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Chapter XX

Developing "Internal Internships" for a Microsystems Engineering Curriculum

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Experience gained from developing a Master's program featuring an extended industrial internship is applied to the creation of a curriculum in microsystems engineering. We describe how the external industrial internship is replaced by an "internal internship" carried out at Texas Tech University in a state-of-the-art micro- and optoelectronics research laboratory. The internal internship is a two-

course sequence designed to emulate the most beneficial features of an industrial internship. The specific focus of this implementation is UV fluorescence-based micro total analytical systems. We anticipate from the results of our industrial Master's program that students completing this curriculum will be well prepared to make immediate contributions in industry, at a national laboratory, or through continued graduate study.

INTRODUCTION

Our experience over the past six years at Texas Tech University (TTU) developing an innovative Master's degree program emphasizing semiconductor industry internships has been that these internships are extremely effective in producing well-trained engineers. Industrial interns typically face multidisciplinary problems and team projects not common in university courses or research. They are expected to interact harmoniously with their project leader and other team members, while also demonstrating initiative and self-reliance. They must learn to communicate clearly and succinctly in oral presentations and written reports. These practical skills are not as easily absorbed in a traditional academic setting, where they may seem contrived. The high percentage of our graduates finding employment in the semiconductor industry, and their continued professional advancement, attests to the success of industrial internships. However dependence on industrial internships has some drawbacks, particularly when educational objectives are more diverse. ….

INDUSTRIAL INTERNSHIP PROGRAMS AT TTU

Since 1996, extensive and novel internship programs have been developed at Texas Tech to educate M.S. students in microelectronics. We have participated strongly in this effort. The program began in the Department of Physics in 1996. The M.S. in Applied Physics was recognized as a Category I degree program in the special American Institute of Physics report on physics education [3, 4]. The project was greatly advanced through a grant from the National Science Foundation (NSF) . The Department of Electrical and Computer Engineering independently began a parallel program in 1998 emphasizing product engineering. These programs were merged in 1999, and continue to graduate students in EE and Physics through the Program for Semiconductor Product Engineering (PSPE). PSPE is now fully self-supported through industrial sponsorship. The program combines focused graduate courses in microelectronics with an extended internship in a microelectronics company[1]…..

Our primary metric for the success of the microelectronic internship program is the percentage of graduates who, two years after matriculating, have gained a position in the microelectronics industry. As can be seen from those years for which complete statistics are available (1996–1999), 40 of the 46 entering students accepted such positions. We also consider it a successful outcome when a student decides to continue graduate study towards the doctorate, at Texas Tech or elsewhere. As can be seen from the more recent

[1] For current details see www.ee.ttu.edu/pspe.

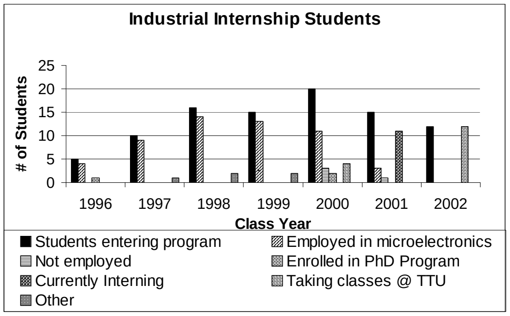

FIGURE 1
TTU INDUSTRIAL INTERNSHIP PROGRAMS

data, this outcome is becoming more popular, which we attribute in part to the strong students our program attracts, to the increase in microelectronics-related research at TTU and also, unfortunately, to the downturn in the economy. The overall goals of the Industrial Master's program are as follows:

1. Provide excellent graduate education for students interested in microelectronics through advanced and targeted coursework.
2. Provide the students with the opportunity to participate in industrial R&D projects and learn about current technical issues, methods, and use of instrumentation not available at any university.
3. To learn how to work in the corporate environment of a microelectronics company.

These are clearly different from the goals of "traditional" graduate education. In stark contrast to goal 1 in the internship program, traditional curricula usually require courses from the major department that are general in scope. Students carry out focused research with one primary professor, working in one laboratory. Lastly, university culture is significantly different from corporate culture. A new university culture is emerging to meet the need to conduct interdisciplinary research. Here, students must be more diverse in their abilities and function in a collection of research laboratories. Students still need to be guided by one professor, but work with a variety of professors to accomplish their research goals…

FUNDAMENTAL SKILLS

MEMS 1 (officially titled *Introduction to MEMS and Microfluidics*) is intended as a broad-based introduction to the tools of microfabrication for MEMS and microfluidic systems. It has been taught four times so far. Enrollment was ten students at the first offering, nineteen in the second, and twelve in the third and fourth. We were forced to limit enrollment after the second offering, as the number of interested students overwhelmed the capacity of our laboratory facilities. A textbook [5] and numerous literature references [6-8] are used for this course. Typically two faculty members handle the class, with one coordinating lectures, and the second supervising laboratory activities. Effort for either task is roughly equivalent to teaching an advanced graduate course. On two occasions a postdoctoral visiting scientist assisted with the laboratory component. The main objective of this course is to develop hands-on core processing competency. This entails knowledge of, and facility in, basic fabrication technologies. The emphasis is on silicon processing, including photolithography, thermal oxidation, evaporation, lift-off, and etching of metals and oxides. Also introduced are polydimethylsiloxane (PDMS)

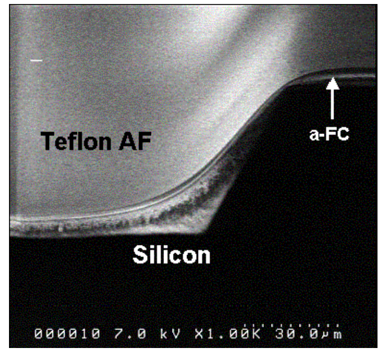

FIGURE 5
SEM CROSS-SECTION OF COATED CHANNELS IN SILICON

casting using ultra-thick negative photoresist molds, bulk silicon micromachining, doping and spin-on polymer coating. The course is based on a series of interdisciplinary projects. Topics range from a chemoresistor for humidity sensing to a bulk-micromachined accelerometer. Projects are designed so that students spend an average of one hour per week in the classroom, and about three hours per week in the laboratory. Projects are designed to take three to five weeks, allowing a total of three to four projects per 15-week semester. Several projects have taken significantly more time on the first run-through. Currently it is a three-credit course, though four credits would be more appropriate. Figure 2 shows an array of student-fabricated humidity sensors prior to cleaving and packaging. Figure 3 shows an array of bulk micromachined accelerometer proof masses. Simulation projects give students insight into device principles and introduce them to a useful analysis tool, while reducing the demand on laboratory equipment. Figure 4 shows a hot wire anemometer simulation using the CFD-ACE software suite.

FIRST INTERNAL INTERNSHIP: INTERDISCIPLINARY TEAMWORK

The first time that the MEMS 2 class was taught, it was not based on the internship paradigm. Rather, it was designed to train every student in the major technical aspects for μTAS development, while also advancing laboratory capabilities in several key areas. To this end we formulated a project grid, shown in Table 1, to systematically rotate students through a number of different sub-projects in the development of fluidic-based microanalysis systems. The rows describe project milestones, whereas the columns consist of the necessary technological areas. Column 1 projects are optics based, Column 2 involves fabrication of microfluidic structures, Column 3 deals with specific chemical processing, and Column 4 deals with both chemical and biological binding. Each team of two or three students (a total of nine students were enrolled) was given a project from Row 1. After three weeks they moved diagonally to the next row. The students gave presentations after each module and handed off the projects to the subsequent groups. This required detailed pass-down meetings and documentation in order to ensure continuity and minimize redundant work.

The goal of the technology development of Column 1 was an optical set-up capable of performing spectroscopic measurements. An existing optical microscope was coupled with a CCD camera and a spectrometer using fiber optics and LabView programming to create an optical detection system. The system performance was evaluated using various microfabricated liquid core waveguides (LCW). In an LCW a low-refractive index (n_{LCW}) tube confines a water-based fluid. Since water has $n > n_{LCW}$, the water serves as a waveguide. Following the second column, the student teams successfully microfabricated channels in PDMS, glass and silicon. They designed, manufactured and tested a peristaltic micropump in PDMS. In the third column, the overall technology objective was to fabricate LCWs in PDMS, glass and silicon coated with Teflon AF [9] or nanoporous silica. The teams developed surface modification processes to improve Teflon AF bonding. Figure 5 is an SEM of a Teflon-coated microchannel in silicon. Adhesion of Teflon to silicon is improved using a plasma-deposited amorphous fluorocarbon. Students refined a sol-gel technique to deposit nanoporous silica [10].

Technology 1	Technology 2	Technology 3	Technology 4
Optics	PDMS	Coatings I	Bonding I
Intensity Meas.	Glass and Silicon	Coatings II	Bonding II
Spectroscopy	Pumps	Advanced Etch	Antigen Binding I
Integration	Injectors	DAC	Antigen Binding II

TABLE 1
INITIAL MEMS 2 PROJECT GRID

In the fourth column, the student teams performed various wafer bonding experiments in order to create sealed microchannels. They bonded PDMS to glass using oxygen plasma modification of the PDMS surface, and developed processes for thermal glass-to-glass bonding and anodic silicon-to-glass bonding. Finally, the students experimented with immunosensor technology. This involved integrating fiber optics and commercially available antibodies for a wide variety of applications. With this technology, a sensor can be designed to detect virtually anything for which antibodies can be created (that is, virtually everything!). Students capped channels in a silicon wafer with a PDMS layer. Oxygen plasma surface modification was used for the bonding. Figure 6 shows the fluorescence tagged antibodies adhering to the silicon channel, although not to the PDMS cap.

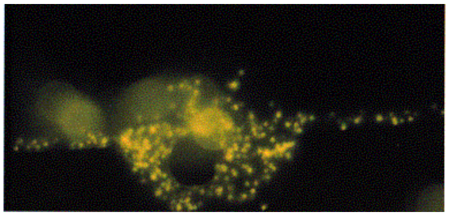

FIGURE 6
FLUORESCENTLY TAGGED CELLS BOUND TO THE INSIDE OF A PDMS/SILICON CHANNEL

Oral presentations were the primary assessment tool. MEMS 2 students were evaluated based on the reproducibility, quality and functionality of the final processes and devices they produced. Teams were also judged based on their use of archival research, written and oral presentation and effectiveness of technology transfer to the other teams. Presentations were videotaped and made available to students who wished to improve their speaking style. In this version of the course, students often spent as much as 10 hours a week in the laboratory. It was clear by the end of the semester that the projects were too ambitious. Five faculty from various departments were involved in designing the course components and making the necessary equipment available. Two of these were also responsible for administrative duties. The students were all experienced in the Maddox Laboratory. Without this, the faculty burden would have been impractical. The course was redesigned to address these issues.

The second time that MEMS 2 was offered, the internal internship paradigm was used. We structured this course with a Client (or customer), Team Leader, Team (CLT) relationship. The “Clients” were the course instructors, the Team Leader was a MEMS 3 student, and the Team was a group of two or three students from MEMS 2 (for a total of seven MEMS 2 students enrolled). With this structure, shown schematically in Figure 7, the Clients specified goals for the desired analytical system(s). These were to create a fluorescence-based μTAS capable of following: 1. Determining the concentration of fluorescein in a solution of unknown molarity. 2. Determining metal salt concentration in a solution of unknown molarity using chemiluminescence. 3. Determining epithelial to stromal cell ratio in an unknown mixture of these cells. Each team was required to use a different optical illumination/detection scheme. These schemes are listed in Table 2.

The most important operational difference between the two implementations of MEMS 2 was that in the internal internship model the principal student technical contact was a peer. We observed that this provides a definite advantage, due to the lack of barriers between the Leaders and Teams. This is in contrast to barriers, real or perceived, between professors and students. The key subject difference in the internal internship structure is that the teams are responsible for every technology necessary for their device, and do not transfer between device architectures.

DETECTION SCHEME	Embedded waveguide	Deposited waveguide	Etched silicon microchannels
Team (EE/ME/Phys)	0/2/1	1/0/1	2/0/0
Team Leader (Major)	1 (ME)	1 (EE)	2 (EE)

TABLE 2
BASIC MEMS 2 & 3 OPTICAL DETECTION SCHEMES

Clients communicated device requirements to the Team Leaders. Each Team Leader had the primary responsibility of communicating these to their Team. The MEMS 2 Teams were required to make presentations to the Clients on a regular basis. The Team Leaders were invited, but not required, to attend. Faculty gave feedback directly to the Team and to the Team Leaders. In the future the internship model will be more strongly emphasized by having Teams present to Team Leaders, with the course instructors present only as observers.

Assessment of the CLT internship structure was based on several factors. Individual team members and entire teams were given laboratory practical examinations (representing site visits) by the Clients. Individual practical exams were given following a reasonable period for the students to gain this knowledge. Presentations were used as an important guide for our assessments. Team Leaders were also asked to thoroughly assess Teams and Team Members. The specific questions asked on the assessment were:

- (Assess Member’s) Fabrication skills and laboratory contribution.
- Analytical skills and design contribution.
- Reliability, attitude, attendance, and team morale contributions, such as:

a. Abcdef
b. Ghijklmno
c. Pqrstuvxyzabcd

These assessments were passed on to the Teams, following filtration by the instructors, to insure that feedback was tactful and constructive.

DISCUSSION AND SUMMARY

Discussion

We have constructed a three-course sequence that emulates an industrial internship program. The first course provides needed fundamental skills and foundation knowledge, just as our industrial Master's students take a semester of basic courses to prepare for their internships. MEMS is also effective as a stand-alone course. Success stories include one graduate working in the MEMS industry, one full time employee and three interns in the microelectronics industry, and ten students currently involved in research at TTU.

The remaining two courses in the sequence play the role of an internship. In the first, the student is an interdisciplinary team staff member, in the second, the leader of such a team. While it is not necessary for the student teams in the MEMS 2 course to have student leaders, it is preferred, since we have observed that peer-to-peer communication is more open than student-professor interaction. In theory MEMS 3 could be taught without MEMS 2, but this seems awkward and unlikely. Thus course schedules must be such that MEMS 2 and MEMS 3 are taught concurrently.

At the time of this writing, the MEMS 2/3 sequence is being taught for the second time with the CLT structure. Six MEMS 3 students are supervising five teams totaling 15 MEMS 2 students. The key refinement has been to have teams cooperate on different aspects of a single project, rather than each pursuing competing versions. In this way we hope to successfully achieve the integrated device design goal, rather simply components of it, and to provide the Team Leaders with industry-critical project integration skills.

ACKNOWLEDGEMENTS

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1. [NOTE: Begin typing References on this line, listing them in sequence in the order cited in the paper. Use the following individual formats for journal papers, books, chapters in books etc., but do not include these headings or bunch your references under any of these headings]

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Appendix

Guide to Using Bullets, Numbering, Headings, Tab Stops, and Paragraph Styles in Microsoft Word®

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