Session

Interdisciplinary ECE and ME Education in the Electro-Thermal Performance of CMOS SOC Devices

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ECE and ME: Together Again

This interdisciplinary educational initiative presents curriculum and research, which is leading to a change in the traditional presentational of microelectronics, digital logic design, and heat transfer in engineering education. In the traditional and prevalent model, Electrical and Computer Engineering (ECE) and Mechanical Engineering (ME) each have its own set of courses and requirements within the boundaries of a specific discipline. However, the explosive growth in microelectronics and the resulting integrated circuit densities, not only for advanced processors but also for the system-on-chip (SOC) design methodology[1], now demand ECE and ME graduates with a keen and focused interdisciplinary knowledge of the thermal performance and packaging of such VLSI devices. Furthermore, industry is demanding engineering graduates with the experience to become immediately productive without extensive additional training.

This engineering educational initiative addresses these salient concerns by creating a program of cross-training courses, dynamic modular courses, and interdisciplinary projects and research with the support of the microelectronics industry. The microelectronics industry is acutely aware of the need for innovations in packaging and thermal management to supplement the advances and promise of low power consumption CMOS design and the SOC design methodology. Such innovations are needed if the clock speed and computational power of compact future systems are to increase. This initiative addresses the development of curriculum in such micro and nano scale technology in microelectronics and VLSI and in the materials science, heat transfer, and thermal management of such devices and, as a consequence, builds a closer working relationship with the microelectronic industry

This interdisciplinary engineering educational program, which involves ECE and ME, has three components to better prepare undergraduate, graduate and continuing professional education students to become practitioners in microelectronics technology:

1. The cross-training of senior undergraduate engineering students in ECE and ME with modules of appropriate ECE courses taught to ME students and, conversely, modules of ME courses taught to ECE students.
2. Intermediate graduate and continuing professional education courses in ECE and ME, which continue this cross training.
3. Modular advanced graduate courses, which can be dynamically modified to satisfy industry requirements and research opportunities in microelectronics technology.

Interdisciplinary research projects with industry sponsorships at all levels are important to the program. The sequence of updated graduate courses also provides life-long learning opportunities for practicing engineers in the microelectronics industry. A comparison of the traditional curriculum and the interdisciplinary ECE and ME curriculum is summarized in Table 1 below.

The Curriculum: Bringing It Together

This interdisciplinary approach to engineering education could not occur without structural changes in the undergraduate ECE and ME curriculum. The microelectronics industry is seeking undergraduate ECE students familiar with heat transfer, packaging and materials, and undergraduate ME students who are familiar with the salient issues in microelectronics.

To accomplish this, the content of four existing undergraduate senior elective ECE and ME courses were modified. One quarter of the course content in each thread was modified for the interdisciplinary cross training, with modules provided and taught by the cooperating faculty in ECE and ME. In the Fall, ME students in this elective thread take ME 372 Heat Transfer and ECE students take ECE 355 Microelectronics. To enhance the interdisciplinary experience, undergraduate ECE and ME students conduct joint projects, such as a microelectronic circuit rendered in computer-aided design (CAD) for which a finite element analysis (FEA) heat transfer model is developed. In the Spring, ME students take ME 305 Deformation and Fracture of Engineering Materials and ECE students take ECE 375 VLSI Design. The scheme of cross training by the cooperating ECE and ME faculty and joint projects continue, as in the Fall. Furthermore, undergraduate ECE and ME students in this interdisciplinary program are also required to have a joint ECE/ME senior design project in the Fall (ENGR 361) and Spring (ENGR 362) semesters with academic and industrial advisers.

ECE and ME graduate students may not have taken the interdisciplinary senior elective program. ME graduate students would then take ME 472 Advanced Heat and Mass Transfer and ME 405 Advanced Deformation and Fracture of Engineering Materials. EE graduate students would then take ECE 455 Advanced Microelectronics and ECE 475 Advanced VLSI Design. These graduate courses are analogues of the interdisciplinary senior ECE and ME elective program. The interdisciplinary cross-training modules are also available as individual independent and distance learning study courses for students with an appropriate background.

After completing these prerequisite requirements, graduate students take ME 760 Special Topics in Heat Transfer and ECE 600 Algorithms for VLSI Physical Design Automation. One quarter of the course content here continue the curricular concept of cross-training and joint projects.

There are also two modular courses containing specialized topics in the electro-thermal performance of CMOS SOC devices. ENGR 510 Modular Electronics and ENGR 610 Advanced Modular Electronics each consist of four modules. ENGR 510 has cross-training modules in advanced microelectronics or advanced heat transfer and modules on the SOC design paradigm, materials, and thermal reliability in micro and nano scale design. ENGR 610 has modules on the fabrication of nano scale devices, mixed analog-digital VLSI CAD, advances in thermal management, and advances in electronics and photonics.

Table 1. A comparison of the traditional and the interdisciplinary ECE and ME curriculum.

	Traditional Curriculum in ECE and ME	Interdisciplinary Curriculum in ECE and ME
Objective	Engineering science and design in individual ECE and ME disciplines	Tracks in microelectronics and nanotechnology for: • Juniors and seniors in ECE and ME • Professional certificates at the graduate level • MSE and PhD research concentration
Major Courses	Standard ECE courses No systematic or interdisciplinary life-long learning Certificate program available in traditional courses	• Undergraduate ECE students will take microelectronics, VLSI and nanotechnology, including 25% thermal and materials science; ME students will take heat and mass transfer and materials science, including 25% microelectronics and nanotechnology • Graduate engineers and graduate students will take prerequisite undergraduate courses, then advanced courses
Modular Courses	None	• Topics in design and packaging of microelectronics and nanotechnology, VLSI, SOC, power dissipation, materials reliability, micro and nano scale heat transfer • Modular courses soon to be available as distance education
Capstone Courses	Senior design (two-semester) projects, little industrial involvement, occasional cross-disciplinary projects	• Required cross-disciplinary senior design projects with academic and industrial advisors
Society Involvement	Undergraduate students are advised to join either IEEE (ECE) or ASME (ME)	• Students are advised to join IMAPS in addition to both IEEE and ASME • IMAPS local chapter organizes monthly meetings and student presentations in industry-oriented topics in microelectronics
Outcome Measurement	EIT exam encouraged but not required in most ECE programs for employment of graduates, survey of employers and alumni	• Employment of students in the microelectronics industry • Engineers from the microelectronics industry join the professional certificate program • Industrial satisfaction with the program measured by continuation of sponsorship

It is anticipated that the demand for additional modules will become apparent as the microelectronics industry participates in this interdisciplinary educational program. Module topics in applied microelectronics include micro and nano electromechanical systems (MEMS and NEMS), biomedical and environmental microelectronics and nanoelectronics.

Brief descriptions of the undergraduate senior elective (EE/ME 3XX), and graduate (EE/ME/ENGR 4/5/6/7XX) courses provide some details of the material presented:

ME 305/405 Deformation and Fracture of Engineering Materials. Elastic and plastic deformation of materials. Introduction to dislocation theory and failure analysis in metals, plastics, and composites. Life prediction, reliability and fracture control. Introduction to microelectronics materials.

EE 355/455 Microelectronics. Analog and digital integrated circuit design, manufacturing processes, and physical layout. TTL, BiMOS and CMOS circuits. Power dissipation, heat transfer, and the design of I/O structures in packaging.

ME 372/472 Heat and Mass Transfer. Principles and applications of heat and mass transfer by diffusion, convection and radiation. Steady, unsteady, and multi-dimensional heat transfer. Forced and free convection. Heat exchanger theory and heat transfer with phase change. Thermal management in microelectronics.

EE 375/475 Introduction to VLSI and Nanotechnology. Combination and sequential circuits using CMOS devices. CAD for the modeling, simulation, layout and design for testability and mapping to standard cells. Materials for micro and nano technology.

EE 600 Algorithms for VLSI Physical Design Automation. Principles and algorithms for VLSI physical design. Partitioning algorithms, basic algorithms for floor planning and pin assignment. Introduction to multi-chip module (MCM) and SOC microscale heat transfer.

ME 760 Advanced Heat Transfer. Survey of heat and mass transfer phenomena. Advanced analytical methods in conduction, convection and radiation, and combined systems. Similarity and boundary layer concepts. Numerical methods. Heat transfer in the manufacturing processes. Thermal management in microelectronics and micro-scale heat transfer.

ENGR 510 Modular Electronics. Microelectronics (required for ME) or heat transfer (required for ECE). Materials required for micro and nano design. Thermal properties of materials and thermal reliability in micro and nano design.

ENGR 610 Advanced Modular Electronics. Fabrication of nanowires and devices. Mixed analog-digital VLSI. Advances in thermal management, electronics and photonics.

Involving Industry

Adjunct faculty from the microelectronics industry have been recruited to teach the interdisciplinary modules. Since a module is taught for only a portion of a semester, usually three or four weeks, and offered in a professional setting one evening a week, recruiting these industrial practitioners has been greatly facilitated. The College also has a close working relationship with the Keystone Chapter of the International Microelectronics and Packaging Society (IMAPS). During the initiation phase of the interdisciplinary program, the College hosted an IMAPS Keystone Chapter meeting to highlight the new paradigm for engineering education in the electro-thermal performance of CMOS SOC devices.

As a result of the inception of this interdisciplinary engineering education program and its promulgation, regional microelectronics companies have shown great interest. Over the last three years, undergraduate and graduate students in the program have presented their project and research results in a variety of forums[2, 3, 4, 5].

Impact, Dissemination and Evaluation

This interdisciplinary program represents a significant change in the delivery of engineering education in microelectronics not only in our College, but to universities and related industries. This curriculum, integrating a portion of the technical cores of ECE and ME, requires careful assessment of performance in the delivery and the response of our students and employers. This task is aided by the assessment of all engineering courses, which continues in our College with efforts to exceed the requisites of the criteria of ABET 2000.

This interdisciplinary curriculum especially emphasizes the ABET 2000 criteria to design and conduct experiments (Criterion b) and to function on multidisciplinary teams (Criterion d). The coupling of microelectronic design, materials science and heat dissipation requires the analysis of simulations, the sequencing to experiments with new simulations and the fabrication of devices based on initial results. This coupling of the ECE and ME disciplines also requires a multidisciplinary team, with students and faculty who are centered on the two poles of the applied engineering science.

The impact that this interdisciplinary program has on the student and the microelectronics industry is of a major significance. The curriculum enables us to foster a stronger relationship between the College and the microelectronics industry. The interdisciplinary approach of the curriculum prepares students to understand the interrelationship of engineering disciplines. The engineering student that completes this program understands the heat distribution problem when designing large-scale integrated circuits and their packaging.

The current paradigm usually has the final design of an integrated circuit, developed by the electrical engineer, presented to the mechanical engineer to design the package and solve any heat dissipation and distribution problems. Frequently, the integrated circuit must be redesigned due to circuit problems that occur subsequently because of such problems. This interdisciplinary educational program trains students to be aware of the complete process of integrated design, beginning with the circuit CAD layout and proceeding to the evaluation and solution for the final package. This interdisciplinary program promotes a close working relationship between faculty and microelectronic practitioners. Since each course is prepared and taught in part by industrial practitioners, sponsored by the faculty, the student gains a much closer working relationship them and their industry. Such exposure produces a student better equipped to contribute to the growth of microelectronics technology.

Dissemination of the curriculum objective and developments are featured on the website of the System Chip Design Center (SCDC, www.temple.edu/scdc) of the College. The SCDC was established in May 2000 by an initial grant from The Western Center Design (www. westerndesigncenter.com). The objective of the SCDC is to strength the tenants of the system-on-a-chip (SOC) design paradigm in the existing ECE digital logic and microelectronics course sequences.

Temple University is a member of the Greater Philadelphia Louis Stokes Alliance for Minority Participation (AMP) program. This program is made up of nine colleges and universities committed to increasing the number of African American, Hispanic, Native American, and Woman students receiving Bachelor of Science degrees in the science, mathematics, engineering, and technology (SMET) disciplines. Participation in the AMP program provides an organizational and group dynamic for the interdisciplinary programs that fosters social and intellectual stimulation for students. It offers summer and academic year programs to involve students in research projects in faculty laboratories.

Dissemination of the educational research results are and will be promulgated by presentation at local and national meetings of technical societies, especially IMAPS, IEEE, ASME, and ASEE. These forums represent exemplary opportunities for discussion and evaluation of the proposed curriculum.

The evaluation process will be based on outcomes, as defined by the ABET 2000 criteria, and on how effectively the two stated objectives of this interdisciplinary educational program have been achieved. To determine if the first objective of this program, better preparing engineering students to become practitioners, has been achieved, a mail and Internet survey is and will be conducted with companies that have employed students trained under this program. A comparison is and will be made with the employment performance of student participants and non-participants in this interdisciplinary educational program.

The second objective of this interdisciplinary program is to build a closer working relationship with the microelectronics industry. This objective has both a short and a long-term evaluation process. In the short-term, the participation of practitioners as advisers in the courses is critically examined: how many practitioners agreed to participate and how well did they interact with students? In the long-term, a survey of the participating microelectronic firms will be conducted to determine what changes in practitioner attitudes have occurred as a result of their participation in this interdisciplinary educational program. It will also be necessary to examine how implementing this program has changed the reputation of the College: are more microelectronic firms interviewing our ECE and ME graduates; what is the employment rate in the microelectronic industry of the graduating seniors and matriculating graduate students that participated in this program; and has the enrollment of the College increased?

The Future

Microelectronic systems now perform a wide variety of crucial tasks in our daily lives[6]. They have systematically replaced mechanisms that had operated solely mechanically or hydraulically.

These microelectronic systems are smaller, lighter, economical, more flexible, and easier to service. Microelectronic systems are found in personal and commercial transportation systems, consumer and military electronics, and financial and health-care institutions. In the future, microelectronic systems will become even more pervasive.

This portent leads to the conclusion that interdisciplinary ECE and ME education with an inherent emphasis on microelectronics, heat transfer and materials science will be necessary in a variety of engineering and scientific disciplines. This interdisciplinary and integrated curriculum between ECE and ME can be a model for other science and engineering faculty and departments to create similar curriculum of interest to local industry in fields such as the biosciences, physics and chemistry.

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