A Microfabrication Laboratory Class Targeted to Freshmen

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Abstract – A new freshman-level course is under development at the Department of Electrical and Computer Engineering at the University of Louisville. The aims of the course are to increase undergraduate retention through a hands-on, fun laboratory experience in the cleanroom, improve recruitment of engineering students by advertising the availability of the course, give the students an early introduction to planar fabrication techniques, and fabricate transistors that can be used in future laboratory classes. The lab takes place in a state of the art, 10,000 sq. ft class 100/1000 cleanroom in the new Belknap Research Building. At the end of the semester, the students take home a wafer and packaged transistors that can be used in future labs or projects. There is only a minimal lecture component, as the course emphasizes learning by doing.

Keywords: retention, recruitment, freshman, microfabrication, electrical engineering

INTRODUCTION

Over the last 20 years, the undergraduate enrollment of electrical engineers has dropped by 46% within the United States [1] and by 59% at the University of Louisville. These trends have put pressure on the Department of Electrical and Computer Engineering at the University of Louisville to increase enrollment by improving recruitment and retention of undergraduates. This has created a strong motivation for a new course that targets freshmen with the following aims: (1) to increase undergraduate retention through a hands-on, fun laboratory experience in the cleanroom, (2) to improve recruitment of engineering students by advertising the availability of the course, (3) to provide the students with an early introduction on planar fabrication techniques, and (4) to fabricate transistors on a wafer that the students take home at the end of the semester. The new course is offered for the first time in the spring of 2007.

A cleanroom laboratory course is traditionally only offered to seniors and graduate students. This course makes the cleanroom accessible to undergraduates, and freshmen in particular, with a future aim of involving high school

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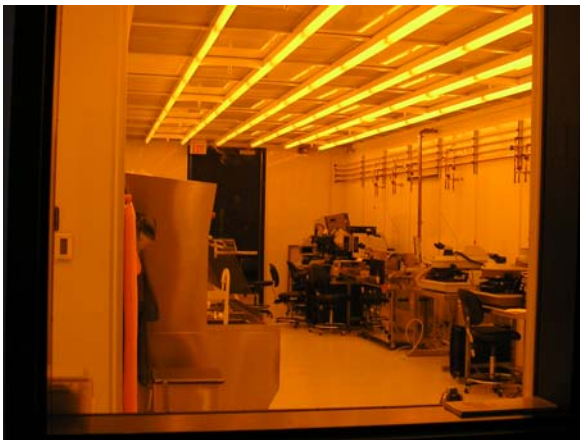


Fig. 1: The Belknap Research Building (left) which contains the cleanroom, and one of seven cleanroom bays (right), looking through a window from the hallway.

students. To the authors' best knowledge, there is no similar course offering in the nation offered at the freshmen level.

The lab takes place in a state of the art, 10,000 sq. ft. class 100/1000 cleanroom in the new Belknap Research Building (Fig. 1). The students fabricate working MOSFET transistors, starting with bare silicon slices. They perform all the steps themselves, albeit under the watchful eye of the teaching assistant, Kunal Pharas. Finally, they test the transistors that they fabricate. At the end of the semester, the students take home a wafer and packaged transistors that can be used in future labs or projects.

There are many benefits to the students who take this class. This course provides an early introduction to the big picture of microfabrication, an industry that ships billions of dollars of product every month, as well as the details of microfabrication. This course is interdisciplinary, including topics from chemical engineering, materials science, chemistry, physics, optics, electronics, mechanics, and industrial engineering. After completing this course, the students will have a better appreciation for their core engineering courses, and thus are more likely to do well in the core engineering courses. At the end of the semester, the students will have a wafer and packaged transistors that he/she can take home and show his/her friends and family. This helps instill a sense of accomplishment and pride in the students. Because the course is graded on a pass/fail basis, this course provides a relatively stress-free method of learning exciting topics while having fun at the same time.

The University of Louisville could potentially see a benefit from improved recruitment and retention of undergraduates. In addition, because the topics covered are generally considered advanced level, the students may see a greater value in obtaining a graduate degree. This program is unique in the country, and thus it provides the University of Louisville with a method of differentiating itself from other universities within the country, as well as world-wide. Finally, the use of the cleanroom by freshmen helps justify the considerable cost that the University of Louisville invested in the cleanroom to policy makers, to the public, and to the students on campus.

This course introduces students to the big picture of microfabrication, an industry that ships billions of dollars of product every month, as well as introducing students to the details of microfabrication. By fabricating wafers with many transistors, the students will experience the economies of scale inherent in batch fabrication of wafers, and better understand the economic arguments for making smaller feature sizes.

The transistors that are fabricated and packaged in this course may be used by the students in projects of their own, or they may be used in future laboratory classes.

IMPACT ON RECRUITMENT AND RETENTION

This course is expected to have a positive impact on both the recruitment and retention of undergraduate students in the ECE Department. Recruitment is expected to be enhanced for several reasons. First, the department can advertise that all ECE students have the option to enter the cleanroom, as early as their freshman year. This is a claim that no other university can currently match. The authors have noticed a "cleanroom mystique," enhanced by a sense of the "forbidden area," science fiction movies and older Intel commercials. When a student first enters a cleanroom, this "cleanroom mystique" has been observed to cause student's eyes to light up and some students even become giddy. The "cleanroom mystique," combined with the option to enter the cleanroom during the freshmen year, is likely to help recruit students.

A second reason that recruitment is expected to be enhanced is that the admissions office already sends its campus tours past the cleanroom. Having the class advertised outside the cleanroom, and seeing students working in the cleanroom, is likely to enhance recruitment of undergraduates. Third, the class is a natural to advertise in the media. The University of Louisville likes to promote a positive image by showcasing the cleanroom, and thus the class is likely to be advertised as part of this on-going effort. Fourth, this class differentiates the University of Louisville from all other universities, providing a compelling reason to put the University of Louisville at the top of the potential student's list of schools to apply to. Fifth, the students who complete this course will go home with a wafer that will be shown to their friends and family. These friends (some of whom may be just one year behind, or seniors in high school) will see the wafers and see the great things that the students do at the University of Louisville. This will create great word of mouth advertising for the University of Louisville.

It is expected that students who take the course will have a higher retention rate than those who don't take the course. Because of its interdisciplinary nature, this course should provide a motivation for the students to do well in their core engineering courses. The students take home a wafer, as well as packaged MOSFETs, providing them with a keepsake that can be shown off to other people (parents, siblings, and friends still in high school). Enhancing the pride of the students should lead to improved retention.

COURSE DETAILS

The course is being offered as a special topics 1-credit laboratory that makes extensive use of the 10,000 sq. ft., class 100/1000 cleanroom located in the Belknap Research Building. Each section of the class meets once per week for a three hour lab session. There is no homework, but a weekly "topic of discussion" is given out. Except for the first week, there are no lectures. The course is designed to immerse students in the laboratory setting, and to allow the students to learn by doing.

Because the course is an optional course offered at the freshman level, it is desired to minimize the impact of the course on the student's academic performance in their required courses. There is no homework, but the students are encouraged to ask questions. The course is only 1 credit hour, and is graded on a pass/fail basis. A survey of the students taking the course in the Spring 2007 semester show that the grading scale was an important consideration for many of the students.

The first week consists of a required safety lecture; the only lecture in the semester. Each student gets their own wafer, and the TA has an "extra" wafer for each

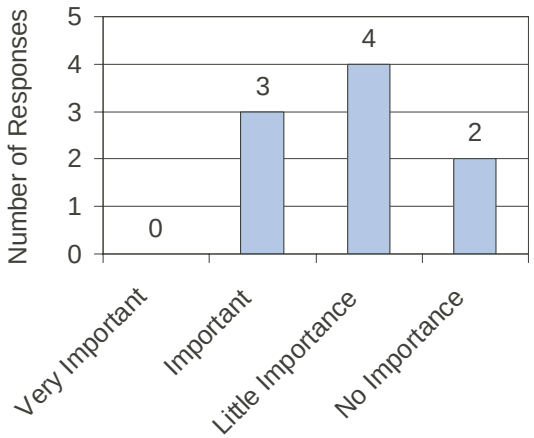
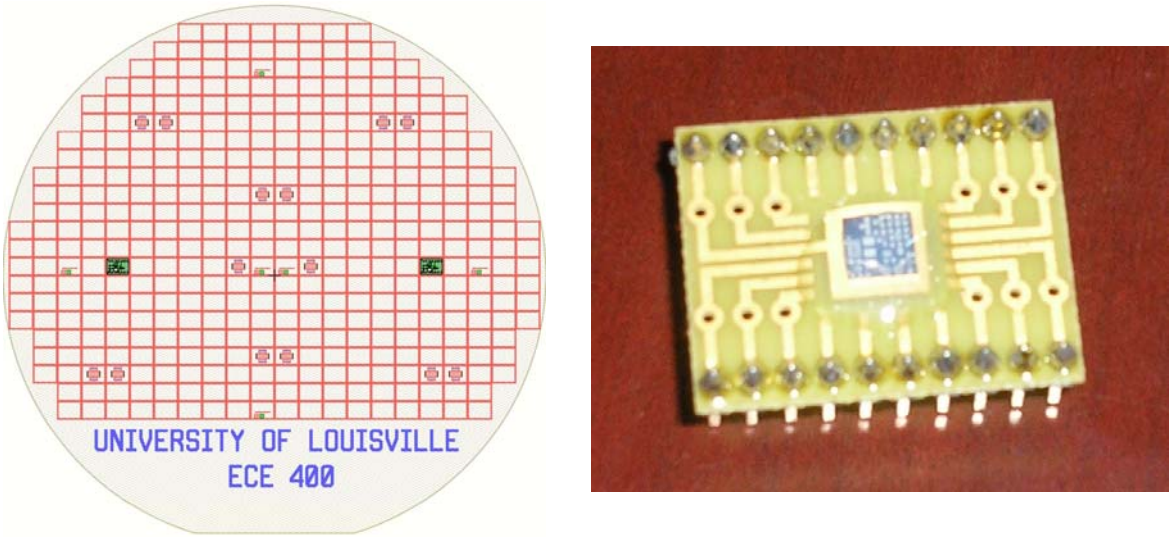


Fig. 2: Results of survey asking the students taking ECE 400 in Spring 2007, "How important is the grading scale (pass/fail) in your decision to take the course?" The results show that the grading scale was important for many of the students.



(a) (b)

Fig. 3: (a) A layout of the wafer that is being fabricated by students in the ECE special topics course, ECE 400. The wafer contains many MOSFET transistors, as well as solar cells, diodes, and test structures. (b) A sample chip that has been packaged on a printed circuit board and protected with a coat of epoxy. The epoxy is transparent, permitting the silicon die to be seen.

section. For the next nine weeks, the students will work in the cleanroom, processing their wafers. The TA may show the students how to perform the steps with the "extra" wafer, and then the students can perform the steps with their wafers. The "extra" wafer can be given to a student in the event that a wafer is broken. This is a realistic concern because silicon wafers are very fragile.

After the wafers are finished (Fig. 3a), the wafers are diced and several die are packaged. The die are not packaged in a conventional DIP package. Rather, they are packaged on a small printed circuit board with an epoxy coating (Fig. 3b). This packaging method allows the IC to be seen while still protecting the transistor and wirebonds.

Finally, the students test their transistors on a curve tracer and in a simple circuit. The curve tracer gives the opportunity to demonstrate how transistors really work. The simple circuit gives the students the opportunity to see how the transistors may be used.

While fabricating the transistors, there are occasional "waiting periods" when the students are waiting for a piece of equipment to complete a task. These waiting periods are usually short, but can range from 5 minutes up to 1 hour. These waiting periods provide an opportunity to discuss the theory of how the equipment operates. Furthermore, weekly topics of discussion are given to the students, and a set of prepared questions are used by the TA to stimulate discussion of current topics.

CLASS COMPOSITION

There are nine students taking ECE 400 in the spring 2007 semester. A short survey showing the composition of the students is shown in Table I. With the exception of a single sophomore student, the students are all freshmen. Most of the students are from the Electrical and Computer Engineering Department (ECE), but two of the students are from the Computer Engineering and Computer Science Department (CECS). The student composition is fairly homogenous, with every student being male, and most students being Caucasian. The survey results clearly show the need to increase the diversity of the students taking the course.

Class Year	**2009**	**2010**
	1	8
Major	**ECE**	**CECS**
	7	2
Race	**Caucasian**	**Asian**
	4	1
	Yes	**No**
Are you the first generation in your family attending college?	1	8
Do you have any engineering-related work experience?	2	7
Has this course affected your career goals?	5	4
Would you recommend this course to others?	9	0

Table I: Results of survey of students taking ECE 400 in the spring 2007 semester. The number entries are the number of students who answered with a particular designation. ECE stands for Electrical and Computering Engineering, and CECS stands for Computer Engineering and Computer Science.

This course has had an apparent impact on the students. Five of the students say that this course has affected their career goals. Anecdotally, it may be stated that the students are very enthusiastic. The students are all willing to recommend the course to other people.

SAFETY

A laboratory class for freshmen must have a high standard for safety. The first week of the class is the only lecture, a safety seminar. The safety seminar goes over all the rules of conduct in the cleanroom, proper chemical usage, and proper procedures to follow in the event of an emergency. The first lab session starts with an overview of the cleanroom and the safety gear in place, such as location of eye-wash stations, showers, emergency exits. The following rules have been adopted:

1. Students do not prepare chemical baths.
2. Students must be double gloved when using chemicals.
3. Students must wear proper attire when using chemicals (face shield, apron, etc.)
4. TA must be present when students are in the cleanroom.

The state of the art cleanroom is designed to minimize the chances of a student coming into accidental contact of a chemical. Unlike a typical freshmen chemistry lab, no beakers are used. Instead, all chemical baths are integrated into ventilated wet benches with their own dedicated well. The wells have pneumatically-controlled drains, and the TA can prepare fresh baths prior to class when required. The attire of the students is consistent with the rules of the cleanroom. The cleanroom has over 150 sensors to ensure that there is no chance of exposure to chemicals. An alarm requiring evacuation of the cleanroom triggers if toxic gases are detected, if a spill is detected on the floor, or if the exhaust flow rate is low.

CONCLUSIONS AND FUTURE DIRECTIONS

A new freshman-level course is under development at the Department of Electrical and Computer Engineering at the University of Louisville. The course is offered as a special topics course in the Spring 2007 semester. The aims of the course are to increase undergraduate retention through a hands-on laboratory experience in the cleanroom, improve recruitment of potential engineering students, give the students an early introduction to planar fabrication techniques, and fabricate transistors that can be used in future laboratory classes.

The lab takes place in a state of the art, 10,000 sq. ft class 100/1000 cleanroom in the new Belknap Research Building. The safety aspects of running freshmen student through a cleanroom are addressed. The students fabricate transistors on a wafer, package the transistors, and test the transistors. A Teaching Assistant supervises the students through the process. At the end of the semester, the students take home a silicon wafer and packaged transistors that can be used in future labs or projects. There is only a minimal lecture component, as the course emphasizes learning by doing.

This course is currently being offered as a special topics course. In the future, a new course will be introduced: *ECE 101: Freshman Experience*. The new course designation is designed to properly indicate the focus of the course, and yet be flexible to accommodate other freshman 1 credit hour introductory classes that may be envisioned by the Department of Electrical and Computer Engineering at the University of Louisville.

Future work involves the long-term assessment of the class on undergraduate retention. The current class will be tracked to see whether or not they stay in engineering. Those students who remain in an engineering program at the University of Louisville will also be tracked to evaluate their relative academic performance compared to the performance of the average engineering student.

REFERENCES

[1] Engineering and Technology Enrollments, Engineering Workforce Commission of the American Association of Engineering Societies, Inc.

Shamus McNamara

Shamus McNamara received the B.S. and M.S. degrees in Electrical Engineering at Rensselaer Polytechnic Institute in 1994 and 1996, respectively, and the Ph.D. degree in Electrical Engineering at the University of Wisconsin-Madison in 2002. He has been a post-doc at the University of Michigan, and is a co-founder of a startup company. He is currently an Assistant Professor at the University of Louisville in the Department of Electrical and Computer Engineering. His research interests lie in the fields of microfabrication and MEMS.

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Kunal Pharas obtained his MS degree in Electrical Engineering from the University of Louisville in December 2006 and Bachelors degree in Electrical Engineering from Engineering College Bilaspur, India in 2002. His areas of interest are design and fabrication of microstructures with special emphasis on MEMS Devices. He has over one year of experience in working in the Cleanroom. During his MS degree he held various positions as Teaching Assistants in the Electrical Engineering Department for the Analog Circuits Laboratory, Chemistry Department for the CHEM-202 course and as a Graduate Assistant in REACH (Resources for Academic Achievement).

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