided design, simulation, and the use of SYPREM IV, a software package that is available on the PUNCH Hub at Purdue-WL through the Internet. Thus, for a unit on PN junction devices as a basic building block for optoelectonic devices, we will cover optical spectrum, light absorption, electron-hole recombination and generation, light induced current, compound semiconductors, and optical properties of compound semiconductors to explain the underlying physics of the device. In

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order for students to understand how to obtain the various current-voltage characteristics, electromagnetic theory will be integrated into the design aspects of the device. To accomplish the goal of facilitating the integration of knowledge, the following types of knowledge will be incorporated in the course:

2.1 Solid-State Physics

This includes semiconductor fundamentals, carrier modeling, carrier action, photon properties as applied to solar cells, LEDs, and photodetectors, and we will include efficiency consideration, spectral irradiance, compound materials, and substrate selection.

2.2 SUPREM Software

This is a software package that simulates the processing steps used in the manufacture of silicon integrated circuits (IC) and discrete devices. This includes inert-ambient drive-in, oxidation of silicon, polysilicon, and silicon nitride, ion-implantation, expitaxial growth of silicon, and low and high temperature deposition and etching of various materials.

2.3 Electromagnetics

Topics in electromagnetics will include the solution of Laplace and Poissons' equations to study static performance of various devices. In addition, Maxwell's equations in static fields are incorporated into device performance.

2.4 Device fabrication

This knowledge type includes the IC processes required for the manufacture of various devices, including diodes in the form of solar cells, photodetectors, and LEDs, and other devices such as BJTs, MOSFETs, and SCRs. The PN junction diode is used as a building block in the IC processes of other devices.

2.5 Computer Simulation

This considers of the use of modeling for low and high frequencies. Secondary effects such as hot electron effect, aluminum spiking, short channels, and mobility degradation will also be included for short channel devices.

2.6 Applications

The course incorporates real-world analog and digital applications of semiconductor devices.

3.0 Course Contents

The course contents will include the following:

3.1 Semiconductor Materials

This section introduces students to semiconductor materials from the properties and structures points of view, the physics associated with carrier modeling and action, and the concept of recombination-generation using the equation of continuity and related concepts of diffusion length and carrier life times.

3.2 Basics of Device Fabrication

In this section we cover fabrication processes including oxidation, diffusion, ion implantation, lithography, thin film deposition, and epitaxy.

3.3 PN Junction Diodes

Students are asked to integrate knowledge of solid-state physics and electromagnetics through an application of Poisson's equation to describe the static characteristics of junction diodes, including charge, potential, and field distributions across the junction. Breakdown voltage is also characterized in this section.

3.4 Dynamic Analysis

Students are asked to integrate knowledge of methods of circuit analysis and principles of electromagnetics to develop small signal models, the capacitance-voltage relationship, and transient behavior.

3.5 High Current Phenomena

High-level injection is introduced with limiting cases such as punch-through, breakdown, and avalanching.

3.6 Application to Photodevices

Students are introduced to applications using photodevices, including photodetectors, solar cells, and LEDs. In order to understand how these devices operation, students must integrate knowledge of optical spectrum and R-G center concepts with PN junction characteristics.

3.7 Applications of Photodevices to Electronic Products

Finally, applications in modern communication networks using optical fibers, solar cells to power hand-held calculators, battery chargers, and communications are covered.

3.8 Computer Simulation (2 weeks)

Students are given a tutorial on the use of the Purdue University PUNCH semiconductor Hub and the software supported by the Hub. Accessed through the *I*nternet, this hub is a set of network-based laboratories that provide toolkits of programs for various fields. Students, researchers and engineers can access software, use software tools, view results, and download data via a specialized www server that interfaces to standard www browsers. SUPREM IV, a software package available on the Hub, simulates the processing steps used in the manufacture of silicon integrated circuits and discrete devices. The processing steps modeled include inert-ambient drive-in, the oxidation of silicon, polysilicon, and silicon nitride, ion implantation, epitaxial growth of silicon, and low and high temperature deposition and etching of various materials.

Students begin their work with PUNCH by using an existing library example to learn to edit, execute, and print a SUPREM file using a step-by-step tutorial that was written for this course. They are then introduced to the main SUPREME commands that they will use in the course for operations such as the initialization, writing, titling, diffusion, ion implantation, printing, and plotting.

3.9 BJT Devices

Students will learn the principles and methods of fabrication. They will be asked to integrate principles of electromagnetics and circuit theory to understand static and dynamic characteristics of BJT devices. They will also use SUPREM IV software to integrate knowledge of device characteristics and fabrication of devices.

3.10 MOSFET Devices

Students will be introduced to the essentials of MOSFET devices. We will cover the structure of MOS devices and integrate knowledge from physics, circuits, and electromagnetics to understand their static and dynamic characteristics. Finally, they will perform experiences using SUPREM IV.

4. An Example

CMOS Circuit with ion-implantation well.

Students study the effect of ion implantation in reducing the latch-up trigger problem of CMOS Circuitries. This utilizes knowledge from BJT devices “parasitic devices”, NMOS, PMOS, ion implantation versus diffusion characteristics in forming P or N regions. Ideas of reducing parasitic device effect by lowering BJT current gain are used. The project requires the use of both diffused Well CMOS versus Ion-Implanted Well CMOS Circuits.

5. Assessment of the Course

Two student self-assessment surveys were designed to assess the objectives of the course for the first offering during the Fall 2000 course. For both surveys, a scale of Strongly Agree = 4.0, Agree = 3.0, Disagree = 2.0 and strongly disagree = 1.0 was used. The feedback obtained from this process will be used to improve student satisfaction and student learning in subsequent offerings.

The first survey assessed student satisfaction with the course and its various elements. The results, shown in Table 1, indicate that the students were satisfied with all aspects of the course except for interpreting device behavior using principles of physics (2.95, item 8) and using SUPREM (2.89, item 12). Item 15 demonstrates further interest in courses in the same area (3.14).

Table 1. Student Satisfaction With the Course

	Item	Average (N = 22)
1	I am satisfied with the semiconductor fundamentals I learned in this course.	3.14
2	The amount of coverage of semiconductor fundamentals met or exceeded my expectations based on the course description.	3.32
3	I enjoyed the approach taken by the course where the pn junction was used as a basic building block to study the electrostatics, dynamics, and transient behavior of different devices.	3.22
4	Learning about energy band diagrams for the different devices was helpful in learning the static characteristics, including potential, field, and charge distribution.	3.41
5	I enjoyed learning about photo-electronics, including photo-detectors, solar cells, and LEDs.	3.54
6	I enjoyed learning the compound semiconductors and their alloys in photo-electronics applications.	3.27
7	I enjoyed learning about devices in the SCR group and their models.	3.07
8	I enjoyed learning to interpret device behavior based on solid-state physics principles.	2.95
9	I enjoyed learning about device fabrication.	3.18
10	I enjoyed watching the videotape on IC fabrication at Texas Instruments.	3.41
11	I enjoyed learning to use SUPREM software.	2.89
12	I enjoyed learning to use PURDUE Punch Hub and the available resources.	3.00
13	If I were to take more electives that would benefit from PUNCH Hub, I would hope that those courses would use it.	3.07
14	I enjoyed having to integrate knowledge of different types, including electromagnetic principles, solid-state physics, device modeling, and professional software (SUPREM).	3.11
15	The ECE Department should offer more courses in solid-state devices such as CCDs, microwave devices, etc.	3.14

The second survey assessed students' self-assessment of learning success, and the results are shown in Table 2. The results indicate that student feel that they have learned successfully (3.0 or better) in the areas of the science of semiconductor materials, the use of calculus based mathematics, the use of course related engineering knowledge to solve problems and do engineering design, and to design semiconductor devices. They were less confident in their ability to use SUPREM (2.95) and to be able to design a procedure to test the semiconductor devices that they designed (2.80).

Table 2. Student Self Assessment of Learning Success

1	I believe that I successfully learned the materials in the course that were based on the science of semiconductor devices.	3.22
2	I believe I successfully learned the materials that required the use of calculus-based mathematics.	3.27

3	I believe that I can use the engineering knowledge (other than knowledge of science and math) that I learned in the course to solve engineering problems and do engineering design within the scope of the course.	3.10
4	I believe that I learned to use SUPREM software package at a level sufficient to solve course assignments.	2.95
5	I believe that I am able to design semiconductor devices using the techniques and methods taught in the course.	3.11
6	I believe that I am able to design a test procedure that will help me determine if the semiconductor device that I designed meets the desired specifications.	2.80

Students were invited to write comments, and the results were as follows:

- Too much information was covered in the course.
- There were problems in setting up the accounts on PUNCH HUB.
- SUPREM III, the software that was originally assigned, was not running properly, and students had to switch to SUPREM IV.

Further assessment of student satisfaction with the new format incorporating integration of knowledge will be carried out by comparing student satisfaction in the new course with their satisfaction in electives that use the more conventional engineering science approach with respect to motivation, completion rate of homework, performance on exams, quality of design projects, and depth of understanding.

6. Concluding Remarks

The results of the two assessments of student satisfaction, one with the elements of the course and the other with their self-assessment of their learning success, indicate that we have been successful with our first attempt at teaching the course. The feedback suggests that we need to work on improving the section of the course that involves the use of SUPREM software on the Purdue University Hub. After working on increasing student satisfaction and learning with SUPREM, we will focus on the other elements of the course and use further survey to determine if the changes led to improvements in satisfaction.

7. References

[1] URL: http://www.hoosiers.iupui.edu/gened/gnedprin.htm

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[3] Rizkalla, M.E., Phile, R., El-Antably, A., and Yokomoto, C.F., "Development of a Senior Elective for EE and EET Majors in the Design of Electronics Instrumentation for Electric Vehicles." *Proc. 1998 ASEE Annual Conference,* Session 2502, June 1998.

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