MICROSYSTEMS PACKAGING EDUCATION: NEEDS, CHALLENGES AND RECENT INNOVATIONS

Rao Tummala[1] and Leyla Conrad[2]

Abstract *Microsystems and Information Technology is the largest industry accounting for $1.2 Trillion currently and are expected to grow to $3.0 Trillion within a decade. Two critical items, however, must be addressed before this growth can become a reality. First, new technologies are needed both to create new products and to expand the existing products going beyond the last 40 years of the microelectronic revolution. These new technologies must lead to marketable products that are higher in performance, lower in cost, thin, light, portable, and highly reliable. Second, new human resources trained in these new technologies and products must also be developed to propel the market growth. These engineers are needed to explore, design, develop, manufacture and market the products globally. Both of these issues are global problems that require global efforts and solutions.*

To meet the above needs for microsystems packaging engineers, both in quality and quantity, the Packaging Research Center (PRC) at Georgia Tech recognized the need for a comprehensive and system-level curriculum and it developed such a program. There are certain characteristics of this program that include: a strong cross-disciplinary and yet a fundamental flavor, a system-level perspective, an emphasis on industrial perspective and team research. These characteristics require a more systematic approach to undergraduate and graduate education than is currently pursued.

While the VLSI segment of the $1.2T IT market has developed extensive research and educational programs, the IC and Microsystems packaging market segment, however, is primitive without degree programs, curricula, design tools and courses. This paper describes some of the details of the newly developed undergraduate and graduate programs to address these.

HUMAN RESOURCE NEED FOR MICROSYSTEMS PACKAGING ENGINEERS

Microsystems packaging is going through paradigm changes. Contrary to the past, these changes must yield thin, light, portable and low-cost system technologies with high performance digital, high bandwidth (optical), analog, RF and MEMS system functions. The intersection of these IC and systems packaging crossroads is paving the way for a fundamentally new paradigm pioneered by the PRC, referred to as "System-on-a-Package," or SOP [1].

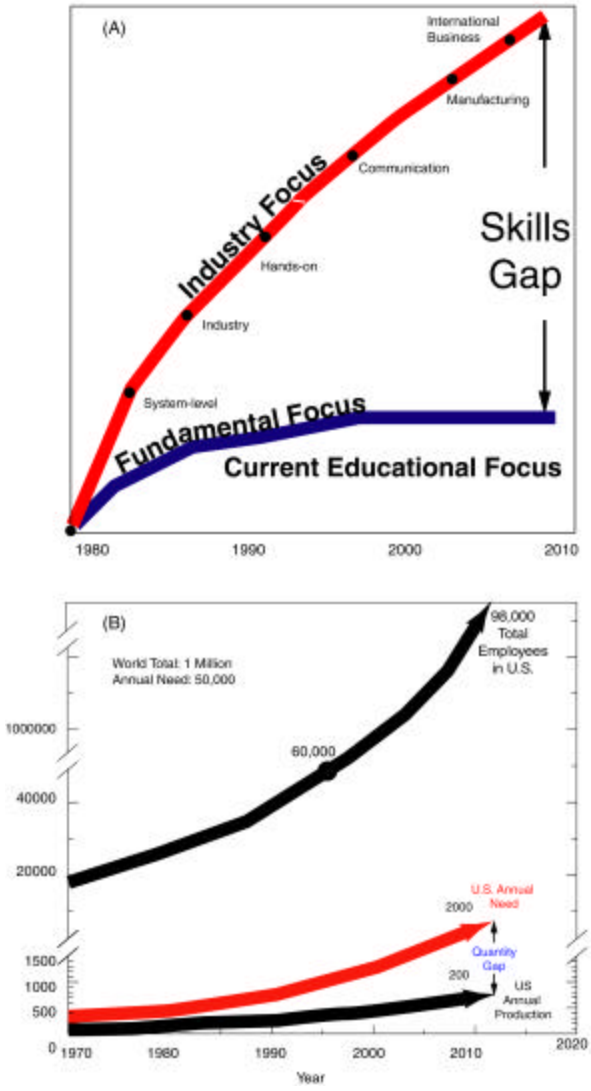


FIGURE 1
(A). REQUIRED SKILLS IN PACKAGING ENGINEERS;
(B) ANNUAL NEED OF MICROSYSTEMS PACKAGING ENGINEERS IN THE U.S.

Equally important to the new system-level SOP technologies are the skilled human resources required to both explore and develop these technologies and to take them to the global marketplace. The industry may see the need to focus its domestic activities on system-level design and development and offshore manufacturing and assembly in other regions such as the Far East. This will minimize the system-level costs, balance workload and enable more focus on global

[1] Rao Tummala, Georgia Tech Packaging Research Center, 813 Ferst Drive, Room 351, Atlanta GA 30332 rtummala@ee.gatech.edu
[2] Leyla Conrad, Georgia Tech Packaging Research Center, 813 Ferst Drive, Room 354, Atlanta GA 30332 leyla.conrad@ee.gatech.edu

marketing of products. Therefore, the human resource needs of the 21st Century will be dramatically different from the past and fall into two categories: (1) the number of skilled engineers (quantity); and (2) the educational background and skills of these new engineers (quality) [4].

Skills Quality Need

The skills illustrated in **Figure 1A** are based on industry surveys conducted by the PRC. They include: (a) deep fundamental, system-level and manufacturing knowledge; (b) global knowledge of the marketplace such as markets, business, economics, foreign language and culture, (c) leadership and communication skills.

Figure 1A also shows the so-called skills gap defined as the gap in skills between what industry would like in its engineering workforce vs. what the universities are currently producing.

Quantity Need

In addition to the above quality of skills, the quantity of engineers required to support the expected growth needs attention. If growth in packaging and semiconductors were consistent with the above projections, this would translate into a need for 90,000 systems packaging engineers in the U.S. and a million engineers worldwide in 2008. As indicated in **Figure 1B** the total new annual U.S. demand for systems packaging engineers is about 1,000 per year now and will be about 2000 in 2008. In contrast, the total degree recipients with microsystems packaging skills at all levels from all U.S. universities is less than 200 per year.

Educational Barriers

The microsystems packaging market is as big as the semiconductor market. Despite this, packaging isn't an academic subject in the academic community. As a result, there are no degree programs, no curricula and no classical textbooks. The reasons for these are several:

- **Lack of Cross-discipline Curricula:** Microsystems packaging is the ultimate cross-disciplinary technology. As such, it did not lend itself to any conventional educational program.
- **Lack of Knowledgeable Faculty:** The same qualifications are required in the faculty as they are in students. Most faculty are not educated in microsystems technology since there has been no degree program at any university in the past. If they have become educated in a subject(s), usually it has been in one or more aspects of the technology, but not the total, capable of system level teaching.
- **Lack of Infrastructure:** The infrastructure includes books, design and modeling tools and facilities for hands-on education that emulates the complete product development process in the industry from design— to build— to operate. It is difficult for universities to absorb the costs of expensive facilities and equipment.
- **Perceived Lack of Academic Content:** Most universities, as well as most of the industry, viewed microsystems packaging education to be much more manufacturing-centric, thus lacking fundamental academic basis.
- **Lack of Elective Courses**: The typical undergraduate curriculum does not provide room for any new programs, particularly if that program involves other disciplines.
- **Lack of Fundamental and Entry-level Textbooks:** While there have been many books since late 1980s, most of these are reference books.

UNDERGRADUATE MICROSYSTEMS PACKAGING EDUCATION AT PRC

During the 1990s, major research advancements occurred with the establishment of interdisciplinary research centers at several universities: Cornell, SUNY-Bingamton, Virginia Tech, Georgia Tech as well as the Universities of Arizona, Arkansas, Colorado, and Maryland. These centers not only excelled in one or more packaging research themes, but also created extensive educational programs. Until the establishment of these centers, packaging education was almost entirely centered on an individual professor who concentrated on a few research projects with his/her students and therefore lacked the culture of cooperative interdisciplinary teams. However, there is no undergraduate focus at any of the universities in the U.S. or elsewhere.

The PRC's educational vision is to provide students with the fundamentals of microelectronics and microsystems packaging education and research. The Center's students develop knowledge and skills in this multidisciplinary engineering discipline, coupled with a general knowledge of the entire microelectronics manufacturing enterprise and an ability to effectively communicate and work as a member of a research team. Over the past six years, the PRC, in partnership with the electronics industry, has designed and developed one of the most comprehensive, system-level and global electronic packaging education programs in the world.

The PRC recognized the need for undergraduate education reform as its core strategy. It also recognized that in order to develop such a successful undergraduate education program, it must have the following elements: 1) curriculum, 2) microsystems packaging track or focused program, 3) undergraduate textbook, 4) industry perspective, 5) team research.

Microsystems Packaging Curriculum

Of all these elements, the development of a curriculum is the most difficult to achieve. The curriculum requires both theoretical classroom and hands-on practical education emulating the industry experience spanning a broad set of system technologies. It requires an undergraduate textbook that introduces the subject matter with emphasis on fundamentals.

The PRC has designed and developed an extensive undergraduate curriculum over the past six years as presented below. This curriculum consists of: 1) system-level courses; 2) fundamental courses in electrical, thermal, materials, and reliability; 3) hands-on courses that emulate the entire product cycle from design to fabrication to electrical and mechanical testing.

1. System-level Course

This system-level course (ECE 4460) introduces students to packaging technologies, technology drivers, electrical performance, thermal management, materials, optoelectronics, RF integration, reliability, system issues, assembly, and testing. Students completing the course should be able to: (a) obtain a fundamental understanding of packaging and its role in system design; (b) understand the various system-level trade-off issues in packaging; (c) explain the bottlenecks associated with System-on-a-Chip (SOC) and System-on-a-Package (SOP) solutions; (d) work in teams to understand and appreciate the interdisciplinary nature of packaging; (e) understand semiconductor roadmaps and their impact on packaging; (f) solve packaging related problems based on first order approximations.

2. Fundamental Courses

As summarized in **Figure 2A** several fundamental courses in major sub-fields of microsystems packaging have been developed, leading to an undergraduate curriculum. Contents of these courses are updated periodically to incorporate the recent research findings.

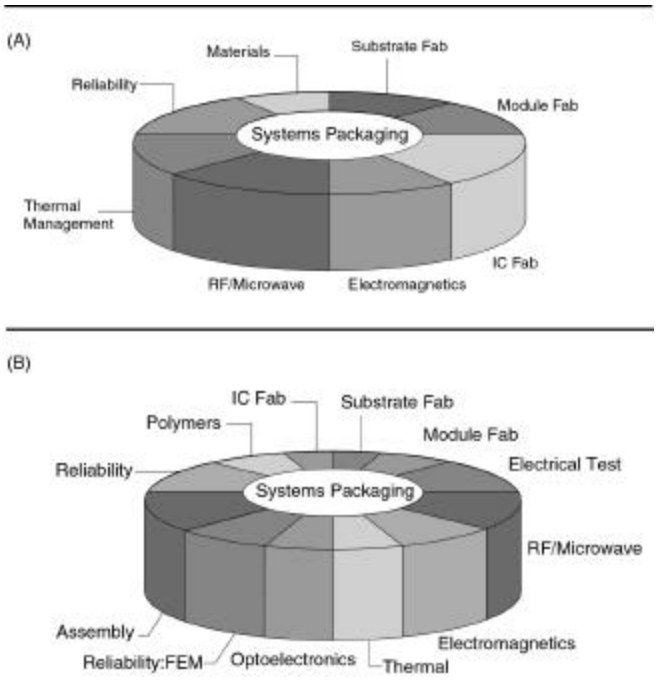


FIGURE. 2
(A) UNDERGRADUATE CURRICLUM; (B) GRADUATE CURRICULUM

3. Hands-on Courses

A key aspect of the undergraduate program is to provide students with hands-on courses that emulate the industry experience ranging from: (a) electrical and mechanical design of IC, packaging and systems; (b) chemical fabrication of materials; (c) build and assembly of systems; (d) electrical testing of the final product. The PRC calls this hands-on course "Design-Build-Operate (DBO)." Two such courses were developed with focus on: (1) substrate wiring and integral passives technologies including multi-level thin film fabrication; and (2) module technologies including assembly, reliability, thermal management and electrical test. Each course includes the necessary theoretical lectures but the primary focus is on laboratory exercises that permit students to electrically design, chemically build, mechanically assemble and electrically test microelectronic system packages. The substrate DBO (ECE 4803) includes topics such as interconnect design, dielectric deposition, via formation, metallization, and substrate testing. The module DBO (ME 4803) course covers flip chip assembly, functional test, reliability modeling and thermal management.

Focused Programs of Study

With the availability of system and fundamental-level courses, a new undergraduate curriculum with an electronic packaging focus was developed. Students participating in this program are required to take one system-level course, one of the hands-on DBO courses and a fundamental course

as a packaging elective and the Capstone Design Experience course in packaging.

In the recently developed ECE4005 Capstone Design Experience course students work in teams on microelectronics related projects such as optoelectronic and RF data link hardware and its applications. Some of the highlights of this course include: design of 2.4 GHz power amplifier and receiver circuits for fabrication; design of a 1394 protocol optoelectronic data link; and development of a D1 based digital video link for the PRC opto-RF prototype.

First Undergraduate Textbook

A key ingredient for implementing the curricullum and the above focused program involving fundamental and system-level courses is clearly the availability of an undergraduate book which provides both the breadth of microsystems and the fundamentals of all the microsystem technologies. Until very recently no such book existed. In the past year, the PRC has undertaken to write the first undergraduate book entitled "Fundamentals of Microsystems Packaging." with emphasis not only microelectronics but also photonics, RF/wireless and MEMS. This is referred to as Microsystems Packaging in the book, as illustrated in **Figures 3A and B**.

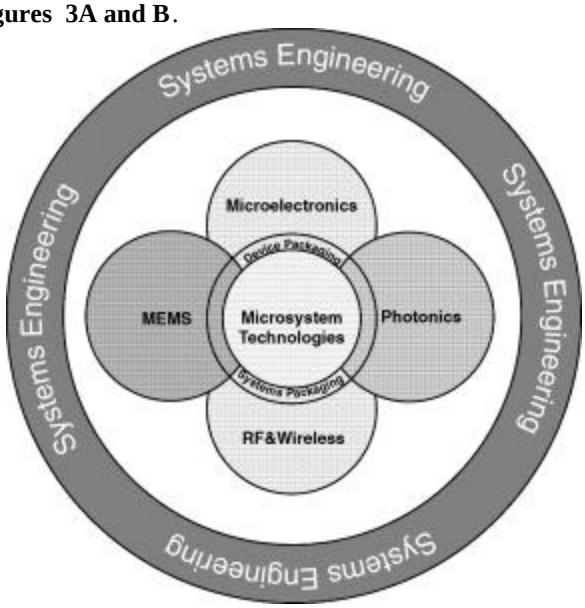
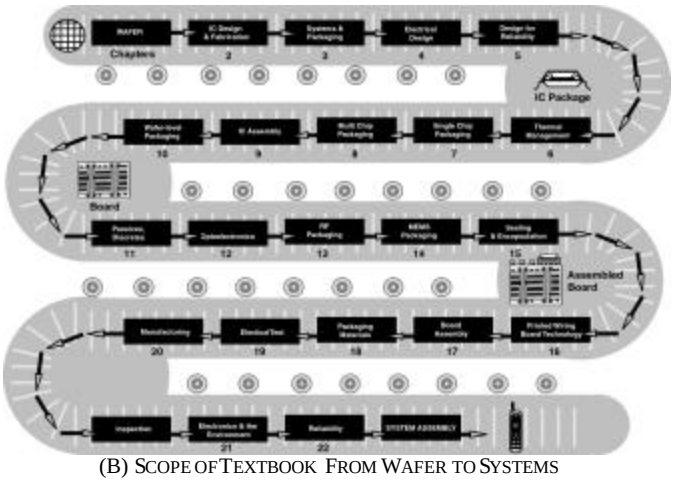


FIGURE. 3
(A) DEFINITION OF MICROSYSTEMS PACKAGING



(B) SCOPE OF TEXTBOOK FROM WAFER TO SYSTEMS

Undergraduate Team Research

The PRC views the undergraduate research to be a very important part of its undergraduate program. The undergraduate research falls into three catogories: academic year component, summer component and outreach component.

Industry Perspective

The PRC recognizes that its primary responsibility is to educate the students for industry need. One way to accomplish this need is by means of industry intern and cooperative education. PRC students receive industry perspective through a variety of channels that include: interacting with member company engineers at the Industrial Advisory Board meetings; attending conferences and workshops organized by the PRC; industry involvement in research projects; and co-op/internship experience at companies.

GRADUATE PACKAGING EDUCATION AT THE PACKAGING RESEARCH CENTER

Graduate microsystems packaging education incorporates fundamental science and engineering, system-level engineering, communication skills and industry perspective. In addition, it includes: 1) business, management, and a familiarity with foreign culture and global markets at the M.S. level; and 2) SOP system-level and team research at the Ph.D. level.

Fundamental and System-Level Courses

The PRC has developed several new graduate courses and mo dified some of the existing ones over the past six years to come up with its graduate curriculum as indicated in **Figure 2B**.

Figure 4 provides the total number of Georgia Tech students enrolled in the packaging.

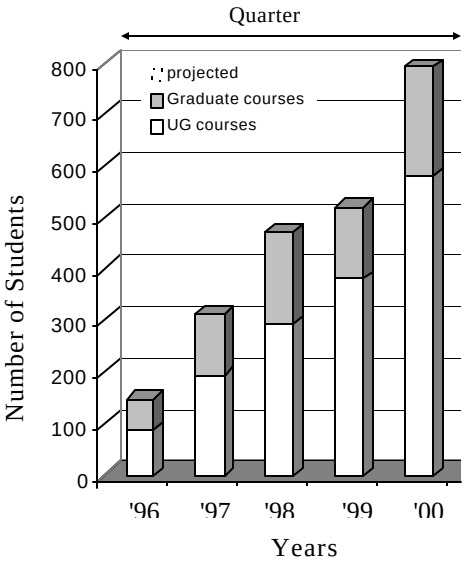


FIGURE. 4
GEORGIA TECH UNDERGRADUATE AND GRADUATE STUDENTS ENROLLED IN PACKAGING COURSES

Masters Curriculum

The PRC realized the need to create a Masters program - - one with not only fundamental and system-level attributes but also business, management and global aspects of packaging technology [5]. With the availability of the graduate courses , a graduate Electronic Packaging Certificate and Practice-Oriented Masters (POM) program were developed. The students entering these programs are working towards their MS degrees in their home departments.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the National Science Foundation and the PRC industry partners for their support. The PRC educational program has been supported by the National Science Foundation under grant numbers EEC-9402723, EEC-971384, and EEC-9810227.

REFERENCES

[1.] Rao R Tummala, Fundamentals of Microsystems Packaging, McGraw-Hill, May 2001

[2.] Rao Tummala, "SOP: Microelectronic Systems Packaging Technology for the 21st Century," Advancing Microelectronics, Vol. 26, No. 3, p. 29 (1999).

[3.] Rao Tummala, Gary May and Leyla Conrad, "Georgia Tech's Electronics Systems Packaging Education: A Model for 21st Century," The Circuit, Vol. 2, No. 1, p. 8 (1999).

[4.] Rao Tummala, Leyla Conrad and Gary May, "The Needs, Evolution, Status and Challenges of Microelectronics Packaging Education in the U.S.", Proceedings of the 49th Electronic Components & Technology Conference, p. 885 (1999).

[5.] Leyla Conrad, Rao Tummala and Gary May, "The First Entrepreneurial and Practice-Oriented Masters Program in Microelectronics Systems Packaging," Proceedings of the 50th Electronic Components & Technology Conference, p. 1002 (2000).