Graduate Laboratory Courses in Microelectronics

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Introduction

This paper follows last year's Frontiers in Education presentation[1] describing the background to the introduction of 1-credit graduate laboratory courses in the Watson School's Department of Electrical Engineering. Briefly summarizing, the Department's 6-credit thesis requirement for the MSEE was the cause of some dissension among part-time students from industry. Other departments on campus and another local MSEE programm offer non-thesis options which were clearly seen by the "customers" to be more attractive. Eventually the Department introduced a compromise alternative: a combination of a 3-credit project (which is essentially a "mini-thesis") and three 1-credit graduate laboratory courses. (The project, not being a "thesis," is not strictly subject to the University's publication requirement and offers the Department an additional flexibility in dealing with the unexpected confidentiality problems which can arise from work performed by students under legal constraints imposed by their companies.)

The remainder of the paper outlined some specific laboratory objectives. It is the purpose of this paper to present more detailed descriptions of the laboratory course requirements in the Microelectronics area. (It should be noted that there are also similar laboratory course packages in each of the other Departmental areas of concentration -- Controls, Computer Engineering and Signal Processing -- and in Electromagnetism.)

Further Developments

Before moving on to describing the individual courses, it is worth discussing the total experience to date with them. As was previously indicated,[1] the EE582A Spectrum Analyzer Applications ran in Spring 1987 with a small but adequate enrollment. In Spring 1988, the registration dropped markedly, but it was still possible to operate the course effectively as a self-study with relatively clear-cut experiment notes developed for the first offering. In the Microelectronics area, three courses were offered in Fall 1987: EE587B Semiconductor Device Testing, EE587C Thick Film Hybrids and EE587D Thin Film Deposition Techniques. It was expected that at least one of these would attract a viable enrollment, possibly by absorbing some enrollments from the other two. As it turned out, enrollments here were insufficient to justify the urgent completion of the remaining development work required, and all were finally cancelled. In Spring 1988, EE587C Thick Film Hybrids was taken by one student as an independent development project.

These developments were clearly very disappointing and were reported orally at the FIE '87 paper presentation. Naturally, the graduate lab concept was re-examined in the light of these poor enrollments, resulting in a reaffirmation of the Department's commitment to the program. The initial point of concern was that the verbal support and enthusiasm from both industry and students did not represent a true level of interest. However, the real problem lies in the fact that enrollment levels in the Microelectronic courses, although adequate and growing, are still modest. (The program is only four years old.) When one considers that only 50%, say, of eligible students will take the project/labs option in preference to the thesis, and then recognizes that if these are predominantly part-time students from industry taking an average of four years over the degree, it becomes clear that the problem is simply one of an inadequate population of eligible students in the first place.

Put into this perspective, the solution would appear to be to offer the courses less often -- say every three years -- to gather a larger pool of candidates. There are two problems with this option: it virtually eliminates full-time students passing through the program faster from participating in the lab courses, and there is a severe loss of flexibility to take the lab course at the appropriate time in relation to other courses. The alternative, which is preferred at this point, is to structure the lab courses as essentially self-study exercises to minimize supervising manpower. This can be achieved by either setting them up as mini-projects (possibly assisting research students) or paying meticulous attention to detail in writing a lab manual. In these ways, courses may be offered upon demand to small numbers as enrollments grow.

Another avenue to increased enrollments is to encourage students who choose the thesis option to also take three lab courses in lieu of one lecture course. This possibility exists already, but has never been actively promoted.

It is worth noting that for all courses except Thin Films the apparatus must be established for undergraduate laboratory work anyway, so the addition of the graduate laboratory program represents only incremental development overhead. In Thin Films, the apparatus is similarly being established for research activities, so again there is only marginal extra effort involved in establishing the lab course.

As a closing comment to this section. it has been interesting to observe how complaints about the absence of a non-thesis option have vanished with the introduction of the project/laboratory alternative, but with most of the protesting group selecting the thesis. Without wishing to get into the psychology of the situation, one suspects that the existence of a choice was more important than the actual choices themselves.

Graduate Laboratory Syllabi

The five laboratory courses in the Microelectronics group are described below. The experiments outlined represent current capability and are set to some degree by the equipment now held. Time commitments are set for the 1-credit load by analogy with undergraduate laboratories, i.e. a nominal twelve 3-hour sessions plus reports, but the structure is flexible where advantage can be taken of other time blocks. In Thin Films, for example, the organization is for five full-day experiments which can run on one hand as a full-week program (perhaps concurrently with a non-credit continuing education version supporting a teaching assistant) or as pairs of 4-hour evening blocks.

EE587A Integrated Circuit Fabrication. Corequisite: EE575 Semiconductor Device Processing (Spring).

IC Fabrication runs concurrently with the senior laboratory and does not therefore have the same problems with numbers that the other labs do.

Students are provided with 10x glass masters of the masks to fabricate a test IC containing a simple MOSFET, Schottky diode, a C-V (oxide) dot, a planar diode, a lateral low gain "BJT" structure and a ring-oscillator of PMOS or NMOS inverters. These are used as samples in EE587B. The fabrication process is designed for one spin-on N diffusion (P), and one solid source P diffusion (B) and multiple oxidations (which will cover both dry and steam). The 10x mask reductions are made on an image repeater from the glass masters, but in film rather than glass as a matter of economy. Eventually both wet and dry etching will be used, but RIE will not be introduced until the rest of the procedure is functioning reliably. The finished wafer is scribed and a selection of dice are mounted on headers for wire bonding and final evaluation.

EE587B Semiconductor Device Testing. Corequisite: EE576 Semiconductor Device Design (Fall).

Ideally, testing should follow manufacture, but that is not possible due to other constraints. So the devices used here, although the same test patterns built in EE587A, are provided by the lab manager rather than manufactured by the same students performing the testing.

Most of the work is performed on a wafer prober linked to an HP4145A Semiconductor Parametric Analyzer and an HP4280A C-V System. The test devices include the diode (I_s, C-V versus temperature T) MOSFET (threshold, drift mobility, C-V vs T) BJT (diffusion constant vs T) and C-V dots. Yield statistics and mapping are used to highlight process problems. Yield thresholds are set and changed arbitrarily to enable wafers to be reused by other groups. One property of particular interest is the tracking characteristic of adjacent devices.

In addition, four point probe surface resistivity data is correlated with direct junction depth profiling by abrasive techniques. Hall effect and other related test techniques will be added as available.

EE587C Thick Film Hybrids. This is the only lab without a lecture course corequiste; some theoretical work is therefore incorporated into the lab. Originally there was to be two lectures, but now the materials will be covered by self-study with a motivational test.

Each student will perform a preliminary calibration print of the resistor paste to be used on the hybrid circuit, using the test pattern mask supplied. The bulk of the experiment will be to take an electronic circuit design, test it in discrete form, redesign as appropriate for thick film implementation and build it as a thick film hybrid using one conductor, one resistor and a solder print, with SMD discretes. The thick film process will include layout design using a CAD terminal, direct cutting of Rubylith on a plotter bed, 10x photo reduction, direct UV mask manufacture on the screen, printing and firing, abrasive trimming of resistors, mounting of discrete devices, pin bonding, encapsulation and test.

EE587D Thin Film Deposition Techniques. Corequisite: EE578 Thin Films: Preparation, Properties and Applications (Fall).

The philosophy of the course is to present the widest possible exposure to various vacuum, deposition and thin film measurement techniques. The equipment used will usually be committed to current research projects, so scheduling may be a problem. On the other hand, with small enrollments, students may actually work directly with the research students for one data-gathering cycle.

1. Turbopump; electron beam evaporation; discontinuous Pd film; environmental effects (H_2) on resistance; use of electrometer, mass spectrometer, quartz crystal microbalance for thickness. (Current research project.)

2. Cryopump; thermal evaporation; discontinuous Au film; carbon coat and lift film for STEM; measure electrical properties. (Current research project.)

3. Diffusion pump (load-lock system); RF magnetron deposition of glass; ellipsometric study of film.

4. Diffusion pump; DC magnetron; Cu film;

measure film stress (and adhesion).

5. Diffusion pump; plasma etch; SEM examination.

6. Ion pump; thermal evaporation of Al; optical thickness monitor (photoresistor); calibrate with optical interference instrument.

EE587E MOS VLSI Design. Corequisite: EE574 MOS VLSI.

Details for EE587E are still sketchy. It is intended to run the course in cooperation with the Department of Computer Science, sending projects jointly to MOSIS for foundry implementation. The design would be done towards the end of EE574 with testing completed upon the return of devices in the following summer. 3-micron CMOS technology is assumed with most designs falling into the digital filter or switched capacitor network fields.

Miscellaneous

Future developments in the Microelectronics laboratory area will be dictated by two recent moves.

SUNY-Binghamton has set up the Institute for Research in Electronic Packaging as an interdisciplinary organized centered in but not limited to the Watson School. Current research areas span electrical, mechanical, materials, thermal, systems and manufacturing. As these research activities grow, they will inevitably bias the instructional program and the graduate laboratory courses. (EE577 Semiconductor Device Packaging already runs regularly.)

The Watson School is establishing a Materials Engineering specialization within its MSAS (Applied Science) program, which will probably lead to a further graduate laboratory course in materials analysis. Positioned midway between the Mechanical and Electrical Engineering Departments, the course would cover optical microscopy, scanning and transmission electron microscopy, X-ray and electron diffraction, surface analysis (Auger, ESCA, SIMS) and RBS, etc.

Conclusions

Despite low enrollments, the Department of Electrical Engineering is committed to the graduate laboratory concept. While the program grows, the laboratory courses must be structured to permit them to be taken on a nearly individual basis.

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References

1. J. E. Morris and G. L. Sackman, "Graduate Laboratory Courses," Proceedings 17th Annual Frontiers in Education Conference, RHIT Oct. 24-27, 1987, pp 641-644, IEEE Press.

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