Multifunctional Materials Integration Undergraduate Focus Track: A Cross-cutting Curriculum to Prepare Students for the Interdisciplinary Projects of the Future

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Abstract

A new cross-disciplinary upper division undergraduate track in Multifunctional Materials Integration (MMI) is developed that brings students from backgrounds ranging from electrical engineering to materials science and mechanical engineering into common courses to prepare them to thrive in a modern workplace where they will work in teams whose members will have various backgrounds and expertise. The track will include a common breadth element that each student in the track will take as well as the opportunity for the students to specialize in a depth sequence of elective courses.

Keywords

Engineering Education, Multidisciplinary, Multifunctional Materials

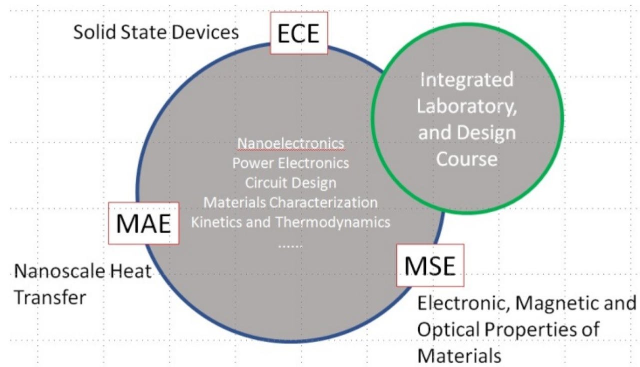
Background

A convergence of the various fields of engineering is happening as major engineering breakthroughs continue to be ever more interdisciplinary. This means that while a modern engineer may specialize in one area, it is critical to communicate across traditional disciplinary boundaries and possess at least a basic understanding of the underlying principles of other areas to integrate ideas with collaborators across disciplines.[1] The University of Virginia (UVA) has launched an interdisciplinary research effort in Multifunctional Materials Integration (MMI) that aims to develop the next generation of electronic and photonic integrated circuit technologies and extends from atoms to systems. This requires collaboration between the traditional fields of electrical and computer engineering (ECE), materials science and engineering (MSE), and mechanical and aerospace engineering (MAE). To help prepare undergraduate students to thrive in such an environment, we have developed an upper division specialty track that will bring students from these three majors together and provides the breadth of knowledge required for collaborative discourse as well as a depth of understanding that will enable them to make meaningful contributions through specialized expertise. The depth comes from a choice of additional three advanced elective courses. In this paper, we detail the design of the program as well as the challenges faced in bringing students from a diversity of majors into the same upper division courses.

In 2013 the ECE department at UVa began a dramatic revision of the basic core material, which lead to the design of the *Fundamentals Series*. This change in curriculum, focusing on a studio style, learner-centered approach is already demonstrating value as students completing the new class sequence are going into their upper division classes more prepared, with better intuition and understanding of the high-level application space in which they will be working.[2] This necessitated to realign the upper division courses to match this enhanced preparation, and provides an opportunity to reexamine what most benefits modern engineering students in their advanced undergraduate courses.

Our goal is to deliver a cohesive vision and curriculum that will build off of the knowledge and lessons learned developing the ECE *Fundamentals* classes through the planning and implementation of a focused upper division, cross-departmental track in MMI, with innovation at the individual class level as well as integration in the track as a whole. The cross-disciplinary MMI curriculum will prepare students for graduate school and industrial careers, while simultaneously completing the conversion of the undergraduate curriculum to the learner-centered paradigm that was initially fostered with the ECE *Fundamentals* classes.

MMI Course Structure



This first task in structuring the MMI track was to create a cohesive curriculum that provides context for subjects that are traditionally taught within different individual departments, but that are required for effective design in multi-functional integration. A track of course was identified to enable students to develop a broad and deep understanding of the fundamental concepts related to MMI research. This task also included alignment between classes, ensuring the desired overlap carefully designed to maximize retention, and allowing classes to build off of one another. The expertise developed through the redesign of the ECE core and movement towards a more interdisciplinary program is the nucleus for establishing a core program for students in MMI. The structure of the future MMI certificate will be based on three core classes positioned in MSE, ECE, and MAE that every student will attend, combined with a pool of electives from which the students will choose three additional classes. This course of study fits seamlessly within the current ECE major and is compatible with the MSE minor and engineering science MSE concentration.

The MMI core courses will span from atomic structures and interfaces though devices, circuits and systems and mirror the engineering goals of MMI. Additionally, the major design experiences or capstone projects that students across the program pursue in their fourth year create a culminating project which will showcase what they have learned. Teams composed of students from multiple majors, who have gone through the program, work together to tackle a project that cannot be solved solely through the knowledge from one discipline alone. The three core classes are being adapted from existing classes in ECE, MAE, and MSE to give the students a background breadth of atoms up through devices. The first is *ECE 3103, Solid State Devices*. The second is *MSE 3670, Introduction to Electronic, Magnetic and Optical Properties of Materials*, and the third is *MAE 3130, Nanoscale Heat Transfer.* A future goal of this effort will be to get each of these three classes cross-listed in each of the three associated departments.

After having developed a broad base in MMI related fields, the students will be encouraged to select three elective courses that best match their interests to provide a depth of study in one particular area that will prepare them for either graduate school or careers in industry. This combination of breadth and depth will enable the students to succeed after graduation, and well into the future. The tentative list of electives includes Fundamentals of Nanoelectronics, MicroElectronic Integrated Circuit Fabrication Lab, RF Circuit Design, Microwave Lab, Analog Integrated Circuits, Optical Communications, ECE Optics and Lasers, Microwaves 1, Elements of Heat and Mass Transfer, Thermodynamics and Kinetics of Materials, Structure and Defects, and Nanoscience and Technology. Each of the faculty teaching these courses will specifically set aside time in the course to relate the topics covered to the overall themes of the MMI and how they relate and intersect with the topics covered in the other MMI courses. Each of the MMI-centric courses will be built on existing courses and will be offered in the "learner-centered" environments found to be successful in the ECE *Fundamentals* series.

As part of the MMI curricular development effort, a number of the courses fundamental to this area have already begun to be formulated to this model. This effort is central to supporting the MMI initiative at UVA as this model for instruction inherently supports cross-disciplinary/departmental learning and exposes students from different majors to work being done outside of their immediate field. One particular example is the MMI core class, *Solid State Devices*. This course bridges the ECE curriculum with MSE and focuses on the MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor). This course enables students to understand what transistors are, how they work, how they are manufactured, including the basic material properties critical to their function, and band theory. Additionally, students focus on why they are so important in today's integrated circuits. To this end, the class explores how semiconductor materials can be used to make basic devices including p-n junctions and metal-semiconductor contacts. At the end of the semester, students design a transistor to specifications and apply the concepts they have learned to a vast array of related semiconductor devices.

The course is fundamental to enabling students to develop next-generation hybrid and multi-functional devices and systems that integrate materials science, electronics, thermodynamics, and mechanics. As part of its incorporation as a core course in the MMI focus track, revisions have been implemented in the class to link students' knowledge from the nanoscale to the macroscale. Fundamentally, the course bridges materials science and integrated circuits, and enables students to understand the physics of semiconductor devices which are the basic building blocks of integrated circuits, sensors, and systems. This program will begin to roll out in Fall 2018 for students in the class of 2020. By providing both breadth across a wide range of interconnected fields as well as depth and expertise in a given area, students will learn how to communicate and contribute in multidisciplinary projects similar to what they will experience as engineers in the workplace.

References

1. 2020 C on the E of, II P, Education C on E, Engineering NA of. Educating the Engineer of 2020:: Adapting Engineering Education to the New Century. National Academies Press; 2005. 209 p.

2. Powell H, Brandt-Pearce M, Williams R, Weikle R, Harriott L. Incorporating Studio Techniques with a Breadth-First Approach in Electrical and Computer Engineering Education. In ASEE Conferences; 2016 [cited 2016 Nov 4]. Available from: http://peer.asee.org/25661

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