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Initiation of Undergraduate Electrical Engineering Research at Lincoln University (PA)

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Abstract: This paper describes and discusses several recent faculty-student research activities at Lincoln University (PA), an HBCU. Specifically, it makes connections between NSF-sponsored faculty research and the projects that several undergraduate Engineering Science and Physics students have been working on. The Engineering Science is a relatively new major at Lincoln. New research experiences are particularly useful, so integrated learning is an attractive methodology for some of the engineering courses. The paper includes several case-studies detailing the student projects in connection to their academic progress. It also suggests the opportunities for our students upon graduation. The key findings of this study are that the research activities enabled by this research initiation grant are sufficiently diverse; they provide necessary supplements for the courses taught to students who specialize in electrical engineering. Research experiences that students get through this project are particularly useful for their future graduate studies and industry careers.

Key words: undergraduate research, integrated learning, electrical engineering, optoelectronics

1. Introduction

This paper deals with impacts of undergraduate experimental and computational research in electronics, photonics, and photovoltaics on student development, academic performance, and the range of opportunities that open for them upon completion of their studies at Lincoln University (PA). Projects developed by the faculty are outlined and presented here in the context of existing and new physics and engineering curriculum. The discussion that follows is supported by case studies that look at several students' research experiences, specifically at what new information, skills and qualifications they gained from the project.

Our school is a 4-year historically-black university (HBCU) founded in 1854 as the first minority-serving educational institution in the US. Traditionally, Lincoln University has had a strong Physics program that produced a number of successful scientists, some of whom received their doctorates from prestigious universities.

The new Engineering Science (ES) major was introduced at Lincoln in 2014, in addition to the existing Physics major. As of December 2016 our school had about 17 engineering students, and about the same number of physics students. The new major includes Electrical and Computer (ECE) and Civil and Environmental Engineering (CEE) concentrations.

This article focuses on the impacts of the joint faculty-student research supported through the author's NSF

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grant on the ECE part of the ES program and also on the existing Physics program. Traditionally, Physics at Lincoln University was taught as a combination of lectures and labs using syllabi that defined the studied topics and the sets of experiments in a rigid manner. This way of teaching is currently being critically reviewed by some universities, and is often replaced with integrated lecture-lab courses. The new pedagogical approach is broadly known as "integrated learning" (Carlson et al., 1999; McCowan et al., 2002). Examples of successful application of integrated learning to engineering and natural science courses can be found, for instance, in Vikas (2012), Vierna et al. (2013). Problem-solving skills are ultimately important to any engineering education. Therefore, student capstone projects, independent research, and industrial experiences have always constituted a significant part of electrical engineering curriculum.

Having started from the original Physics major curriculum sequence, the author and his colleagues developed and proposed a new one that satisfies the requirements for the 4-year baccalaureate-level engineering program. One of the distinct features of our ES curriculum is that it allows significant flexibility in the choice of electives, capstones, and independent studies, in addition to the required set of core science, general education, and engineering courses (Lincoln, 2015). Because our school also allows double majors, engineering electives can also be taken by Physics and other STEM students. In the following section, connections are made between faculty research and the engineering curriculum at Lincoln.

2. How the Faculty Research Helps Undergraduate Engineering Education

In 2015, the National Science Foundation funded one of the author's proposals, NSF-RIA 1505377, dealing with the computational and experimental characterization of semiconductors that can be used in concentrator photovoltaics. The goal of this project is to study the effects of various modes of non-radiative recombination in photovoltaic materials, such as polycrystalline Si, on the charge carrier transport, when incident light intensity and, therefore, the optically-injected minority carrier density is high. Initial studies have shown that recombination rates may sometimes be density-dependent.

This research combines together three different studies of semiconductor material and device characterization: (1) near-infrared photoluminescence (PL) imaging of semiconductor wafers that is capable of revealing signatures of extended defects in silicon (Horn et al., 2005); (2) optoelectronic characterization of the semiconductor wafers, including AC impedance spectroscopy (Lvovich, 2012) at various constant levels of incident light intensity and transient photoconductance measurements using pulsed sources (Joshi, 1990); (3) numerical modeling of carrier transport in semiconductors including various models of electron-hole pair recombination. At least the last two areas of this research, optoelectronic characterization and computational modeling, are traditional for undergraduate and graduate electrical engineering programs. The students who participate in the NSF project have opportunities to learn several topics that are important for future electronics engineers (in brackets is given an estimated level of complexity):

- Advanced applications of equivalent AC circuits in the context of AC impedance spectroscopy (Lvovich, 2012) (sophomore to junior);
- Engineering data analysis, including parameter extraction from current-voltage (I-V) curves, calculation of PV conversion efficiency;
- Basic digital image processing, as they work with IR photoluminescence images of Si wafers (sophomore to senior);

- Fundamentals of optoelectronic measurements and optical metrology, including optical intensity, spectral, and external quantum efficiency measurements (freshman to senior);
- Fundamentals of finite-element numerical modeling, as they help the faculty with the setup and development of computational models for charge carrier transport (senior);
- Fundamentals of experiment automation and real-data acquisition (sophomore to senior);

Infrared PL stress imaging (research area 1) is not currently performed at Lincoln due to the lack of specialized equipment. The author collaborates on this with the University of Illinois at Urbana-Champaign where experiments of that nature are routinely done by graduate students at Talbot Lab there.

There also exist multiple connections between this faculty-student research and the taught lecture-based courses. For instance, our Engineering Science program's core courses in Electronic Circuits and Electronics are mostly theoretical. At the same time, AC impedance spectroscopy experiments are strongly intertwined with the material taught in those courses. To be exact, equivalent AC circuit analysis in those experiments expands the range of applications of useful concepts such as frequency-domain transfer functions, Argand plane analysis of circuit functions.

Another example is transient photoconductance spectroscopy. Students who are involved in this sort of experimental research are expected to study Electronics, Differential Equations, and Modern Physics. The latter two courses are science required courses/science electives, respectively. Combining the theory and experiment is crucial to the student meaningful learning of these subjects. Experiments, in fact, help them to see critical links between electronics, photonics, and the underlying mathematics. Among other courses that are closely related to the author's research are: Waves and Optics, and Optoelectronics and Photonics. A course in Digital Image Processing is one of the core courses, and any project aimed at either image denoising or feature extraction is particularly helpful to understand how to apply image processing algorithms to real-world problems.

A separate category of student work on the project is experiment automation. Although this activity is rather "technical support" than "applied research", its inclusion into the list of student research projects helps us to bridge the gap between the theory that is currently taught to students and the practical skills required from graduating electrical or computer engineers when they enter job market.

3. The Outcomes of the Project and Discussion

Preliminary research on concentrator photovoltaics was conducted in the author's group even before the NSF-RIA grant was awarded, using local funding. During 2014-15, four students were involved in a project dealing with the evaluation of collection efficiency of luminescent plastic concentrators for solar cells.

With the help of the current NSF grant, we have equipped a new research lab that can be used by both Engineering Science and Physics students. This lab hosts several newly acquired instruments, including a carrier lifetime tester from Sinton Instruments that is considered photovoltaic industry standard (Sinton, 2016), a solar simulator, signal generators, oscilloscopes, a precision variable DC load.

In addition, the same lab that was formerly an Advanced Physics lab has retained most of its equipment that can be utilized for experiments in modern physics, such as Franck-Hertz and Millikan's oil drop experiments (Melissinos, 2003), measurements of the optical activity of materials, nuclear magnetic resonance, and spectrophotometry.

Figure 1 shows the layout of the new optoelectronics/advanced physics lab and a student at work.

Figure 1 Electronics and Advanced Physics Lab (A), a Research Student at Work (B)

Figure 2 presents the lab equipment and software most commonly used in electrical engineering faculty-student research at Lincoln University.

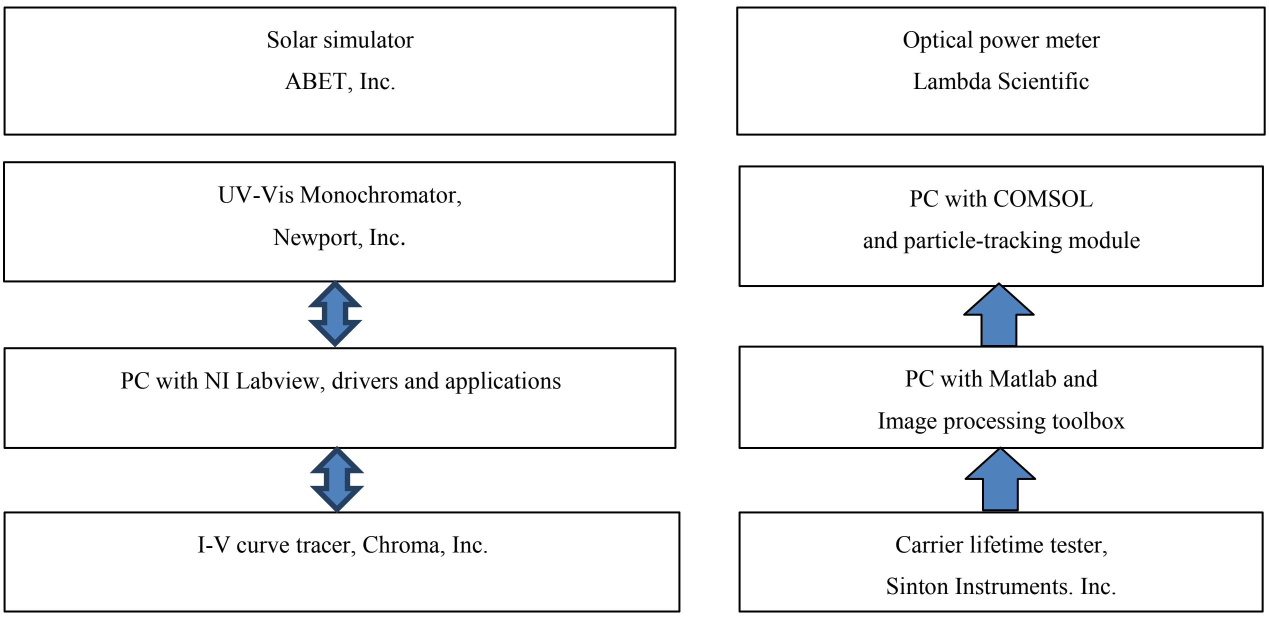

Figure 2 Lab Equipment and Software Used in Faculty-Student Research

The optoelectronic equipment and software presented in Figure 2 is available to our faculty and students of engineering and physics majors. In addition, our labs are also equipped with experimental kits for optoelectronics and fiber optics, basic research in lasers and physical optics, electronic circuits.

The following are profiles of Lincoln University engineering students who receive stipends through the author's research grant. The students are listed below as S1 to S5:

S1. Senior in Engineering Science. Specializes in experiment automation and real-time data acquisition. Co-authored one IEEE conference paper. Completed one engineering capstone project on the use of GPIB language to automate the measurement of I-V curves of solar cells. The student has accepted a job offer from Lockheed Martin Corporation;

S2. Senior in Engineering Science. Helps develop and test computational models of carrier transport in semiconductors using COMSOL Multiphysics software (COMSOL, 2016). Works on an engineering capstone project dealing with semiclassical modeling of carrier transport in Si wafers using various models for non-radiative recombination (Shockley-Reed-Hall and Auger) (Chaung, 2009). The student has also co-authored two future conference papers (APS and IEEE), and is currently negotiating her graduate admission into the University of Delaware;

S3. Junior in Engineering Science. Conducts AC impedance spectroscopy experiments for silicon wafers under variable illumination. Presented at the Lincoln University Annual Science Fair in November of 2016. The student is a prospective summer intern in Materials Science and Engineering at the University of Delaware in 2017. She was also a summer intern at Brookhaven National Lab in 2016;

S4. Senior in Physics and Biology. Conducts experiments on transient photoconductance of Si wafers. Co-authored and APS paper (Semichaevsky et al., 2016). The student is currently negotiating her graduate admission into the University of Delaware as well as several other schools;

S5. Sophomore in Engineering Science. Learned advanced Matlab programming, including image processing and data management. Contributed to the infrared photoluminescence image processing (denoising) for the data collected by a collaborator. The student is planning to travel to Thailand as a part of an exchange program.

In total, seven undergraduate students have worked on this project as of December 2016. The two students not listed here were Computer Science majors who only contributed to the project during several weeks, mostly as Matlab programmers.

This research project can serve as a source of ideas and inspiration for undergraduate student research activities at all levels. It also provides a wide variety of topics, including those summarized in Section 2. One of the factors that affect student interest and motivation is the availability of exchange and research opportunities at larger schools. To address this, the author has developed common research with the faculty at the University of Delaware, University of Illinois, and is currently developing a new connection with Davidson College in North Carolina.

4. Conclusions

The new Engineering Science program at Lincoln University (PA) has benefited from the author's research initiation project in several ways. Several students were assigned research projects that complement and supplement their traditional lecture-based coursework in engineering and physics. Some of the experimental results were or will soon be presented at conferences, including collateral research publications.

Historically, this is one of the first attempts to develop an integrated learning environment in STEM education at Lincoln University. The students have completed successful individual projects, including engineering capstones; this helped them develop their critical thinking and scientific writing skills. The author's research project is multifaceted, providing opportunities in several areas of electrical engineering, from semiconductor physics and optoelectronics, to experiment automation and image processing.

Engineering and Physics students involved in this research represent about 15% of the total number of enrolled students in these programs at our school. Successful implementation of this project will hopefully open new opportunities for collaborative research and will help make our Engineering Science program more competitive.

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