M.S. in Physics: Professional in Photovoltaics
Started in Fall 2010
Program Director: Prof. Sanjay V. Khare
(Contact: http://astro1.panet.utoledo.edu/~khare/)

I. Objectives

The primary objective of this program is to offer a Master of Science (MS) program in Physics with a concentration described as Professional in Photovoltaics (PV) (MS-PP) as a terminal degree with immediate employment prospects in industry. The MS-PP degree is a "job ready" degree. This will be achieved by a four pronged approach:

(i) To prepare master's students with a strong foundation in the fundamentals of PV science and technology through focused course work.
(ii) To complement their science education through course work in management, orienting them to realities of the business aspects of manufacturing.
(iii) To expose M.S. students to a summer of research experience on the UT campus in laboratories of world-expert faculty in the PV area.
(iv) To place them as interns in PV manufacturing facilities for six months to enhance their practical training and employability.

II. Targeted Students: The MS-PP program will be targeted to students completing a B.S. in Physics, Materials Science or related Engineering disciplines such as Electrical, Chemical, or Mechanical.

III. Curriculum and Schedule: The first cohort of students began the MS-PP program in fall semester of 2010 and will graduate with their degree at the end of summer 2012 for a total residence of two fall semesters, two spring semesters, and two summers in the program.

The syllabus for the MS-PP program is based on six distinct components. 1. Physics Core 2. PV Theory Core, 3. PV Experimental and Manufacturing Techniques Core (PVEMTC) 4. Scientific Communication, 5. Industrial Internship and 6. Business Principles. Students will complete a total of 37 credit hours of work through these cores.

1. Two courses each of 3 credits comprise the physics core. These are PHYS 6320, Quantum Mechanics I and PHYS 6250, Electrodynamics I. Unlike the regular MS in physics program, other core areas of physics will not be emphasized in this program. Some statistical physics as required for PV (e.g. in doping of semiconductors and its effect on the electronic band gap) will be covered in the second core. The graduate level emphasis on quantum mechanics and electromagnetism is important since the photo-electric effect that enables the conversion of solar radiation in the form of photons to be converted to electricity is easy to understand with a grasp of quantum mechanics and electrodynamics. This should enable students to get a good understanding of advanced concepts introduced in the second core.

2. Two courses each of 3 credits make up the PV Theory Core. These are PHYS 6630 Semiconductors I, PHYS 6990 Fundamentals of Solar Cells. This core will introduce to students four distinct aspects of PV solar cells: (i) the basic semiconductor physics of the active material, (ii) the optical aspects of sunlight absorption, transmittance, reflection and refraction, (iii) the fabrication of- and types of- materials involved. These include the active materials, the substrate, the back reflector to maximize light absorption, packaging

for protection from the ambient atmosphere and dust. (iv) Finally, issues relating to electrical current generation, leakage, heating, and other mechanisms related to the electrical characteristics of solar cells, will also be covered.

3. Direct experience performing experimental work in PV and other laboratories will form the PV experimental and manufacturing techniques core. Typical student entering a traditional M.S. or Ph.D. program in physics perform some teaching or research assistantship (TA or RA) duties per week (not exceeding 20 hours/week). The MS-PP students will utilize these hours to conduct Independent Study courses of 1 credit per semester for a total of 3 semesters, under mentorship of faculty working in the PV area. They will also do a laboratory course in the fall semester of the second year related to experimental techniques. The entire summer of the first year will be spent doing a small research project. All of these hours doing experiments will be occupied in the first two semesters of the first academic year, summer of the first year and in the first semester of the second academic year for a total of 4 semesters. No theory courses will be taken in either the first or second summer.

The PVEMTC will be designed to provide a complete range of hands-on experiences so that those who graduate with the MS-PP will have a detailed understanding of the experimental and technical aspects and challenges of the PV industry. Major topics to be covered over the four semesters include materials deposition processes, junction formation, device preparation, manufacturing and techno-economic concerns, and electrical, optical, and environmental testing of operational devices.

It is important to note that UT faculty work quite closely with commercial enterprises and entrepreneurs through UT's Wright Center for Photovoltaics Innovation and Commercialization (PVIC). PVIC is supported by the State of Ohio and seeks to leverage UT's leadership in PV to further grow the PV industry in the region, state, and nation. Consequently, students participating in the MS-PP program are likely to work closely with commercial enterprises and entrepreneurs. Students will naturally be exposed to business aspects of PV through the PVEMTEC.

4. Having excellent scientific communication skills is a must in the workforce of the 21st century. A typical professional in today's knowledge economy works in a multi-cultural cross-functional team environment. Furthermore, teams are often spread across international borders. With this in mind students in the MS-PP have a fourth core based on this essential skill-building. Such skill will be built through the physics seminar course. Students in this course listen to a 40 minute seminar given by a fellow student on a specific topic of research. MS-PP students will take this 1 credit course for the first two semesters. During these semesters they will make presentations on a PV related topic.

5. Industrial Internship in nearby industrial research or production facilities will form the fifth component of the program. This industrial apprenticeship will be performed primarily in the spring and summer semesters of the second year for a total duration of about six months. The internship will be for a total of 6 credits. This is *one of the important features that will distinguish this MS-PP degree from many others*. It is expected that this is an extraordinary value addition to the education of the students since they can apply their knowledge learned in the previous three semesters to the work-place through this period. It gives employers a chance to build a working relationship with a potential future employee and also train them on site.

UT is in an excellent position to create valuable internships for MS-PP students. UT has developed excellent collaborations with PV related industry. To initiate the Internship portion of the program, we will survey our corporate, academic, and national laboratory resources to develop descriptions of internship jobs. Each student will have a UT faculty mentor and an Internship mentor/sponsor at the chosen outside institution. Completion of the Internship portion of the MS-PP will require at least 24 weeks of work on projects specified by the corporate host/sponsor. Projects will be well defined to ensure good overlap between the student's interests and capabilities and the sponsor's needs. The Internship program will be a natural extension of UT's already intimate relationship with its corporate partners. Several companies, such as Brush Engineered Materials, Xunlight, and Pilkington have expressed interest in hosting MS-PP Interns. Expected possible outcomes include joint publications, patents, or presentations, and possible job opportunities.

6. Three business courses taken during the first three semesters of the program will form the sixth portion of the MS-PP. These courses have been chosen for students with three goals in mind. (i) To understand the path that leads from basic academic research to profit-making commercial activity. (ii) To comprehend the complexity, inter-connectedness and international aspects of modern supply chains from raw materials to the final product sold to the end user. (iii) To gather the tools needed to manage and successfully complete large industrial projects. The whole aim of the MS-PP is to produce a well-rounded science MS graduate with a good understanding of business implications of the technical work they will perform in private industry. These courses fulfill this need very well.

Detailed syllabi of the courses are listed below:

1. Quantum Mechanics I – PHY 6320/7320 – 3 credits – This graduate course is designed to teach quantum theory and its application to physical problems. Topics include dynamics in the Schrodinger and Heisenberg pictures, invariance principles and angular momentum theory, perturbation theory, the variational method.
2. Classical Electrodynamics I – PHY 6250 – 3 credits – This graduate course is designed to teach students electrostatics. The intent of this course is teaching the students about the equations of Laplace and Poisson-Maxwell's equations and their solutions.
3. Fundamentals of Solar cells – PHY6980/8980 – 3 credits – This graduate course aims to improve the knowledge of students about the various forms of alternative energy. The students, after the completion of this course will understand the various designs of solar cells, their operation and acquire knowledge about various solar cell technologies.
4. Semiconductors I – PHY6630/8630 – 3 credits – This graduate course aims at providing students, knowledge about semiconductors from atomic level to the device level. This course is intended to teach students the underlying physics behind semiconductor operation. The course structure covers the review of topics: Modern Theory of Solids, Semiconductor and Metallic Materials, Semiconductor Devices and Dielectric Materials.
5. Physics Journal Seminar – PHY 6020/8020 – 1 credit – This graduate course is intended to improve each student's skills and experience in the preparation and

delivery of effective scientific presentations and inculcating in them confidence for delivering an effective and engaging presentation. This course will expose students to an array of current, interesting, and important research topics in the areas of condensed matter, materials science, chemical physics, and nanoscale physics, and other active topics in physics.

6. Industrial Internship – PHY 6940* – 1-6 credits – A minimum of 6 credits of this course is required to complete the MS-PP degree. This course will involve students working in a company related to solar cell manufacturing. This could be in the Toledo area or anywhere else within the US. One industrial mentor and a PV area faculty member will serve as mentors. Students will write a report at the end of their 24-week internship describing the successful completion of a project suggested by the company. The company mentor and the faculty member at UT will assess and grade this report to assign a course grade to the student.
7. Technology Commercialization – EFSB 6690 – 3 credits – This graduate course addresses the entire technology commercialization process, from idea to market. A key feature of the course is a "strategic opportunity evaluation" of an actual early stage technology.
8. System Analysis and Design – INFS 6560 – 3 credits – This graduate course discusses the concepts, tools, and techniques for information systems analysis, design and development. It also includes contemporary methodologies for systems development including CASE tools, prototyping and RAD project work.
9. Supply Chain Management – BUAD 6600 – 3 credits – This graduate course presents an integrated approach to value chain management and analyzes key challenges, practices and trends concerning primary business functions and processes. The course also examines the strategic ramifications for the supply chain in an emerging digital economy.
10. New Venture Creation – EFSB 6590 – 3 credits – This graduate course addresses the issues faced in starting a new venture, including the identification of new business opportunities and the effective and efficient evaluation of the economic feasibility of these opportunities. This course will provide an opportunity to students to learn and discover the different facets challenges while starting a new business.
11. Independent Study – PHYS 6990 – 2 credits – This will be the independent study course undertaken under the supervision of a PV faculty advisor. The same advisor need not be taken for all three semesters. A project of independent study should be chosen of mutual interest to student and advisor for each semester.
12. MS Thesis Research – PHYS 6960 – 1-3 credits – Research work under the guidance of a member of the graduate faculty. Designed to prepare the student to propose and carry out thesis research required for the MS. degree or non-thesis research for the MS-PP degree.
13. Photovoltaic Materials and Device Physics Laboratory – PHYS 6280 – 3 credits – Fabrication and characterization of solar cell materials and devices, addressing materials science and physics of substrate preparation, absorber and window deposition processes, metal contact formation, and measurement of physical properties.

A table showing the complete flow through of the program is shown below.

Table I. Scheduling of classes for the MS-PP program. Number of credits shown as (x) for each course. Total of 37 credit hours to be completed in 24 months.

Semester	**Standard Courses (Credits)**	**Individualized**
First Year, Fall	Quantum Mechanics I - PHY 6320 (3) Semiconductors I - PHY 6630 (3) Technology Commercialization – EFSB 6690 **OR** New Venture Creation – EFSB 6590 (3) Physics Journal Seminar – PHY 6020 (1)	
First Year, Spring	Classical Electrodynamics I – PHY 6230 (3) Fundamental of Solar Cells - PHY 6980 (3) Supply Chain Management – BUAD 6600 (3) Physics Journal Seminar – PHY 6020 (1)	
First Year, Summer	None	PV research at UT – PHYS 6960 (2)
Second Year, Fall	Photovoltaic Materials and Device Physics Laboratory – PHY 6280 (3) System Analysis and Design – INFS 6560 (3)	Independent Study – PHYS 6990 (3)
Second Year, Spring and Summer	None	Internship Program at Company – PHYS 6940 (6 total)

Application Process: Applicants may submit applications following procedures outlined at: http://www.utoledo.edu/as/physast/forms.html .

***Industrial Internship PHYS 6940** (variable credits 1 – 6). This course is taken by MS-PP students, in spring and summer of the second year, for a total of 6 credits to fulfill the 24-week internship requirement to complete the degree.

Catalog Course description: Experiential learning in an academic adviser-approved business, industry or non-profit.

Syllabus:
The internship may be paid or volunteer employment in an approved business, industry, governmental laboratory, or non-profit institution. It may be completed in the summer or

on a part-time or full-time basis during the school year. The student must register for PHYS 6940 during the period of internship.

The following requirements apply:

1. The internship will be earned at a rate of 1 hour of credit for a minimum of 4 weeks of full time work in the place of internship, with a maximum of 4 credits earned per semester.
2. The internship must be approved in advance by the internship coordinator for PHYS 6940.
3. At the end of the internship, the on-site supervisor of the internship experience must supply a one-page letter to the internship coordinator confirming that the student has completed the appropriate number of hours of work.
4. At the end of the internship, the students must write a report, typically 20 to 30 pages explaining what they did for the internship, what the experience taught them technically and professionally, and how this experience helped them to achieve their career objectives.