An integrated upper division course in electronic materials and electromagnetic engineering - “Wave Phenomena for Electrical Engineers”

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Abstract *The Foundation Coalition at Arizona State University offered for the first time a novel upper division integrated course in Electrical Engineering in the Fall ’97 semester. This first offering combined two upper division courses into an integrated class that sought to reduce the compartmentalization and emphasize the substantial overlap of the separate courses. The courses involved were (1) an introduction to the properties of electronic materials and (2) the first course for EE majors in electromagnetic engineering. The main thread that integrated the two courses was “wave phenomena.” This paper will discuss the organization of the course, the nature of the course integration, details about the technology infusion, and a brief description of the tool used to carry out assessment of the course and the students’ performance.*

Introduction

The Department of Electrical Engineering at Arizona State University has started the process of developing an upper division curriculum that would be a natural extension of the Foundation Coalition lower division classes that are presently in place. Coursework that meets the Foundation Coalition goals follow the following design rules: [1-4]

1. The coursework must be integrated.
2. There must be significant technology infusion.
3. Active learning strategies must be employed.

The Electrical Engineering program at ASU has six major program areas at the undergraduate level:

1. Communications
2. Control
3. Electromagnetics
4. Electronic Circuits
5. Power Systems
6. Solid State Electronics

In order to complete the degree requirements, EE students must take 18 hours of technical electives. In order to meet a breadth requirement, they must select courses from at least three of these program areas; to satisfy a depth requirement, they must choose two in one area. It is the contention of both the EE department and the Foundation Coalition that it is sensible to integrate many of these upper division courses. Just as integration at the lower division reinforces the connections among courses of various disciplines, integration both within and across EE program areas could meet the Foundation Coalition goals and help students satisfy the technical electives in a more meaningful way.

To begin the program, a first integrated class combination was offered in the Fall ’97 semester. This first offering combined two upper division courses, ECE352 and EEE340, into an integrated class that seeks to reduce the compartmentalization and emphasize the substantial overlap of the separate courses. The course ECE352 is an introduction to the properties of electronic materials, while EEE340 is the first course for EE majors in electromagnetic engineering. We have chosen this pair because of the links between the topics normally covered in courses on electronic materials and electromagnetism. These courses are required in the program of study - they are not technical electives - and normally are taught sequentially. One of the stongest ties between the two courses is that of wave phenomena - although it is never stressed when the courses are taught independently. The concepts of matter waves, electromagnetic waves, lattice vibrations, etc., can be united to produce a strong component in the EE curriculum, and the course was dubbed, “Wave Phenomena for Electrical Engineers.”

The integrated course

The integrated course is offered in a two hour block, four days of the week. It was necessary to produce a new syllabus that integrated the engineering material so that the combination had a seamless feel. In brief, both courses begin with some preliminary mathematical details - but for the most part, mathematical issues are introduced in a just-in-time fashion. Then the wave phenomena aspects of both courses is examined. The integrated course concludes with two perspectives on issues in material science and engineering. In a conventional electromagnetic engineering offering, statics are covered first, material properties second, and any remaining time is devoted to Maxwell’s equations and electromagnetic plane waves. We re-ordered the E&M material to start with Maxwell’s equations and plane wave solutions. An outline for both portions of the class is shown in Table 1.

Table 1. Organization of course topics

Week	**Materials (ECE352)**	**Fields (EEE340)**
1	Lattices	Vectors
2	Lattice Diffraction	“
3	“	Fields
4	Acoustic Waves	Maxwell’s Equations
5	“	“
6	Matter Waves	“
7	“	“
8	“	“
9	“	Plane Waves
10	Statistical Mechanics	“
11	“	“
12	Metals	“
13	Electrons in Crystals	Static Fields
14	“	“
15	Semiconductors	Materials
16	“	“

In the electronic materials portion of the class, the students are first introduced to waves through lattice diffraction, and then on to lattice vibrations. They are then exposed to quantum mechanics and Schrödinger’s wave equation. Here they discover that the objects that dominate solid state physics, such as the electron, the photon, the phonon, and so on, have wave character.

The course is taught with the aid of a webpage, which serves as (1) a contiually updated syllabus, (2) a bulletin board, and (3) the location of the assignments and representative solutions. No paper materials are distributed in class. A portion of the updatable syllabus is shown in Table 2.

Table 2. Representative weekly schedule, as posted on the class webpage

Day	**ECE352 Component**	**EEE340 Component**	**Reading**	**Assignment**
Monday – 9/22/97	Sound Waves	Maxwell’s Equations (Integral)	R4	
Tuesday – 9/23/97	Sound Waves	Maxwell’s Equations (Integral)		
Wednesday – 9/24/97	Sound Waves	Maxwell’s Equations (Differential)		
Friday – 9/26/97	Sound Waves	Maxwell’s Equations (Differential)	M4	EEE340 #2

Each of the underlined components is a link to the class schedule for that particular period. The link for Monday, 9/22/97, is shown in Table 3.

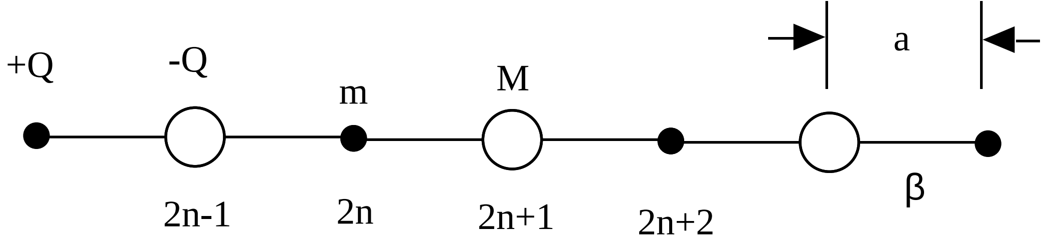
Table 3. Representative daily schedule, as posted on the class webpage

ECE352 Class Schedule - September 22, 1997

Time	**Activity**
10:40 – 10:45	Contact before work
10:45 – 10:55	Review of acoustic waves
10:55 – 11:05	Dispersion
11:05 – 11:15	Group and phase velocities
11:15 – 11:30	Standing waves Class activity

What strengthens this integrated offering is that students see at one time several analytical models that describe waves, their propagation, and their interactions. And what differentiates the course from two stand-alone courses is that the course contains examinations and projects that combine elements of both portions - students are confronted with problems in which the dividing line between electromagnetism and materials concepts is unspecified. In the examinations, for example, the students were asked the following question, as shown in Figure 1:

(1) Consider the one-dimensional diatomic lattice (which is also a valid model for planes of atoms in a 3-d solid). Suppose the lattice is exposed to an electric field.



(a) Write the altered equations for longitudinal motion of the lattice atoms that takes into account the effect of the electric field.

(b) Suppose the electric field is described by a plane wave. What must the Miller indices of the propagation vector be to induce longitudinal motion?

Figure 1. Representative question on integrated examination

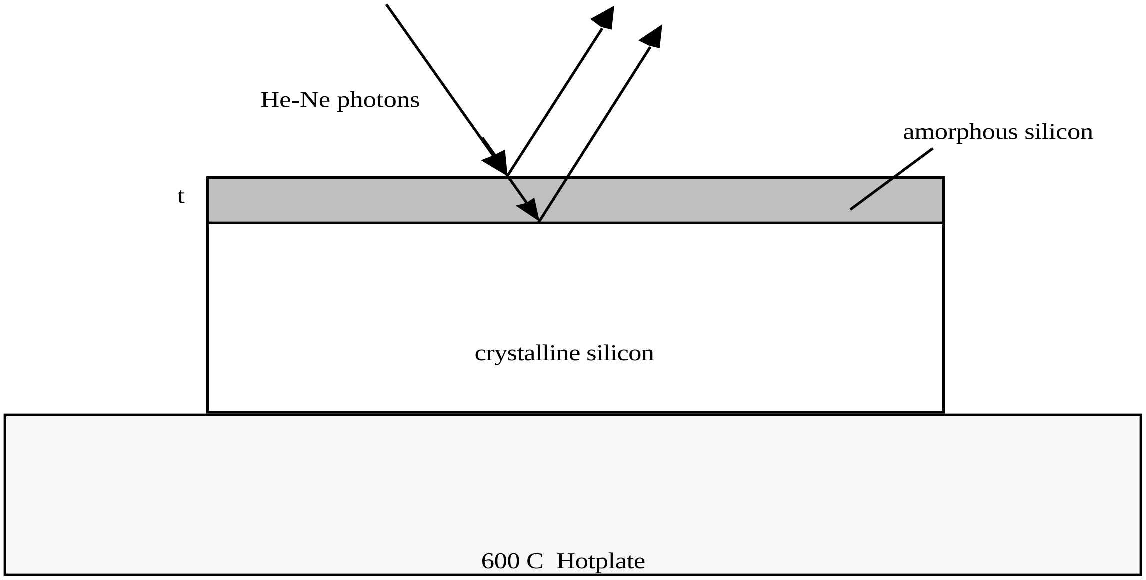
This kind of problem would not be considered “fair” in either stand-alone course, and for good reason. It requires a synthesis of material that is not normally expected in separate courses, and therefore violates the “unwritten rule” that one should not test at a level-of-learning that is different from that used in the classroom. But synthesis of material is the norm in the integrated course.

The synthesis aspect of the integrated course was reinforced with the research project the student teams were assigned. It is described in Figure 2:

Team Project 10/29/97

Your team works at General Silicon, a semiconductor company that carries out ion implantation into silicon wafers. One of General Silicon’s customers asked for a special implantation process recently. They wanted a silicon wafer to be implanted with silicon ions! The purpose of this processing step was to convert a thin region near the top of the wafer from crystalline to amorphous (non-crystalline) material. Your boss has asked you to examine this structure because she is interested in the solid phase regrowth process. That is, if this wafer were to be heated to a high temperature below the melting point, the crystalline material would act like a “seed crystal” and the amorphous material would return to crystalline form. Her hypothesis is that the crystallization kinetics would go this way - the interface between the amorphous and crystalline materials would remain planar and would advance with time toward the top surface as the amorphous layer converts to single crystal silicon. She wants your team to carry out an experiment to verify or disprove her hypothesis. Your team knows that amorphous silicon and crystalline silicon have different relative permativities, so you agree that you will shine light from a He-Ne laser onto the wafer while it is sitting on a hot plate and look at the overall reflectance of the system. If the interface moves, then the thickness of the amorphous layer has changed, and the reflectance should change. So, knowing something about reflectance from dielectric interfaces, you tell the boss that you will carry out the experiment and also perform the necessary analytic modeling of the process to help in the interpretation of the results.

Here is schematic of the experimental setup:



Tasks for this project:

(1) Set up appropriate wave equation analysis for normal incidence reflection from a two interface diectric system.
(2) Solve these equations for arbitrary thickness (t) of the amorphous layer
(3) Demonstrate how these solutions could be used to establish the velocity of the amorphous/cyrstalline interface

Requirements:

(1) The project must be word-processed.
(2) Computer generated graphs, charts, figures are required.
(3) Use you best writing skills to make this report look polished and professional.

Figure 2. Research project for integrated class

The purpose of this project was to introduce students to the kind of engineering problem they might realistically expect to encounter in the work place. It was not just a semiconductor problem, or just an electromagnetics problem, or just a thermodynamics problem – but a real engineering problem that required the students to see that solutions may be obtained only when a number of components from a variety of fields are brought together. This was all of the information given to the students – they were expected to hunt through a variety of sources to find the laser wavelength, the complex permitivites (and their temperature dependence), and all other relevant parameters needed. In actual fact, the students (who worked in teams of three or four) attacked this problem with enthusiasm and vigor. All of the teams were able to complete the tasks listed above, and all of the teams gave interesting and thoughtful presentations to the class describing the process used to model and solve the project.

Assessment

A special assessment tool was developed to examine the efficacy of this integrated course in training students in wave phenomena. We have dubbed this assessment tool the Waves Concept Inventory (WCI), as it is modeled on the successful Force Concept Inventory developed by Hestenes *et al.* [5] to test first year physics students on their knowledge of forces and Newton's Laws. The WCI was administered to the students at the start and at the end of the semester, and to another group of engineering students who were taking the traditional electromagnetics engineering class. In short, it was discovered that both groups of students had very similar starting scores on the WCI but the students in the integrated class had finishing scores that were significantly higher than the students in the traditional class. More details about the format and the statistics of the WCI can be found in a companion paper at this conference [6].

Conclusions

It is the feeling of the authors that the first attempt to integrate upper division courseware in the Electrical Engineering department at ASU was quite successful. The students were given standard class evaluation forms and in brief, the students claimed that the course was difficult, time-consuming, and unconventional, but inspiring and rewarding.

We have also proposed that the EE department might offer these combinations of classes under the Foundation Coalition banner:

Optical Communications:

EEE 437 (Optoelectronics)
EEE 448 (Fiber Optics)

Microwave Communications:

EEE 445 (Microwaves)
EEE 455 (Communication Systems)

Theory and Practice of Semiconductor Devices:

EEE 435 (Microelectronics Laboratory)
EEE 436 (Fundamentals of Semiconductor Devices)

Quantum Processes in Semiconductors:

EEE 434 (Quantum Mechanics for Engineers)
EEE 498 (Fundamentals of Semiconductor Transport)

Electrical Engineering Design:

ECE 300 (Intermediate Engineering Design)
ECE 334 (Electronic Devices and Circuits)

There is no timetable for the development of these proposed offerings, but it is expected that as the Wave Phenomena course becomes successful, other portions of an integrated upper division EE curriculum will be introduced.

More details about the structure of the Wave Phenomena course can be found on the same webpage that the students themselves used:

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