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Materials Science and Engineering at Boise State University: Responding to an Industrial Need

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ABSTRACT

The College of Engineering at Boise State University (BSU) is a new program in only its fifth year of existence. Bachelor's degrees in Civil Engineering (CE), Electrical and Computer Engineering (ECE) and Mechanical Engineering (ME) are offered with M.S. Degrees in each discipline added this year. The industrial advisory board for the College of Engineering at BSU strongly recommended enhancement of the Materials Science and Engineering (MS&E) offerings at BSU. In response to local industry's desire for an increased level of coursework and research in MS&E, BSU has created a minor in MS&E at both the undergraduate and graduate level.

The MS&E program is designed to meet the following objectives: provide for local industry's need for engineers with a MS&E competency, add depth of understanding of MS&E for undergraduate and graduate students in ECE, ME and CE, prepare undergraduate students for graduate school in MS&E, improve the professional skills of the students especially in the areas of materials processing and materials selection, provide applied coursework for Chemistry, Physics, and Geophysics students, and offer coursework in a format that is convenient for students currently working in local industry.

INTRODUCTION

The College of Engineering at Boise State University (BSU) is at an exciting point in its development. BSU is located at the center of a high technology area which has been experiencing significant growth over the last 10 years. Large companies in the area include Micron, Hewlett-Packard, Jabil and SCP Global Technologies. The College of Engineering was formed in 1996 with bachelors degrees offered in Civil Engineering (CE), Electrical and Computer Engineering (ECE) and Mechanical Engineering (ME). The college received ABET accreditation in 2000. In the Fall semester of 2000, masters degree programs were added in CE, ME, Electrical Engineering, and Computer Engineering. In the next five years, Ph.D. programs will be added to the College of Engineering.

The engineering program at BSU is already a nationally recognized program. In its first appearance in national rankings, *U.S. News and World Reports* placed the College of Engineering at BSU 67th on the list for Undergraduate Engineering Programs at non-doctoral granting U.S. engineering institutions.[1] Enrollment in the College of Engineering has grown from approximately 250 to over 800 since the college's inception in 1996. In its first year, the graduate program has admitted more than 60 students. Research funding in the College of Engineering at BSU is currently over $6 million per year. Sources of funding have come from private industry, the Idaho State Board of Education and national agencies (NSF and DARPA).

Local industry support along with external funding has helped to provide excellent laboratory facilities, new office and classroom space, used and new equipment, as well as

internship and collaborative research opportunities. The generous support of these companies for the programs at Boise State is evident in several areas: Industrial Advisory Board, mentoring programs, sponsoring senior design projects, providing adjunct faculty, giving plant tours, providing internships, placing graduates, donating lab equipment, and helping to install and maintain equipment.

MATERIALS SCIENCE AND ENGINEERING PROGRAM

In response to recommendations from local industry, BSU is developing a minor in Materials Science and Engineering at both the undergraduate and graduate level. The program is designed to provide coursework and research opportunities in materials processing and materials characterization. The objectives of the program are to provide for local industry's need for engineers with a competency in materials science and to add depth of understanding in materials science and engineering for CE, ECE, and ME students. This program is an interdisciplinary effort across BSU with participation from at least two faculty members in each of the following departments: Electrical and Computer Engineering, Mechanical Engineering, Chemistry, Physics, and Geophysics. Two of the authors (AJM & WBK) joined the engineering faculty at BSU this year to build this program.

One of the challenges of the materials program is to offer a complete MS&E curriculum in only four or five courses. The intention of the program is that student who completes three or four MS&E courses at BSU would be adequately prepared to enter most graduate programs in MS&E without deficiency coursework being necessary. Other students may only be interested in one or two courses in MS&E. Therefore, each course must offer a fairly complete view of the field without assuming a large body of prerequisite knowledge.

To meet these numerous objectives, the following list of core courses has been developed:

- Introduction to Materials Science and Engineering
- Introduction to Materials Science and Engineering Laboratory
- Physical Properties of Materials (Crystallography, Bonding and Microstructure)
- Thermodynamics of Materials
- Mechanical Properties of Materials (Fatigue, Fracture and Strengthening)
- Electrical, Optical and Magnetic Properties of Materials

Three of these courses were taught for the first time this year. As more experience is gained with these courses, the course outlines and objectives will be revisited to ensure the fundamentals of MS&E are adequately covered. Many of the BSU students work for local industry while taking courses providing a unique opportunity to obtain direct feedback regarding the applicability of coursework to both daily work responsibilities and professional development. In addition, mid-semester in-class surveys that provide questions concerning the applicability of the material are being utilized for assessment. Student feedback during the semester has also been utilized to determine some of the course material. The courses are developed with the Materials Science "pyramid" in mind which links Properties, Performance, Processing, Structure, and End-user Constraints.[2]

In addition to the core courses mentioned above, courses are offered covering specific topics that have relevance to research efforts at BSU, local industrial interests or the special interests of the students. Examples of these courses are Semiconductor Materials, Materials Engineering and the Environment, and Materials Characterization (currently under development in collaboration with faculty in Physics and Chemistry). Other course topics that are being

considered include Magnetic Materials, Thin Films, Failure Analysis and Reliability, Powder Metallurgy, and Corrosion. The frequency of these course offerings will be determined by student interest and the availability of faculty resources.

EXAMPLE – Physical Properties of Materials

Physical Properties of Materials was one of the new courses developed for the program. Course topics are given in Table I. Learning objectives for one of the course topics are shown in Table II. In a typical MS&E curriculum, the material in this course is usually covered in two or three different courses. Obviously, this course cannot cover each topic in as much depth as a more focused course. This course was offered in Spring, 2001 as both an undergraduate and graduate elective. The graduate students were expected to do a research paper and oral presentation in addition to the coursework expected of the undergraduates. Enrollment in the class was approximately 50% graduate student and 50% undergraduate students. Also the class was evenly split between ECE majors and ME majors.

To incorporate student interests in the class, the topics of the final four lectures of the class were chosen by the students. A list of topics in different material categories (polymers, ceramic, metals, and electronic materials) was created from student input in class. Students voted for their favorite topics from each category. Based on the list, case studies of how structure, properties, processing, performance, and end-user constraints in specific applications are linked were given. The student's ability to determine part of the content of the course increased their level of participation during these classes.

Table I. Course Outline for Physical Properties of Material

1. Review of basic concepts	4. Crystallography
Chemistry	Symmetry Operations
Physics	Point Groups
2. Intro to Quantum Mechanics	2-D Crystallography
Wave-Particle Nature of Light	3-D Crystallography
Bohr model of the Atom	Crystal Structures
de Broglie Hypothesis	5. Non-Crystalline Structures
Schrödinger Equation	Glasses
Heisenberg Uncertainty Principle	Polymers
Hydrogen Atom	6. Defects
3. Atomic Bonding	Point Defects
Ionic, Covalent, Metallic, van der Waals	Dislocations
Molecular Orbitals, Hybrid Orbitals	Surfaces and Interfaces
Kronig Penney Model, Energy Bands	7. Microstructures
	8. Case Studies

Table II. Example of Learning Objectives

Physical Properties of Materials – Crystallography Section
At the end of the section of the course on crystallography the student should be able to: • Determine symmetry operations present in a 2-D pattern • Determine the plane group of a 2-D pattern • Draw the conventional unit cell of all 14 Bravais Lattices • Given a specific lattice, draw a primitive unit cell • Determine the Miller indices of a plane or direction in a lattice • Define the terms lattice, basis, and crystal structure • Identify the interstitial sites in common crystal structures • Determine the crystal structure of ionic crystals based on charge balance and cation radius to anion radius ratio.

MS&E RESEARCH AT BSU

At this point, BSU is primarily an undergraduate institution. M.S. programs were added this year in engineering and a Ph.D. program will be added in five years. Within the MS&E program, the approach to research is to provide laboratory experiences for undergraduates. Where possible, equipment will have a dual purpose – in the research lab and as an educational tool. Research projects are being developed through collaborations with existing research at BSU and through interactions with local companies and other universities.

BSU has a strong history of utilizing its laboratories for both research and education. The Idaho Microfabrication Lab, a small Class 1000 cleanroom was completed in 1998. An adjoining room is now used to house processing equipment due to space constraints in the cleanroom.[3] Device characterization and VLSI CAD labs have been developed for educational and research purposes.[4]

EXAMPLE – Degradation of Gate Oxides

A project to study degradation mechanisms in ultrathin (< 5 nm) gate dielectrics is an example demonstrating these principles. The research is being funded through collaboration with a large semiconductor manufacturer and through a National Science Foundation Research Experience for Undergraduates program at BSU. The student utilizes the latest in IC measurement equipment to develop test methods to measure degradation in ultrathin gate oxides. These methods will then be used to study degradation mechanisms in gate oxides that have been grown using several different growth methods in an array of thicknesses. The data will be analyzed to determine if a correlation exists between the type of degradation mechanisms observed as a function of growth methods and thickness variations.

The educational experience of the undergraduate student is the emphasis of the research project. Learning occurs within the context of the project and focuses on several aspects: learning about a specific field, learning to work independently, emphasis on problem solving, and technical communication through a written final report and oral presentation. Direct interaction with the principal investigator (PI), selected papers and excerpts from relevant texts are used to enhance the student's knowledge. The PI discusses bonding and band diagrams in general and as applied to metal-oxide-semiconductor capacitors (MOSCAPs) and field effect transistors (MOSFETs). The latter is discussed so that understanding of MOS device physics and quantum mechanical mechanisms such as carrier tunneling are conceptually understood. The student is then taught how to use test and measurement equipment (e.g., wafer level probe station, HP4145 SPA, HP4155A&B SPA) to characterize MOSCAPs and MOSFETs. The PI and student discuss the characterization results and conclusions that can be drawn from the results. Measurements specific to the study are then taught to the student and results are explained using band theory and device physics. "What-if" scenarios are discussed to promote problem solving. Although not heavily emphasized, the student is guided through the use of software for data analysis and modeling.

After initially collaborating with the PI, the student is encouraged to work independently and focus on problem solving including setting up and or purchasing new equipment. The PI and student meet periodically to discuss results and plan the next phase of experiments. Band theory, device physics and quantum mechanical phenomena are utilized in the discussion of results. Results and discussion will most likely lead to dissimilar testing methods and analysis. If useful, the PI will suggest the student read material directly related to the results, conclusions or problems encountered.

The student is then encouraged to begin writing a final report or presentation. Initially, the report may include only background information and results. The general information is used by the student to gain a better understanding of the concepts in the study and to examine problems from various directions.

NEXT STEPS

The next priority for the MS&E program is to re-examine the Introduction to Materials Science and Engineering course to ensure it fulfills the needs of both ECE and ME students. All ME and ECE faculty, local relevant industrial representatives, and former students will be asked to participate in a survey. Assessment tools are being implemented for both the Introduction to Materials Science and Engineering course and the curriculum as a whole. The details of the undergraduate minor in Materials Science and Engineering are being finalized with the intention of submitting a proposal for approval to the College of Engineering Curriculum Committee in Spring, 2001. The final approval steps are through the University Curriculum Committee and the State Board of Education.

Next Fall, a Materials Characterization course will be developed with faculty members from Physics, Chemistry, ECE and ME. The course will be offered in Spring 2002 for the first time with working engineers as its primary audience. The Chemistry department at BSU currently offers a Biochemistry Emphasis, General Emphasis and Professional Emphasis. In Fall 2001, the Chemistry department will develop a curriculum with a Materials Science Emphasis.

CONCLUSIONS

Several factors have converged to facilitate the rapid development of a MS&E program at BSU. Although no one is unique, the combination has provided an unusual and exciting opportunity to develop a program where no program existed before. These factors include: a strong industry presence through the advisory board of the College of Engineering and the industrial experience of the authors of this paper, an inherent interdisciplinary nature due to the involvement of faculty from all three departments in the College of Engineering and from the departments of Physics, Chemistry and Geophysics, and the support of the administrators in the College of Engineering.

The MS&E program has an industrial focus while still offering an education in the fundamentals of materials science. The coursework is in the evening or during lunch time to accommodate students working in industry and the content is often directly applicable to their current positions. Our students come from diverse educational backgrounds and interests, from the mechanical engineer working for Albertson's (grocery store chain) to the R&D engineer working on the next generation of memory chips for Micron. These diverse goals are met by focusing on the fundamentals and bringing in case studies from different technological fields and with a focus on projects and research papers as an essential part of the coursework.

The program is in no way complete, but the initial framework for a MS&E program has been established. As more experience is gained in teaching the coursework and in assessing the program, modification and improvements will be implemented.

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