Virtual Laboratory Support for Electronics Packaging Education

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Abstract *¾ The preparation of engineers for the 21st century's requirements of rapidly developing information technology as well as microelectronics and electronics packaging technology is a real challenge for today's education. An approach that teaches electronics packaging technology and closely associated informatics topics providing lecture courses, lab sessions and independent research studies supported by a prototype manufacturing and a virtual laboratory environment can hopefully achieve the main goals. The Project for the development of the virtual laboratory has been going on since September of 1999. The following laboratories have been placed on the Web to provide access in electronic format: Printed Wiring Boards, Thin Film, Laser Processing, Thick Films, Surface Mounting and Computer Integrated Manufacturing. Manufacturing equipment of these laboratories appear on photos, with system schematics and description of the principles of operation supported by computer graphics and animations. A method that efficiently combines the traditional blackboard-chalk method with the application of CD-ROM textbooks, highly advanced Internet based virtual laboratory tools and hands-on experiments in prototyping laboratories will also be demonstrated.*

Index terms: electronics packaging education, virtual laboratory, curricula of electrical engineering

INTRODUCTION

The development of information technology has opened new perspectives in engineering education to prepare graduating students for the needs of the 21st century. In particular, there is a very great need for the application of advanced curricula and teaching methods in the rapidly developing field of electronics packaging and associated information technology.

Computing, telecommunication, multimedia electronics, air and automotive transportation, etc. have become the part of our everyday life. The need for high performance, low cost electronics products used in these areas is the most important driving force for the microelectronics packaging industry. In the heart of all electronics products there are the signal processing and memory chips, which are available with high reliability, low power consumption, in very small dimensions and on decreasing price. The challenge for the packaging industry is to find appropriate technology for the design and fabrication of interconnections between the chips and large systems or human beings. These circuits and interconnections convert/amplify the signals to the format and level suitable for information exchange between sensors, actuators, engines, human organs, etc. on one side and processing devices on the other side. The rapid development of electronics packaging technology is accompanied by the dramatic change of the knowledge required from engineers, researchers and scientists working in this field, therefore electronics packaging education for both undergraduate students and working engineers has increasing importance.

PACKAGING EDUCATION CURRICULUM AT BME

There are two educational branches of the Faculty of Electrical Engineering and Informatics at Budapest University of Technology and Economics (BME): the Electrical Engineering branch and the Technical Informatics branch. The curriculum of the Electrical Engineering branch (Table 1), which provides courses for teaching the knowledge of electronics packaging technology, too, has three different levels, as follows:

1. In the first part of the curriculum courses like mathematics, program design, digital technique, informatics, computer science, physics and materials science are obligatory for all students, in order to lay the fundamentals down for the further study.
2. At the middle of the curriculum, a core subject on electronics manufacturing technology, together with other ones on measurement technique, electronics, telecommunication, process control and power electronics, completed by systematic application laboratories, provide the basic study of engineering and technology for all students.
3. In the final semesters, elective degree programs are offered for students to prepare them for their favorite professions. Among these programs students can find packaging oriented ones, too. As parts of these programs the subjects of Research Project and Final Project provide opportunity for the students to carry out research, solve living industrial problems and use high tech equipment in the field of packaging technology.

Electronics Technology - the core subject

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In the fifth semester, among the core subjects there is Electronics Technology, from which the students get basically acquainted with the realization technology of electronic products, and which develops their ability to communicate with the specialists of other fields. In this subject the disciplines of electronics interconnection and packaging technology, and their manufacturing systems are discussed [1-2].

Complementary to the lectures, the students have to perform a set of short exercises to study manufacturing processes, including:

- Technology of Printed Wiring Boards;
- Thick film technology and surface mounting;
- Technology of thin films: evaporation, photolithography and laser processing.

During the subsequent (sixth) semester, in the frame of the subject Laboratory, all students have to carry out an elective, longer prototyping laboratory task, that is, to design, realize, test and/or apply a device or a circuit module by means of a complex manufacturing system [3]. A few topics of these laboratory tasks are listed, as follows:

- Fabrication and test of Multilayer Printed Wiring Boards.
- Design for manufacturing and application of CAD/CAM systems in the field of Printed Circuits.
- Application of laser direct writing for the prototyping of circuit patterns.
- Study of microelectronics masking technologies.
- Analysis and characterization of solar cells.
- Fabrication and test of thin film temperature sensors.
- Analysis and characterization of display devices.
- Fabrication and test of screen-printed and fired thick film hybrid circuits.
- Application and test of infrared soldering technology.
- Analysis of force, pressure, temperature, gas-composition and humidity sensors.

TABLE 1

CURRICULUM OF ELECTRICAL ENGINEERING

Course	Hours/week with requirements										
Title Semester	Σ	1	2	3	4	5	6	7	8	9	10
Social sciences	16	2p	2e	2p	2p		2e	2p	2e	2e	
Mathematics	16	6e	6e	4e							
Probability calculus	4			4e							
Program design	6	4p	2p								
Digital technique	10	4e	6e								
Networks and systems	10		4e	6e							
Informatics	8			4e	4e						
Computer science	6				6e						
Materials science	4	4e									
Physics	12	4e	4e	4e							
Electromagnetic fields	4				4e						
Measurements	4				4e						
Electronics	12				4e	4e	4e				
Laboratory	8					4p	4p				
Power electronics	4					4e					
Telecommunication	4					4e					
Electronics technology	4					4e					
Process control	4					4e					
Main module subjects	24						4e	4e	4e	4e	
							4e	4e			
Subject laboratories	8						2p	2p	2p	2p	
Project laboratory	12								6p	6p	
Final project	24										24s
Secondary module subjects	16							4e	4e	4e	
								4e			
Subject laboratories	4								2p	2p	
Elective courses	16						4e	4e	4e	4e	
Total hours/week	240	24	24	24	24	24	24	24	24	24	24
Examinations	42	4	5	5	5	5	5	5	4	4	
Comprehensive exams	3+1			D	N	M					F

Comprehensive subjects: Digital technique (D), Networks and systems (N), Mathematics (M)

Marks: e: exam, p: practice, s: signature

F: Final examinations for diploma qualification

Degree Programs in Electrical Engineering

In the final part of the curriculum, students are offered a range of technical lecture courses and systematic laboratories, from which to select their degree programs. It means, that before starting the sixth and the seventh semester all students should select a main and a secondary degree program (or module), respectively. The main modules contain two more lecture courses than the secondary ones (see Table 1.), and they include the individual research oriented subjects of Project Laboratory and Final Project. The list of the main and the secondary modules are given in Table 2. and Table 3., respectively.

TABLE 2

MAIN DEGREE PROGRAMS

Main degree programs in Electrical Engineering
Computer Systems and Applications
Electric Power Systems
Embedded Information Systems
Microsystems and Circuit Modules
Power Converter Systems
Process Control and Robot Informatics
Telecommunication
Telematics

TABLE 3

SECONDARY DEGREE PROGRAMS

Secondary degree programs in Electrical Engineering

Applied Informatics
Business Management
Cable Television and Optical Telecommunication
Design and Manufacturing of Electronic Equipment
Digital Signal Processing (Telecommunication)
Electro-acoustics, Studio technique
Enterprise Economy
Informatics in Power Electronics
Intelligent Systems
Management in Electrical Power Engineering
Medical Biology
Mobile Telecommunication
Servo and Robotic Drives
Software Technology
Telecommunication Management

The Department of Electronics Technology is responsible for the education of degree programs whose aims are to teach the materials science aspects, the physical design, the fabrication processes and manufacturing systems of electronic components, circuit modules and units. These degree programs are the "Microsystems and Circuit Modules" main module, and the "Design and Manufacturing of Electronic Equipment" secondary module.

The structure of the curriculum of the Technical Informatics branch is very similar to that of the Electrical Engineering branch. The main difference is that there are only one kind of application oriented degree programs in the structure. Among these programs one can find the "Integrated Enterprise Control Systems" module, whose topic has great importance for all engineers working in production enterprises, including those of electronics packaging technology. BME-ETT is responsible for the education of this module.

Microsystems and Circuit Modules - the main degree program of electronics technology

This main degree program gives detailed theoretical and practical knowledge regarding the inner structure, construction and technology of integrated circuits, VLSI circuits, integrated microsystems as well as high density packaging structures including multichip modules (MCMs), hybrid circuits, surface and through-hole mounted printed wiring board (PWB) assemblies. It deals with the physical design of electronic systems and their circuit units, computer aided design (CAD) methods and with the principles and practice of testing systems, circuit modules, and components. Another important part of the syllabus deals with reliability of electronic units and parts, and with quality assurance. Computer control and organization of production at enterprises are also significant parts of the factual knowledge.

According to its name, the Microsystems and Circuit Modules degree program has two educational directions. Their subjects are listed in Table 4.

The subjects of the "Circuit Modules" direction of the main degree program form a sequence of simulation, design, fabrication and test in the field of theoretical lecture courses and experimental laboratories as well. The systematic laboratory session extends over the 6^{th}-9^{th} semesters with 2 hours/week providing training of the main phases of engineering activity. The topic of each laboratory is in very close connection with a lecture subject of the same or former semester, thus a laboratory gives the practical aspects of the concepts which were theoretically discussed previously.

Design and Manufacturing of Electronic Equipment - the secondary module of electronics technology

This secondary module gives detailed knowledge on

- industrial right protection;
- design and fabrication of multichip modules (MCMs), including substrate design and fabrication, chip assembling and thermal management of the package;
- thermal, ergonomic and EMC design of electronic systems, including the application of CAD systems in the design process, and the running, maintenance and service methods of electronic systems, and
- quality control and reliability of electronic systems, circuit modules and components.

The subjects are listed in Table 5.

TABLE 4
MICROSYSTEMS AND CIRCUIT MODULES DEGREE PROGRAM

Title of subjects Hours/week in semester	6	7	8	9	10
Common subjects:					
Circuit Production	4e				
VLSI Circuits	4e				
Simulation Laboratory	2p				
Circuit Modules direction:					
Design of Circuit Modules		4e			
Electronic System Design		4e			
Circuit Module Design Laboratory		2p			
Electronic Systems and Quality Assurance			4e		
Circuit Module Fabrication Laboratory			2p		
Production Control				4e	
Quality Control Laboratory				2p	
Project laboratory			6p	6p	
Final project					24s
Microsystems direction:					
Design of Microelectronics		4e			
Synthesis of High Level Logic		4e			
ASIC and FPGA Design Laboratory		2p			
Monolith Technique			4e		
VLSI Design Laboratory			2p		
Integrated Microsystems				4e	
Test Laboratory				2p	

	6	7	8	9	10
Project laboratory			6p	6p	
Final project					24s
Total hours/week	10	10	12	12	24

Marks: e: exam p: practice s: signature

TABLE 5

DESIGN AND MANUFACTURING OF ELECTRONIC EQUIPMENT

Title of subjects Hours/week in semester	6	7	8	9	10
Industrial Right Protection		4e			
Multichip Modules		4e			
Electronic Equipment			4e		
Circuit Module Design and Fabrication Lab			2p		
Quality Assurance and Reliability				4e	
Quality Control of Equipment Laboratory				2p	
Total hours/week		8	6	6	

Marks: e: exam p: practice

The secondary degree program includes a systematic laboratory session that extends over two semesters, from the 8th to the 9th, with 2 hours/week. The aim of these laboratories is also to train the main phases of engineering activity, however, in this case with more focus on system fabrication technology.

Integrated Enterprise Control Systems - degree program for technical informatics

The aim of this degree program is to provide knowledge and capability for engineers for the design and realization of integrated enterprise control systems as well as for their installation, configuration, maintenance, control and coordination. Students get detailed knowledge on the structure, operation, computer control, and quality management tools of systems that integrate all functional parts of an enterprise. In the possession of these capabilities and knowledge, the information engineers are able to solve the orgware - computer aided organization and management - tasks of the enterprises.

The subjects of the "Integrated Enterprise Control Systems" module are listed in Table 6.

TABLE 6

INTEGRATED ENTERPRISE CONTROL SYSTEMS DEGREE PROGRAM

Title of subjects Hours/week in semester	6	7	8	9	10
Enterprise Economy		4e			
Enterprise Control Systems		4e			
Enterprise Control Systems Laboratory		2p			
Quality Assurance			4e		
Production Informatics			4e		
Production Informatics Laboratory			2p		
Management for Engineers				4e	
Enterprise System Configuration Laboratory				2p	
Project Laboratory		2p	6p	6p	
Final Project					24s
Total hours/week		12	16	12	24

Marks: e: exam p: practice s: signature

In the enterprise control degree program one can also find a systematic laboratory sequence that extends over three semesters, from the 7th to the 9th, with 2 hours/week. The aim of these laboratories is to train the main phases of engineering activity in the field of enterprise control systems, i.e. how to install, operate, maintain, configure and develop an integrated control system in an enterprise environment.

ADVANCED DIDACTICISM FOR PACKAGING

Education through Prototyping

It is the inherent part of all our degree programs, that problem-oriented knowledge of technology is given to individual students in the frame of Project Laboratory and Final Project, where the practical work of the students is in connection with the research and development activity of the departments [4-5]. The topics of these problem-oriented projects offered by the Department of Electronics Technology can be chosen from the following areas:

- components, thin and thick films, hybrid circuits;
- technology of printed wiring boards;
- high density packaging and assembling ;
- multichip modules, subassemblies and systems;
- sensors, actuators and displays;
- laser technology;
- quality control, reliability and life-time test;
- computer aided design and manufacturing;
- modeling of production systems and enterprises;
- production and enterprise control;
- industrial right protection and management; etc.

An important requirement is that each laboratory project should contain all parts of engineering activity, i.e. the steps of research, simulation, theoretical and physical design, fabrication and test. The students also should study the research and development project in its entirety and should learn to work in a team.

The Department has built up a prototype and small batch fabrication facility and provides its unique service for final year students (for partner departments and for small enterprises as well). The aim is to teach technology through practice: our students have got the possibility not only to design but also to construct and fabricate, i.e. realize the circuits what they design. The prototyping service is available in all the three basic interconnection technologies, i.e. the realization can be carried out using either printed wiring, thick film or thin film technologies, and their combinations, too.

The printed wiring board prototyping facility of the Department is fairly advanced and productive, it is operated like a small enterprise and runs every day. An experimental level integrated production control system has been installed for the prototyping laboratories. On one hand its aim is to track and control the prototypes in the course of fabrication. On the other hand, however, the prototyping facility equipped with the integrated production control system provides a real enterprise environment for the study, research and development work of our information engineering students and researchers. It can be used for the training of interested working engineers as well.

The existing infrastructure, i.e. the principal scientific equipment belonging to the Department, which provides the basis of the prototyping facility, is located in nine laboratories, as follows:

- Laboratory for the Technology of Printed Wiring Boards;
- Laboratory for Thick Film Components and Circuits;
- Thin Film Laboratory;
- Laboratory for Surface Mounting and Assembling Technology of Circuit Modules;
- Laser Processing Laboratory;
- Laboratory for Photolithography;
- Sensors and Actuators Center;
- Laboratory for Quality Control, Reliability Test and System Technologies;
- Computer Laboratory for CAD, CAM, Enterprise and Production Control.

The Department has also direct access to other important scientific equipment, like scanning electron microscopes and surface profilers. Most of the equipment of the prototyping laboratories is presented by advanced Internet technology, so it can be accessed and studied on the web at www.ett.bme.hu/vlab.

ETT-VLAB, the Virtual Packaging Laboratory

The rapid development of electronics packaging technology is accompanied by the dramatic change of the knowledge required from engineers, researchers and scientists working in this field, therefore electronics packaging education for both undergraduate students and working engineers has increasing importance.

Unfortunately electronics packaging education is at a much lower level than electronics and microelectronics education as a whole, and it is at an even more primitive state than electronics education in general. One possible reason of this state is the high cost which is necessary for any kind of access to the expensive facilities, in order to carry out hands-on technological experiments. In consequence, a virtual electronics packaging laboratory environment can provide a useful tool in practical education for instructors and learners as well. Instructors can deliver packaging courses over the Internet, and the easy access to the virtual laboratories would improve the opportunities of student-centered and life-long individual learning. Educational courses for undergraduate students and working engineers can use the virtual laboratories through the Internet in order to support their training and extend their skills into emerging fields.

In an IEEE-CPMT/NSF supported project the BME-ETT created a virtual laboratory environment for teaching micro-electronics packaging technology [6,7]. The first step in the development of ETT-VLAB was completed by May 2000 [7], since then it is accessible through the Internet at the web site of the Department, http://www.ett.bme.hu/vlab [8], and of IEEE-CPMT, http://www.ewh.ieee.org/mm/cpmt/vlab as well. The first page of ETT-VLAB (Figure 1.) presents the laboratories of the Department that have been virtualized. Positioning the cursor to the door of any of the six laboratories the door is opening, showing that your are welcome and you can enter by clicking on it.

Laboratory equipment is the basic part of the virtual environment. The machines, instruments, apparatuses and systems of our Prototyping Laboratories are modeled. They appear on photos, with system schematics and description of the principles of operation supported by computer graphics and animations. The explanation of the physical/chemical principles of the processes - mainly using animations, illustrations, a few descriptions and equations - are also included. The users have the possibility to use the equipment and analyze the processes virtually, and to change the parameters in order to study the results.

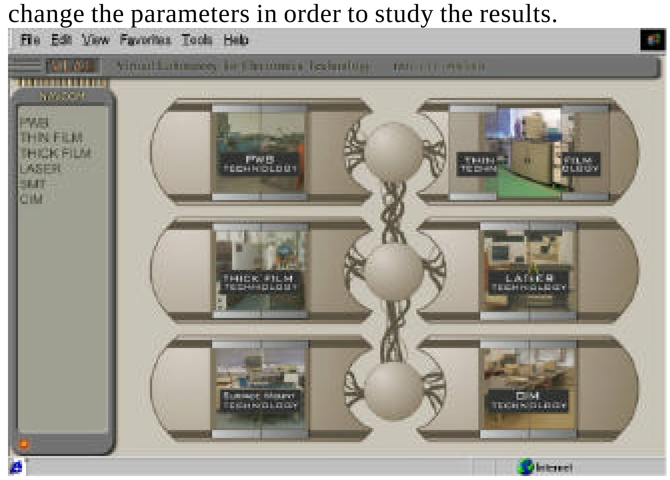

FIGURE 1
THE START PAGE OF THE VIRTUAL LABORATORY

It has been proved that ETT-VLAB fulfills the principal main purposes: students and engineers can improve their knowledge of electronics packaging by studying manufacturing equipment, processes and the resulting products. It provides an excellent possibility for students to make preparations for their hands-on experiments. All of this is placed into an environment that attracts users and helps keeping them longer.

Draw Figures on Blackboard in the Class

Nowadays, the use of overhead projectors, video projectors and personal computers (PCs) comes natural to the majority of professors. By application of these tools tremendous high level information can be provided, however, it is nearly impossible to make notes during such presentations. Another problem is that the decreasing duration of the lectures limits the number and extension of demonstrations. In our opinion the classical "blackboard-chalk" method can not be abandoned completely, because it develops the skills of drawing and notes-making abilities of students to a great extent.

On the basis of the conclusions drawn from the analysis of the education process of electronics packaging technology, we worked out and apply a special didacticism for teaching this discipline for students in larger classes (> 30 students/class). Our didacticism successfully combines the traditional blackboard-chalk method with the use of textbooks published on CD-ROM as well as the highest level Internet based multimedia tools.

Our didacticism works on condition that at the beginning of the semester students can get, buy or download a CD-ROM textbook [1] with all the presentations (slides, movies) of the lectures. The CD-ROM contains the collection of all projected figures as well. Students can study this CD-ROM on their own PC at home before each lecture, or, at least, they can print out the most important figures to make notes and write explanations around them to the same sheet of papers. The CD-ROM also includes ETT-VLAB with its high level animations and interactive movies, so students can study the principles in an almost real environment, they can even virtually operate the equipment or run the process.

On this condition, in the class we prefer the use of the conventional blackboard-chalk method to explain the principle of the topics. We draw very simple schemes, building up the figure line by line within the sight of the students. An example of such a drawing is shown in Figure 2. About 90% of the lecture time is used for drawing and explaining, while the remaining part for the short presentation of the relevant slides from the CD-ROM and the VLAB (Figures 3.).

We found our combined teaching method fairly efficient: it resulted in the improvement of the examination marks of the students. An additional advantage of the CD-ROM textbook is that it can be easily actualized and republished. Together with the existing paper-based materials of the lecture course [2] and the laboratory experiments of the Electronics Technology core subject, it can be placed on the Web to provide easy access to the electronic format.

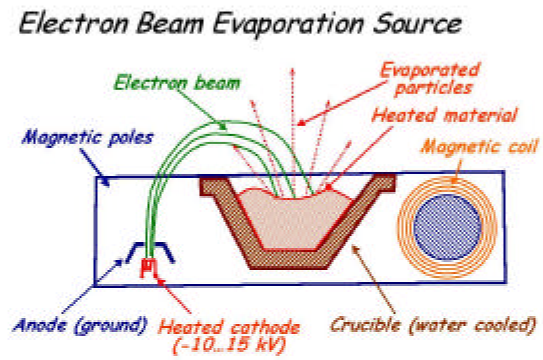

FIGURE 2
THE SIMPLE SCHEME OF AN ELECTRON BEAM EVAPORATION SOURCE AS IT WAS DRAWN ON THE BLACKBOARD

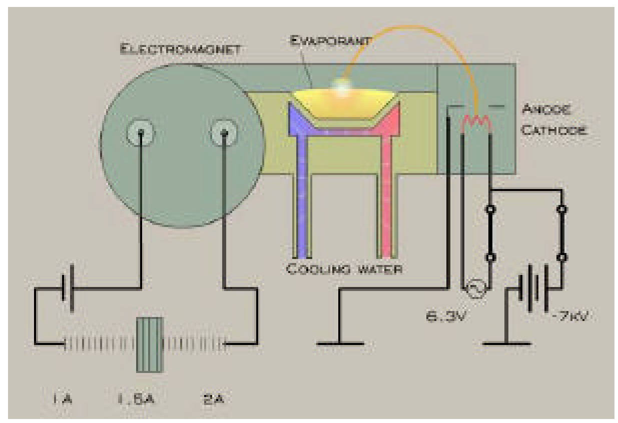

FIGURE 3
THE VIRTUAL ELECTRON BEAM EVAPORATION SOURCE FROM THE VIRTUAL LABORATORY OF ETT-VLAB

CONCLUSIONS

The rapidly developing electronics packaging and information technology increases the requirements for the education of engineering students in these fields. In order to meet the requirements well-structured curricula and advanced teaching methods have to be applied. The Department of Electronics Technology at the Budapest University of Technology and Economics (BME-ETT) developed a didacticism for electronics packaging education that efficiently combines the traditional blackboard-chalk method with the application of CD-ROM textbooks, highly advanced Internet based virtual laboratory tools and hands-on experiments in prototyping laboratories.

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