WIP: An Experiential Undergraduate Certificate in Semiconductor Engineering and Physics

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***Abstract*—This innovative practice WIP paper describes an undergraduate certificate program in semiconductor engineering and physics. This newly-instituted program incorporates experiential learning in each of its three curricular components. Initial assessment data from student surveys after the program's first year as related to student experience and learning show high levels of overall learning in *foundation* courses among respondents - 4.5 and 4.65 out of 5 for lecture and lab - highlighting the importance of experiential laboratory learning. Challenges and opportunities in scaling the program or translating to other institutions are discussed, along with plans for expanding certificate evaluation through a concept inventory and industrial evaluation board.**

***Index Terms*—component, formatting, style, styling, insert**

I. Introduction

The semiconductor field is of immense importance to today's society. The necessity to prepare students for this field is underscored by the recent passage in the United States of the CHIPS and Science Act of 2022 and by the fact that that up to 58% of the new jobs in the field are expected to go unfilled by 2030 [1], [2]. As a result, several new university programs, at both the undergraduate and graduate levels, have been recently introduced to meet this need [3]. This work-in-progress paper details one such program: a new undergraduate certificate in semiconductor engineering and physics (UCSEP) being offered by the University of Vermont. The 17-credit hour certificate, introduced in Fall 2023, is available to students from engineering and physics, and aims to equip them with specific knowledge and skills in semiconductor device physics, design, processes, and metrology for success in the workforce and/or in further academic pursuits.

II. Certificate Structure

The UCSEP curriculum employs experiential learning throughout. Among the findings of researchers who study experiential learning is that these approaches promote student engagement and ownership by making the studied material more relevant [4]. Prior work also identified four abilities that are developed through active/experiential learning: concrete experiences (CE), reflective observation (RO), abstract conceptualization (AC) and active experimentation (AE) [5]. As illustrated in Table I and Fig. 1, the two-year UCSEP curriculum provides multiple opportunities to develop and reinforce these abilities and comprises of three main components: *Foundation*, *Exploration* and *Practice*.

TABLE I
Curriculum Mapping to Active Learning Abilities

Active Learning Ability	**Certificate Component**		
	Foundation	***Exploration***	***Practice***
Concrete Experiences	D†		R‡
Reflective Observations	D		R
Abstract Conceptualization		D	R
Active Experimentation		D	R

† D - development; ‡ R - reinforcement

A. Foundation

Students entering the UCSEP program will have completed an electrical circuits course and a physics course on electromagnetics. All UCSEP students must then complete two core courses: (i) *Integrated Circuit Fabrication & Analysis* and (ii) *Semiconductor Materials & Devices*. These required 4-credit courses have both a lecture and laboratory component, creating a certificate with uniquely integrated hands-on learning. Students study the fundamental techniques of microelectronic circuit fabrication and electronic device characterization through classroom instruction and software simulation. These concepts are then reinforced with laboratory experiences using industry-standard equipment (CE). Fabrication methods are explored using destructive methods and scanning electron microscopy. These exercises allow students to see more elaborate circuit architectures first-hand. For electrical analyses, students use parametric analyzers and probe stations to make measurements on foundry-donated wafers. Students discuss and reflect on these experiences in their laboratory reports (RO).

B. Exploration

Building on the above foundational knowledge, students then choose among multiple courses aligned with their interests to further explore the semiconductor field. These include digital, analog and/or radio frequency VLSI design, solid state

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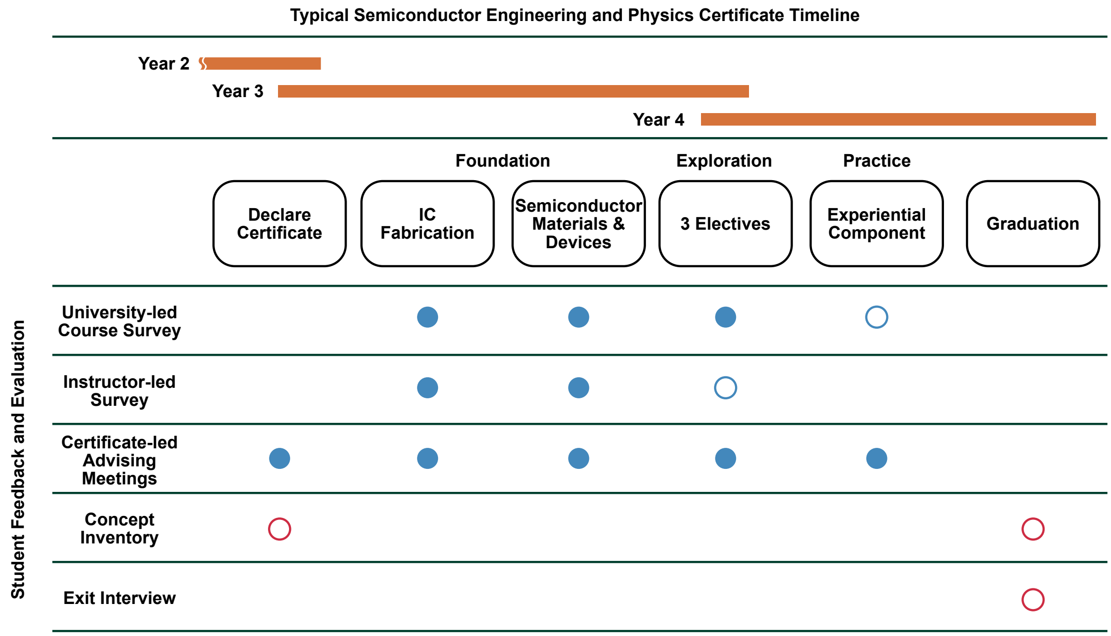

Fig. 1. Recommended timeline for UCSEP program along with current evaluation structure. Students typically take foundation courses fall and spring of their third year. These are complemented with exploration electives and an experiential project taken in their third and fourth years. In-place evaluation components marked by solid blue circles. Blue outlines indicate components that may occur, depending on course and/or experiential option chosen by student. Red outlines indicate mechanism to be implemented. In addition to the standard University-wide course surveys and instructor-led surveys on new lab development, students who have declared the certificate are also assigned the certificate director as an additional faculty advisor, who is available for semesterly advising meetings. To be developed are a formalized exit interview as well as pre- and post-certificate concept inventory to assess learning and retention of key concepts across certificate length.

physics, physical optics, and materials characterization. These courses incorporate projects which develop conceptualization (AC) and experimentation (AE) skills, in the context of semiconductor technologies.

C. Practice

The final UCSEP component provides a means for students to apply one or more of the four active learning abilities. Students can conduct research related to semiconductor technology with one of the faculty, they can pursue an internship with a semiconductor firm, and/or their Capstone Project (typically sponsored by local industry) can be related to the semiconductor field. Regardless of the option chosen for the *Practice* component, students will have concrete experiences (CE), which leverage their course work, and will be writing reflective observations (RO) on these experiences. Furthermore, research and Capstone experiences necessitate applying (and thus further development of) conceptualization (AC) and experimentation (AE).

III. Laboratory Infrastructure

To support the *Foundation* courses in the certificate, two new teaching labs are being established, highlighted in Fig. 2. The primary lab, founded in partnership with GlobalFoundries, is 1170 sq ft and provides seating for pre-lab lectures and data analysis work, a probe station area for electrical characterization of semiconductor devices, and a polishing and microscopy area for de-processing of semiconductor chips. This is supplemented with a 530 sq ft fabrication cleanroom, currently focused on photolithography. These two labs, utilized heavily in the *Foundation* courses, are complemented with existing facilities in electrical engineering and physics programs, which are utilized in the *Exploration* electives. Many of these facilities have also been updated to support the certificate's curriculum.

IV. Results

As noted, the UCSEP program is in its first year. The certificate was designed to be a two-year program, but its completion can, with proper planning, be accelerated. This is the case for the program's first year in which six seniors (five electrical engineering, one mechanical) are graduating with the certificate. We now present the feedback from these and other students who participated in all or parts, respectively, of the curriculum. We present initial results from the *Foundation* courses, *Practice* experiences, and the program overall. Anonymous university course surveys are used to gather information on the updated structure of the foundation courses, while an identifiable survey of foundation course enrollees is used to gather information on both learning in the updated course format and student career/certificate interests and outcomes.

A. Integrated Circuit Fabrication & Analysis

Integrated Circuit Fabrication & Analysis was taught to a cohort of twelve undergraduate seniors: eleven electrical and one mechanical engineer. The lab, highlighted in Fig. 3, consisted of three main modules: (i) physical analysis of

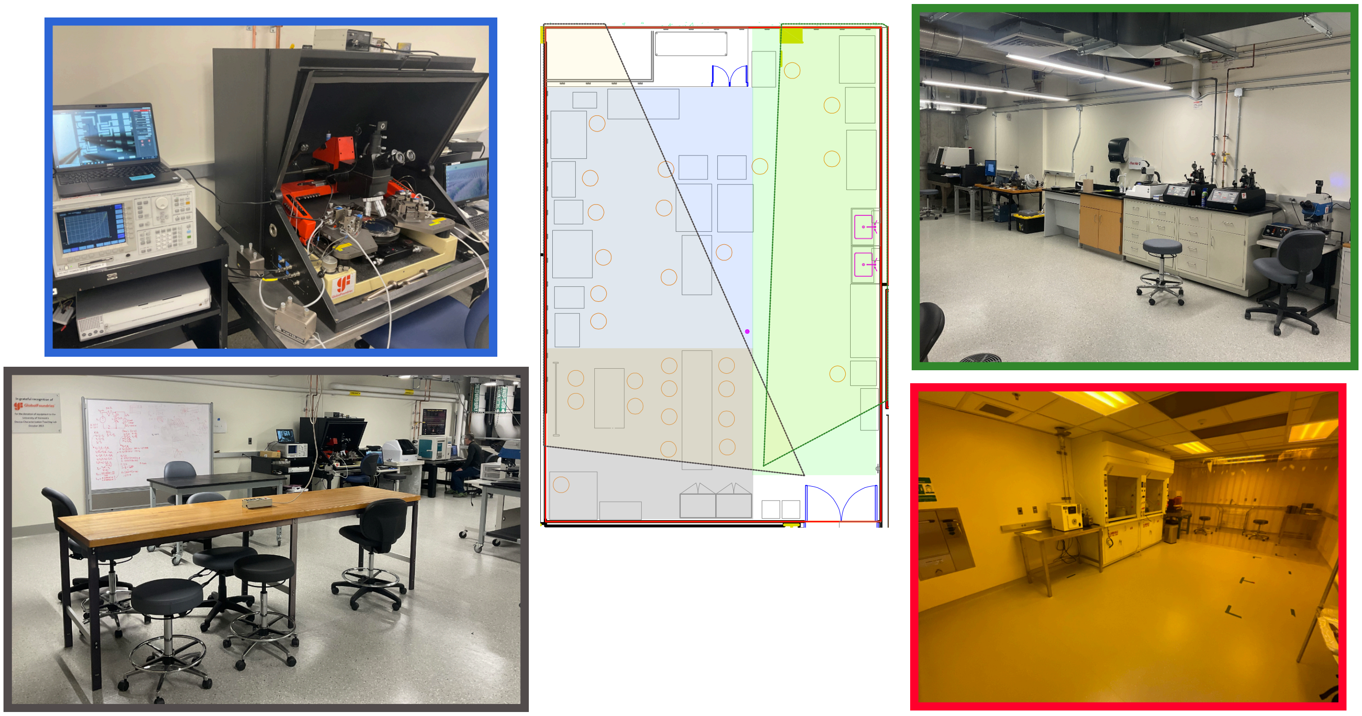

Fig. 2. Laboratory facilities established to support the UCSEP program. The device characterization lab (floor plan depicted center) includes a lecture seating area (grey, lower left), an electrical and materials characterization area (blue, top left), and a polishing and microscopy area (green, top right). These areas are supplemented by the fabrication cleanroom down the hall (red, lower right). Field of view depicted in upper right and bottom left photographs outlined on floor plan.

integrated circuits, (ii) process modeling, and (iii) mask layout design and lithography. Informal student feedback indicated high engagement with the hands-on aspect of physical analysis, e.g., polishing back a semiconductor chip to look at the different layers created in fabrication. Students also enjoyed creating a lithography design and seeing it printed on a wafer at a microscopic scale.

B. *Semiconductor Materials & Devices*

The initial offering of *Semiconductor Materials & Devices* was taught to a cohort of 18 students. Two were junior-level undergraduate students, eight were seniors, and the remaining eight were graduate students. The majors were as follows: nine electrical engineering BS, one mechanical engineering BS, five electrical engineering MS (with one student transferring to mechanical engineering MS during the term), one physics PhD, and two materials science PhD. The laboratory experience primarily focused on material and device measurement techniques, utilizing a BiCMOS device wafer (Fig. 4). Students gained experience measuring and extracting parameters discussed in lecture from real samples. Students were anonymously surveyed at twelve weeks into the course and asked about their level of degree (undergrad/grad), the pace of the class, topics they wished to be covered more or less in the future, and what they found most enjoyable about the course so far. Eight (8) responses were received (4 graduate, 4 undergraduate). Regarding the last question (most

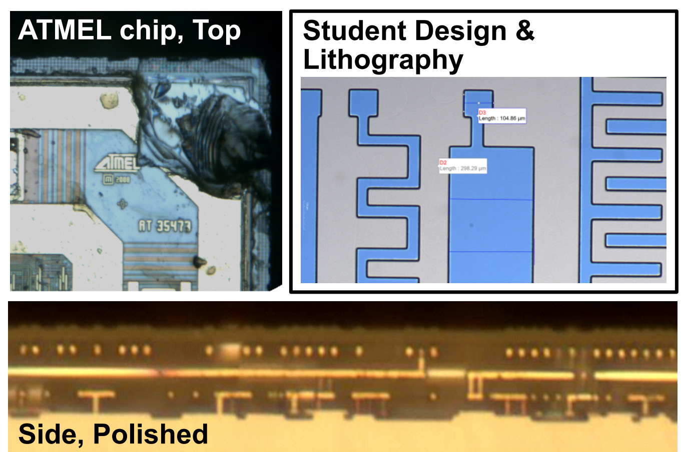

Fig. 3. Some highlights of the Integrated Circuit Fabrication and Analysis laboratory includes a module on physical analysis of integrated circuit processes through top-down and cross-sectional polishing, as well as a fabrication module on optimization of a lithography process, culminating in patterning and measurement of student-made designs.

enjoyable part of the course), three students mentioned the lab component specifically:

> *"I LOVE the lab, it helps make sense of the small scale we study in course. When I took {a similar course as an} undergrad I think most people made it through the course not even picturing what a wafer*

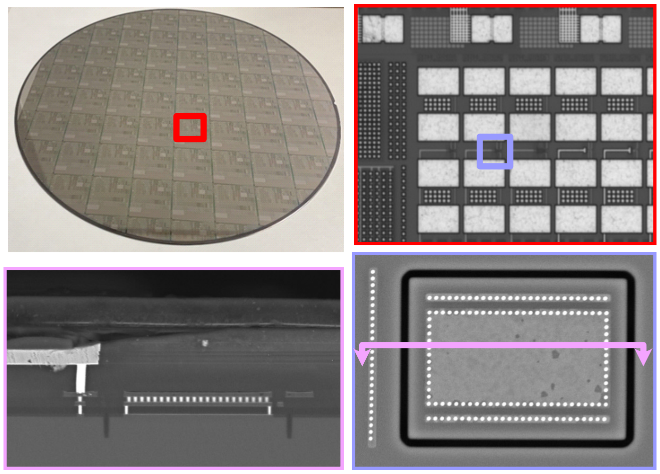

Fig. 4. BiCMOS device wafer (top left) utilized in *Semiconductor Materials & Devices* lab. As students learned physics and theory behind device operation, they located these devices (top right) among those available on the wafer and measured them to extract device parameters. For an experiential project, a mechanical engineering senior identified (bottom right) and cross-section polished (bottom left) one of these devices, putting into practice the foundational knowledge gained in the required fabrication and analysis course while creating a more reliable procedure on polishing for future students. These cross-sections will be integrated with device modeling to try to match measured characteristics with simulation in the next iteration of the devices course.

> *looks like."*

Four mentioned coverage of various devices and how they better understood why and how they worked:

> *"I liked the whole course, but especially relating the content and physics back into electronics and circuits, highlighting where non-ideal effects stem from. Making those connections to other class helps me to put the pieces together and learn more."*

Asked about topics students wished were covered more in the lab, four students mentioned more measurement time and structured discussion regarding parameter extraction. While the lab was designed to be open ended to allow students to explore data and reflect on how to apply the theory they learned in lecture, this feedback shows that there is opportunity for improvement in the next offering, e.g., providing more guided exploration in initial labs and transitioning to an open ended exploration as the semester progresses.

C. Experiential Projects

As noted, this past year a number of students completed the certificate in a single year, having already completed credits in *Exploration* courses. To enable this accelerated completion, a *Practice* component was still needed. As such, our team mentored individual research projects that built on *Foundation* coursework and personal interests, including: lithography characterization, setup of an automated switch system for on-wafer probing using different hardware paths, a procedure for circuit model extraction from measured data, and a refined procedure for cross-sectional polishing of semiconductor integrated circuits. Results were presented in poster format at the University's Student Research Conference. In addition, a student, who partnered with GlobalFoundries for their project, presented their work at the company.

TABLE II
STUDENT RESPONSES TO "RATE YOUR LEARNING IN..."

	IC Fabrication		*Materials & Devices*	
	Lecture	Lab	Lecture	Lab
n	4	3	8	8
mean	4.5	4.67	4.5	4.625
std dev	1.0	0.58	0.76	0.52
median	5	5	5	5

D. Exit Survey

At the conclusion of the academic year, a survey with identifiable responses was given to students who took the *Foundation* certificate courses, requesting information about their motivation for taking the courses, whether or not they were pursuing the certificate, their areas of interest in the industry, and a rating of their learning in the *Foundation* courses (scale of 1-5, 5 being best). Nine students responded - six undergraduate (including five with certificate declared) and three graduate. Self-reported learning is summarized in Table II.

Of the six seniors graduating in the first certificate cohort, two have positions in semiconductor design, one in semiconductor manufacturing, and one each in electrified aviation, electrified marine transportation, and aerospace. Of these last three students, all three expressed either a desire to work in the semiconductor industry long-term or a curiosity on the topic area and careers involved as their motivation for completing the certificate. Additional seniors, who took the *Foundation* courses but elected to not complete the certificate, have also accepted employment in semiconductor design.

V. SCALABILITY AND FUTURE OPPORTUNITIES

While some aspects of the certificate such as cleanroom processing may be difficult to translate to an institution without the requisite laboratory infrastructure, there are several aspects that can be adapted based on local resources. For example, the on-wafer device probing that complements theory in *Semiconductor Materials & Devices* could be carried out on packaged parts to eliminate on-wafer probing, with bias applied via a tabletop source measure unit (SMU) for two terminal devices, or two synchronized SMUs (via GPIB, LXI, etc) for three-terminal devices. Device cross-sectioning and analysis of larger features could be achieved using a microscope and basic hand tools (e.g., diamond scribe, handheld glass/tile cutters) to cleave bare die purchased directly from sources such as Digikey. These activities could then optionally be paired with a short-term intensive experiential component at a partner institution. This type of approach is commonly seen in partnerships between community colleges and larger regional institutions, where the community college provides the majority of classroom instruction for a certificate or two-year degree program in semiconductors and the regional school provides cleanroom or wafer measurement experience for the students through a single semester program (often during summer) [6].

Challenges faced in implementation of the *Foundation* courses were the workflow of the laboratory activities and accessibility of the topics covered to the diverse backgrounds of interested students. While students appreciated the chance to use unique equipment that is often only available in a research setting, the largest criticism of the lab heard from students is that they wish they have more hands-on time and/or smaller group sizes when using the limited number of equipment available. For the next year's offering of the *Foundation* courses, effort will be focused on streamlining the laboratory procedures to allow students to get started on equipment faster, leaving more time for exploration.

Another approach, piloted this past year, is to include a simulation, analysis, or design component in the lab assignment that complemented the hands-on component, allowing for improved multiplexing of students between various resources within the lab. This concept will be fully incorporated and will use industry-standard simulation tools for process and electrical modeling in the *Foundation* labs. These assignments will also serve as an additional way to bridge the idealized theory taught in a one-semester course and the reality of more complex experimental devices. These simulation tools, which allow students to quickly create design variations of devices and see the impact on device structure and output characteristics, offer a means to visualize the complex physics that are occurring in devices, in a self-paced manner. Effectiveness will be gauged via an anonymous lab survey, where students will be asked to assess how the theoretical, simulation, and experimental components contributed to their learning.

Beyond the *Foundation* courses, efforts continue to expand elective offerings in areas such as autonomy and materials analysis, highlighting to students the diverse skills and backgrounds required to meet the widespread workforce shortage in the semiconductor industry. Also planned is a pre- and post-certificate concept survey, designed to track learning and retention of important concepts across the length of the certificate to complement course-specific assessments. These initiatives will be guided by interaction with local semiconductor-related companies who employ UVM graduates through formation of a certificate advisory board, ensuring targeted skills are relevant to evolving workforce needs.

Acknowledgment

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