A Microelectronics Fabrication and Packaging Learning Laboratory for Manufacturing Engineers

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Abstract

Washington State University (WSU) has recently established a Manufacturing Engineering program at its Vancouver campus. Included in a new laboratory building is a microelectronics learning laboratory specifically for teaching this application of manufacturing engineering. Vancouver is located within the Portland, Oregon metropolitan region, sometimes referred to as the “Silicon Forest” due to a high concentration of semiconductor and microelectronics related manufacturing facilities.

The traditional educational path for manufacturing engineers in the microelectronics industry does not usually include many of the critical aspects of manufacturing engineering. This means that engineers in production have to pick up much of the background they need through other, less effective, means. Our goal is to provide a curriculum that will prepare students with the necessary knowledge and skills of traditional manufacturing engineering, and also offer specific manufacturing engineering elective courses directed at microelectronics.

A new lab, including a class 100 clean room, has been equipped with a range of representative equipment for fundamental device fabrication, packaging and inspection/diagnostics. The cost of the equipment is approximately $750,000.

This paper describes the concept, structure, potential and details of the lab equipment. The WSU courses that are slated to utilize this new lab are described to illustrate the educational potential.

Introduction

Washington State University established a new campus in Vancouver (WSUV) in 1989 using temporary facilities. In fall 1996 WSUV moved into new facilities on its own campus. The campus has grown steadily in both physical facilities and academic programs offered. The Bachelor of Science program in Manufacturing Engineering (MfgE) was introduced in fall 1997.

The objectives for the Manufacturing Engineering program are three-fold:

1. Offer accredited engineering courses and degrees to place-bound students in Clark County, Southwest Washington and the Portland, Oregon metropolitan region (employed adults and others who seek to enter the field),
2. Provide engineering courses and degrees to industry employees via on-campus or distance learning, and

3. Advance the economic prosperity of the region through research and development in manufacturing technology and engineering science.

In keeping with our stated mission of offering engineering courses and degrees to place-bound students, the MfgE program at WSUV was created as the first baccalaureate engineering program in southwest Washington. Manufacturing Engineering was chosen at the urging of regional industry. The program operates under the academic oversight of the School of Mechanical and Materials Engineering (MME) at WSU. Manufacturing Engineering at WSUV is fundamental (calculus-based) and practical (intensive hands-on laboratory learning); moreover, it is operated with regard for the interests of regional industry. The manufacturing engineering program is designed to provide the knowledge and skills to enable graduates to make immediate contributions to the regional manufacturing industry. The course of study is based on the existing mechanical engineering program in the School of Mechanical and Materials Engineering, but focuses on manufacturing processes and technologies in greater depth. The program curriculum allows the students to tailor their education to an area(s) of interest to them through the selection of electives. Using the elective courses students can select to have an emphasis area in microelectronics. A new microelectronics learning laboratory provides hands-on exposure for students in this area. The microelectronics emphasis area and the manufacturing focused microelectronics lab are unique in a manufacturing engineering program.

The region, encompassing southwest Washington and northwest Oregon is known as the "Silicon Forest" due to the presence of a large number of semiconductor companies. The electronics industry in the region is vertically integrated (from process equipment and basic materials used in manufacturing all the way to complete electronic products) and has a manufacturing focus. This integrated regional enterprise is an important customer base for the services and products of the Manufacturing Engineering program at WSUV. Representatives from WaferTech, Linear Technology, Silicon 2000, Siemens Solar, Hewlett-Packard, and SEH America serve on the program's Advisory Board, and their corporate executives have been advocates for the new degree program.

Manufacturing processes for microelectronics are unique, having little similarity to processes and equipment in other manufacturing areas. Traditionally, the manufacturing engineering functions in the microelectronics industry have been performed by engineers trained in electrical engineering, chemistry, physics, materials science, mechanical engineering, or optics[1]. These specialists from other disciplines then proceed to learn manufacturing engineering fundamentals on the job, essentially through self-study and company training. Microelectronics manufacturing requires that these various disciplines be integrated[2]. Our manufacturing engineering program with the microelectronics emphasis provides all of the required engineering and science fundamentals along with training in manufacturing operations, cost considerations and other business principals.

The microelectronics specialization area in our curriculum will provide Silicon Forest (and potentially national) industry with graduates trained in the basics of manufacturing engineering, including the integration of processes, plus the specialization that will be needed to function in the microelectronics industry. Moreover, we are able to teach manufacturing engineering to semiconductor company employees who are degreed in other fields such as chemistry or materials science.

U.S. manufacturing industry and the Society of Manufacturing Engineers have identified certain critical "competency gaps" that need to be addressed by manufacturing engineering education programs. The courses and laboratory exercises at WSUV using the completed Microelectronics Learning Laboratory address industry and SME identified competency gaps in four important ways:

1. Manufacturing Processes: The microelectronics learning lab activities apply directly to education in manufacturing processes. Microelectronics differs from traditional manufacturing primarily in the size of the components and features, and the resulting challenges in handling. In addition, some of the unit processes – particularly in device fabrication – are very different from traditional manufacturing processes. For this reason we believe that it is important for the students to have hands-on laboratory experience in the area of microelectronics manufacturing.
2. Quality Principles: The experiments for the Microelectronics Learning Lab are structured around design, fabrication, and inspection (test). The students experience the entire process and are able to immediately use results to make improvements in the design and fabrication processes. This systems-level approach helps to illustrate total quality management (TQM) principles. Part of the lab experience entails detailed examination of not only the devices fabricated in the course, but also of various components supplied by industry.
3. Communications and Teamwork: Students work on lab experiments in teams and are required to submit written lab reports and analyses. In addition, when the opportunity is present, the students will work on teams with industry users in the device analysis area. This will facilitate their exposure to work in the field and to manufacturing engineering practice.
4. Lifelong Learning: Exposure of the degree-seeking students to the industry students and laboratory users will impress upon them the value and need for lifelong learning. In addition, the faculty members will also be able to keep up with the latest developments in the field through the industrial interactions.

A new Engineering and Life Sciences Building was opened for spring semester, 2001. The new building has approximately 40,000 square feet of assignable floor space – primarily labs, but including offices and additional classrooms. Approximately half of the total space is devoted to engineering, primarily the manufacturing engineering program. Approximately 1200 square feet of space in the new building has been designated for the Microelectronics Learning Laboratory. The Microelectronics Learning Lab was a high priority due to its relevance to the local area semiconductor industry and because it will provide an opportunity for WSUV to make an immediate new contribution to manufacturing engineering education. For these reasons this facility is attractive to the local companies who will benefit most from the products (manufacturing engineers educated in semiconductor and microelectronics manufacturing). The Society of Manufacturing Engineers Education Foundation and the M. J. Murdock Charitable Trust have validated our concept and plans for the microelectronics manufacturing engineering emphasis area through peer reviewed proposals and they have awarded WSUV significant grants for the acquisition of the manufacturing and diagnostic equipment for the Microelectronics Learning Laboratory.

Facilities and Equipment

The concept of the Microelectronics Learning Laboratory emerged from a series of industry/academia planning meetings on the WSUV campus during 1998 and 1999. A three-fold synergistic mission was defined, including engineering education, manufacturing diagnostics, and manufacturing R&D, as portrayed in Figure 1. This three-fold mission incorporates two major functions of the university, that of teaching and research, and also includes the service component in the form of providing access to the facilities and faculty to industry for the solution of their specific problems.

The microelectronics learning lab provides facilities, equipment and faculty to enhance the students' classroom education with hands-on laboratory exercises. The same facilities and equipment can be used by the faculty for research, both individual and industry connected, involving solution of complex problems and improvements in manufacturing situations. Difficult industry manufacturing problems can be diagnosed using the equipment available in the microelectronics learning lab along with the expertise of the local Vancouver faculty and if necessary members of the faculty on the main campus in Pullman. Having the industry analysis and research conducted in the same facilities used for teaching will inevitably involve students and enhance their education.

The State of Washington has funded an Advanced Technology Initiative at Washington State University, part of which provided an additional faculty position in manufacturing engineering, specifically in the integrated circuit fabrication area. The ultimate objective of this initiative is to develop the device diagnostic portion of the mission and the new laboratory into a combined university/industry research center.

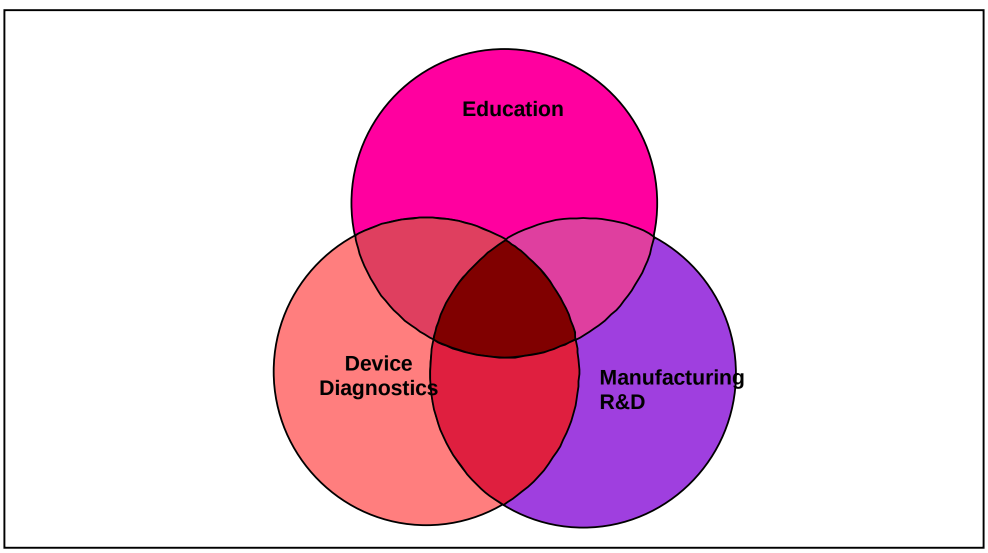

Figure 1. Three-fold mission of the Learning Laboratory

The design of the Microelectronics Learning Lab includes the three major functions, IC fabrication, packaging and device diagnostics. The lab space provided for the Microelectronics Learning Laboratory was divided into four rooms to accommodate the required functions. A floor plan drawing is shown in Figure 2. The physical layout of the area includes a class 100 capable clean room for IC fabrication and packaging, two rooms for device analysis, and a specimen preparation room, clustered into a suite around a central foyer. The design philosophy used was to provide educational exposure to a broad, general range of processes and equipment. All of the equipment was specified with the requirement: "In general the equipment proposed must be representative in terms of capability and quality of that currently used in the integrated circuit industry. However, the production capacity is only intended to be that appropriate to a research and development lab." The equipment was selected to be capable of providing educational exposure to what is typical of industrial use and also to be compatible with anticipated research activity.

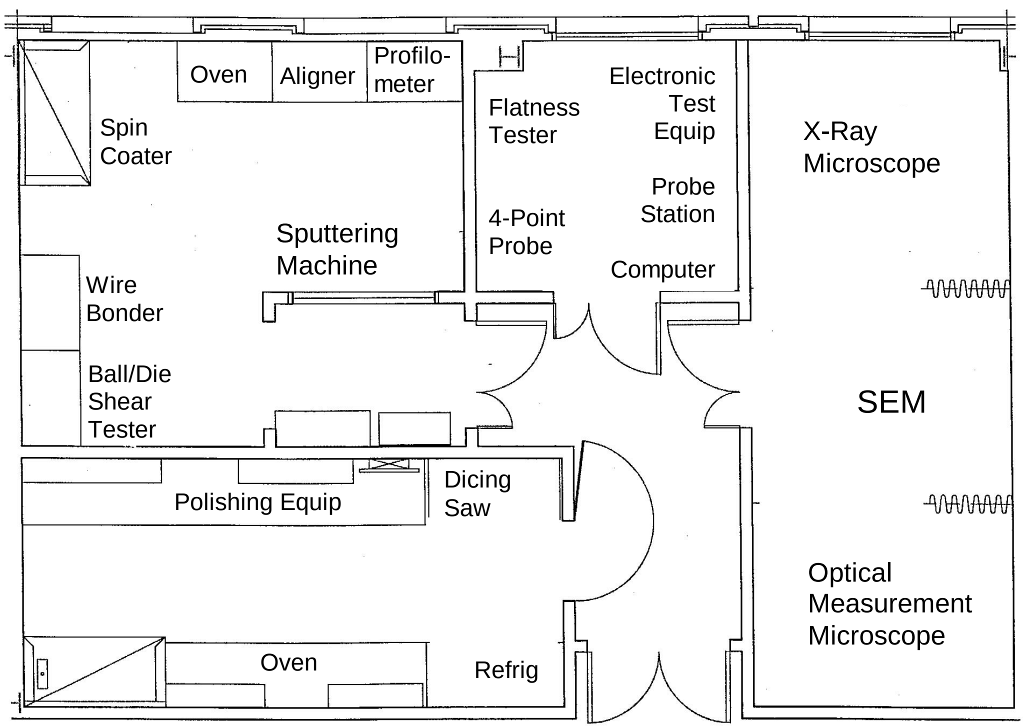

Figure 2: Layout for the Microelectronics Learning Laboratory

Obviously for many reasons a complete IC fabrication facility was not feasible. However, it is still possible to accomplish our mission with a reasonable facility in terms of space and cost. While there are several thousand steps involved in the fabrication of integrated circuits, many of them are repetitious and some are very specific to processes happening in specialized machines. We chose to limit our lab to processes for photolithography and metal deposition and etching. We are not able to produce active devices but the students still experience patterning of wafers, placing them into process equipment and doing post processing (etching and cleaning). The only way this differs from other processes (e.g. CVD, ion implantation, etc.) is the machine the wafer is placed into for processing.

The packaging facility consists of wafer dicing, manual die attach, wire bonding and wire bond testing, some flip-chip assembly, and exposure to opto-electronic assembly. Also included is some "reverse engineering" of commercial IC packages and some second and third level packages.

The device diagnostics area is set up to cover a full range of microscopic examination (optical, scanning electron microscopy, and x-ray microscopy). The laboratory room for the microscopy was built with a two foot thick concrete floor, vibration-isolated from the building structure, to provide a stable base for sophisticated diagnostic work. Capability to perform basic functional testing of simple ICs has also been provided, both "on the bench" and within the SEM, using the newly developed Charge-Induced Voltage Alteration (CIVA) system.

Starting out to create a suitable laboratory for microelectronics manufacturing from essentially a "clean sheet of paper" is an interesting and very challenging endeavor. Since engineering is new to this branch campus, there was no existing equipment to build around. Specifications for the major equipment had to be written and the lesser items selected from catalogs. We had to identify all of the needed equipment (even down to the small tools, swabs, chemicals, containers, etc.). SEH America of Vancouver, donated design consulting, air filtration equipment, lighting and suspended flooring for the clean room. Additional funding to insure complete outfitting of the lab was obtained through grants from SME-EF for some of the fabrication equipment, the M.J. Murdock Charitable Trust for the microscopy equipment and Tektronix, Inc. for part of the electronics test equipment.

A complete listing of the major equipment items for the microelectronics learning lab, and the facilities they support, is presented in Table 1.

Table 1. Critical Equipment for the Microelectronics Learning Lab.

ITEM	Supplier	Model
Electronics Packaging Lab		
Wafer Dicing Saw	Diamond Touch Technology	NISP-780-2
Wire Bonder	Marpet Enterprises	MEI-1204B with Bump feature
Wire Bond Shear Tester	Royce Instruments	System 552
Device Fabrication Lab		
Photoresist Spin Coater	Headway Research, Inc.	6"
Mask Aligner (Manual)	Optical Associates, Inc.	Model 206, Near UV
Metal Sputtering Machine	TBD	
Device Analysis Lab		
Optical Measurement Microscope	Nikon	MM40/L3
Digital Camera	Nikon	DXM 1200
Stereo Zoom Microscope	Nikon	SMZ 800
Manual Probe Station	Signatone	S-1160 (w/ 8 probes)
Electronics Test Equipment		
- Programmable Power Supply	Tektronix	CPS250
- Function Generator	Tektronix	AGF320
- Digitizing Oscilloscope	Tektronix	TDS3054
- Curve Tracer	Tektronix	370A
Wafer Flatness Tester	Nidek	FT-7 (6")
Scanning Electron Microscope	Aspex (formerly R.J. Lee)	PSM-75
X-ray Microscope	Phoenix X-Ray Systems	PCBA/Inspector 100

A list of objectives for the Microelectronics Learning Lab was developed from the manufacturing engineering program objectives supplemented with guidance provided by our industry constituents. These objectives in turn are used to create the objectives for the courses that use this facility. The objectives are as follows.

The Microelectronics Learning Laboratory:

- Gives degree-seeking students hands-on experience with typical manufacturing equipment and processes, and an understanding of the semiconductor industry through structured experiments;
- Provides life-long learning opportunities for employees of regional semiconductor manufacturers through both regular and short courses;
- Provides facilities for faculty and students working on microelectronics and packaging projects (such as senior design projects and academic research);
- Provides sophisticated microelectronics diagnostic equipment that can be utilized by local industries for specialized studies of new developments, problems, and failure analysis; and
- Provides a shared site for Clark College to train electromechanical technology students in semiconductor manufacturing.

The microelectronics manufacturing engineering classes, together with industry-focused short courses and summer session classes, are greatly enhanced by hands-on laboratory exercises. The extremely small dimensions and exacting tolerances of integrated circuit components require very specialized methods for processing and handling. We believe that in order to truly appreciate these processing and handling problems, a student must actually work with the components and the equipment. Thus, in order to teach the specialized processes, we are including at least the following laboratory activities:

- Wafer defect analysis. Fabricated Si wafers will be analyzed for number and type of existing defects – such as stacking faults and oxide precipitates.
- Integrated circuit fabrication. Simple interconnection circuits will be fabricated and their electrical characteristics measured.
- Failure analysis and reverse engineering. Integrated circuits with various failures will be debugged. Packaged circuits will be disassembled and reverse engineered to determine how they were fabricated.
- Chip-level packaging. Integrated circuits will be wire bonded into lead frames or soldered onto substrates in the flip-chip configuration. The parts will be stressed to failure, and the failure mechanism characterized.
- Integrated module assembly. Packaging substrates will be processed, and integrated circuits plus optical and mechanical systems will be attached. The entire package will be tested.

The equipment and facilities support these and other potential future educational exercises. In addition, this facility forms the basis for research activities in various microelectronics areas. We now have the capability to support the WSUV faculty, and we can function as conduit between regional industry and the remotely located main campus of WSU. When the need arises, we intend to add remote diagnostic capability to allow collaboration with industry experts and researchers at the main WSU campus in Pullman (300 miles distant) using, for example telepresence microscopy.

Courses Using the Microelectronics Lab

At the outset there are two courses that use the microelectronics learning lab, Micro-device packaging (MfgE 479) and Integrated Circuit Fabrication (EE 478). The packaging course is new and was recently approved into the manufacturing engineering program. Additional courses for manufacturing engineering using the microelectronics lab can be developed to fulfill future or specific requirements. Examples would be topics such as microelectronics facilities and equipment operations, upkeep and maintenance, fabrication and/or packaging for non-electronic micro-devices.

Micro-Device Packaging Course – The purpose of this course is to provide an overview of packaging methods for micro-devices such as integrated circuits, multi-chip modules, opto-electronic components and MEMS. The micro-device packaging course studies the processes that begin when the IC fabrication is completed at the wafer level. These processes include the basic first level packaging operations of wafer dicing, conventional die attach, wire bonding (including bond joint testing) and visual and electrical testing. Emphasis will be placed on familiarity with the manufacturing tools, equipment and processes, including using sophisticated microscopy equipment. A combination of lectures and labs will provide insight into design and manufacturing considerations and processes for these micro-devices. The course schedule for lecture and lab topics is shown in Table 1.

Table 1: MfgE 479 Micro-Device Packaging Topics (by week):

Week	**Lecture**	**Lab**
1	Introduction, Packaging Materials	Introduction, Safety and Procedures
2	Analytical Techniques	Overview of Microscopes (Optical, SEM and X-ray)
3	Electrical Considerations	Reverse Engineering of a packaged IC using Microscopic Examinations
4	Thermal Considerations	Wafer Dicing
5	Mechanical Considerations	Die Mounting, Wire Bonding
6	Packaging Processes and Materials	Ball Bumping, Coining
7	Reliability and Testing	Microscopic Measurements
8	Hybrids and Multi-Chip Modules	Bond Joint Testing
9	Multi-Chip Module Cost Analysis	Cross Section Microscopic Examination, Using the SEM
10	Printed Wiring Board Assembly	Bond Joint Examination Using SEM and X-ray Microscopes
11	Solder Technology	Soldering
12	Connector Technology	Electrical Connections (Plant Visit)
13	Optical Packaging Considerations	Fiber Optic Connections (Plant Visit)
14	Optical Packaging Considerations	Fiber Optic Connections in the Lab
15	MEMS – Overview of devices and packaging considerations	PWB Assembly (Plant Visit)
16	Final Exam	

The specific objectives for the class are:

- Identify, discuss, and analyze the engineering requirements, product attributes, manufacturing processes and equipment required for micro-device packaging processes.
- Obtain familiarization with the basic packaging and analysis equipment
- Understand the different levels of packaging
- Understand the different IC chip mounting and interconnect methods
- Obtain an introduction to the requirements for optoelectronic packaging
- Obtain an introduction to MEMS devices and the potential packaging process concerns

Items involving the use of the Microelectronics Learning Lab and included in the outcomes for the course are:

Be able to use standard packaging and test equipment including:

- dicing saw
- wire bonder
- ball and die shear tester
- manual micro-probes
- optical microscope (for qualitative and measurement examinations)
- scanning electron microscope
- X-ray microscope

All of the equipment required for this outcome are included in the new lab.

Identification of a suitable textbook for this course was a major accomplishment. The text needs to be sufficiently inclusive and also current enough to include the appropriate technologies and processes. The text selected was**:** Advanced Electronic Packaging, by William D. Brown[3]. The other texts considered are shown in references 4 and 5. Material from other sources will be used to supplement the selected text, including reference 6 for optoelectronic packaging.

Integrated Circuit Fabrication – The IC fabrication course is an existing WSU electrical engineering course and has been taught in the past without any laboratory component. Because of the difference in focus (manufacturing process familiarization for designers vs. practical competency for manufacturing engineers) this course will soon be converted to a new MfgE course. The existence of the new microelectronics lab will enable the conversion of this course from lecture-only to a lecture/lab configuration. The IC fabrication lab exercises will include examination and characterization of bare wafers, basic photolithographic processes, metal deposition and etching processes.

Summary

Washington State University has responded to the requirements of the community and brought manufacturing engineering education to southwest Washington including an emphasis area in microelectronics specifically for that sector of the regional economy. A new laboratory building has recently been completed. This facility includes a Microelectronics Learning Lab that permits a hands-on experience for students selecting courses in integrated circuit fabrication and/or micro-device packaging.

This paper described and detailed the equipment required for the lab and summarized a micro-device packaging course, as an example of the courses that can utilize the lab. Details about an additional course in IC fabrication will be published later after the course has been adapted to a lecture/lab format.

This new facility greatly enhances the value of the manufacturing engineering program at WSUV.

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