Introduction to Special Issue of *Progress in Photovoltaics*: The Thin Film Photovoltaic Symposium Commemorating the 25th Anniversary of the Institute of Energy Conversion at the University of Delaware

Editorial Advisors: Robert W. Birkmire and Steven S. Hegedus

Institute of Energy Conversion, University of Delaware, Newark, DE 19716 USA

A Thin Film Photovoltaics Symposium was held at the University of Delaware on May 1-2, 1997, to commemorate the 25th Anniversary of the Institute of Energy Conversion (IEC). The symposium consisted of a morning session on May 1 with invited talks from distinguished representatives from industry, followed by an afternoon session consisting of five interactive workshops. The workshops were run in parallel and each was held twice, allowing participants to attend two workshops. A ceremony was held on May 2 to commemorate the contributions of IEC to the development of thin film photvoltaics over the past 25 years. About 140 people attended the symposium. Financial support was provided in part by the U.S. Department of Energy, National Renewable Energy Laboratory, and the State of Delaware Economic Development Office.

In the days before and after the symposium, IEC hosted nearly 100 scientists and engineers participating in the NREL/EPRI/Industry/University Thin Film Partnership Research Teams. IEC provides leadership roles in all three teams; a-Si, CdTe, and CIGS. The a-Si teams have been working together over 4 years and a summary of their progress and current issues is contained in these proceedings.

The theme of the technical session was "Proof-of-Concept to Manufacturing." Recognizing that effective transfer of laboratory know-how to commercial scale manufacturing is required to develop a viable thin film photovoltaics industry, the purpose of the symposium was to discuss how this can be accomplished and to define approaches to laboratory scale experimentation that address manufacturing–related issues. These issues are especially relevant since several thin film PV companies are in the midst of scaling up production to 2-10 MW levels this year.

The morning speakers, Roger G. Little (President, Spire Corporation), Allen M. Barnett (President, AstroPower), Harvey Forest (President and CEO, Photovoltaics,

Solarex), Mohan S. Misra (President, Global Solar), and Robert Gay (Project Director, Siemens Solar), presented their views on what is required to take laboratory results to manufacturing and what are the primary challenges in developing a manufacturing facility. These presentations provided the foundation for the workshops in the afternoon. Papers from all the speakers are included in this special issue. The five workshops addressed areas of generic importance to the transfer of proof–of–concept, laboratory–scale experiments to thin film photovoltaic manufacturing: design of critical experiments for scale-up; substrates, contacts, and monolithic integration; semiconductor processing and manufacturing; device and materials characterization in manufacturing; and government/industrial/university partnerships. Participants were selected at each workshop to encourage interaction between researchers and engineers working in industrial, university and government settings and on different materials. Papers summarizing the workshops are also include in this special issue.

In addition to the technical presentations described above, symposium attendees were treated to an entertaining lunch-time talk by Bill Yerkes, currently of Teledesic, who gave his perspective on his 30 years in the PV industry. That evening, a banquet was held to celebrate IEC's 25 years with historical and personal remembrances. The following day, May 2, completed the symposium with speeches from: David Roselle, President of the University of Delaware; Thomas Carper, Governor of the State of Delaware; Bud Annan from the Department of Energy; Charles Gay of the Midwest Research Institute (former director of NREL); and finally, Robert Birkmire, Director of IEC, who described the challenges and goals for the next 25 years of PV.

THIN FILM PHOTOVOLTAICS AT IEC

The Institute of Energy Conversion has made significant contributions to the development of thin film photovoltaic technology over the past 25 years and has actively supported the national PV program. As early as 1970, Prof. Karl Böer had the vision of solar energy supplying the energy needs of individual residences and reducing the United States' dependency on foreign oil supplies. He recognized the potential of thin film photovoltaic cells coupled with thermal collectors as a clean and inexpensive way of accomplishing this. Converting this vision to a concrete proposal, which was funded by the National Science Foundation and electric power utilities, allowed Prof. Böer and the University of Delaware's Board of Trustees to establish the Institute of Energy Conversion in May of 1972. This preceded the first oil embargo and the formation of the U.S. Department of Energy.

In 1972, the most advanced material system for thin film solar cells was copper sulfide/cadmium sulfide (Cu_2S/CdS) which had efficiencies ranging from 3 to 5 percent with a few reports as high as 7 percent. Early research at IEC focused on this cell, resulting in extensive modifications and a steady increase in conversion efficiency.

In 1973, SOLAR ONE, the first house to directly convert sunlight into both heat and electricity for domestic use, was dedicated. Built at the University of Delaware with support from Delmarva Power and Light Company, SOLAR ONE was designed as an experimental structure to accumulate data from its solar harvesting system.

In 1975, Prof. Karl Böer stepped down as the Director of IEC to focus his efforts on Solar Energy Systems (SES), a company that was established to commercialize Cu_2S/CdS solar cells, and to return to his academic interests. Dr. George Warfield was Acting Director of IEC for one year to allow for a national search which selected Dr. Allen M. Barnett. The breadth of research activities was

expanded when the Institute initiated the development of a wholly new photovoltaic material, zinc phosphide (Zn_3P_2) and started an amorphous silicon (a-Si) program. In 1977, the United States Department of Energy (DOE) was established, as well as the Solar Energy Research Institute (SERI) in Golden, Colorado, with Paul Rappaport as the first director.

The Institute initiated, in 1977, a program to develop process designs for the commercial scale manufacture of thin-film solar cells in cooperation with Dr. TW Fraser Russell of the Department of Chemical Engineering, University of Delaware. By 1980 this effort had attracted a three-year, $750,000 contract from Chevron Research Company for the research and development of an improved process for the continuous deposition of semiconductor thin films on an inexpensive metal substrate. This research demonstrated for the first time, at the pilot scale, the feasibility of depositing a semiconductor on a continuously moving flexible web for which IEC was issued three patents.

By 1978 the Institute reported Cu_2S/CdS cells with an efficiency of over 9 percent which paved the way for future funding of thin film photovoltaics. In 1979, Dr. Barnett stepped down as Director to assume the position of Professor of Electrical Engineering at the University of Delaware and to devote his efforts to developing silicon solar cells, leading to a new commercial venture which is now AstroPower. Prof. TW Fraser Russell was appointed as the new Director by the University of Delaware.

In 1980, IEC developed the first thin film solar cell to exceed 10 percent efficiency. This Cu_2S/(CdZn)S device met the DOE's national photovoltaic program goal for 1980. However, issues associated with the stability and encapsulation of these devices led IEC to redirect efforts to a-Si and copper indium diselenide ($CuInSe_2$). In 1982 the University of Delaware dedicated a new $2.5 million,

40,000 square foot laboratory on Wyoming Road as the new home of the Institute of Energy Conversion. In this new laboratory three systems to make a-Si were designed, built and operated: thermal chemical vapor deposition (CVD), photo CVD, and RF CVD reactors.

In the early 1980s, IEC was one of the first organizations to propose multi-junction solar cells utilizing a-Si based cells in tandem. A patent was awarded for this device structure in 1981. The Institute, in addition, established a program to develop tandem solar cells based on $CuInSe_2$ as the bottom cell with either a-Si or CdTe as the top. As a result, IEC developed the expertise to fabricate CdTe solar cells and this was done in both a physical vapor deposition reactor and a close spaced vapor transport reactor. This provided the foundation for IEC to become the only laboratory in the world to have fabricated thin film solar cells with efficiencies greater than 10% utilizing four different absorbing semiconductors; a-Si, CdTe, $CuInSe_2$, and Cu_2S.

Although the mid–1980s were lean years for photovoltaics, IEC continually supported the National Photovoltaics Program and maintained its research efforts in a-Si, CdTe and $CuInSe_2$. Three reactors for making $CuInSe_2$ were developed and operated in this time. This versatility in thin film fabrication has provided increased quantitative understanding of the fabrication process and established IEC as a leader in the design and interpretation of experiments to provide the essential information for commercial scale design. In 1992, IEC was recognized by the United States Department of Energy and the National Renewable Energy Laboratory for its efforts in thin film photovoltaics and was designated as a Center of Excellence for Photovoltaic Research and Education. Professor Russell stepped down as director in January 1996 to return to teaching and research, and Prof. Robert W. Birkmire, a physicist who joined IEC in 1979, became its fourth director.

Today, IEC is a multi-disciplinary laboratory devoted to research and development of thin film photovoltaic cells and is one of the few laboratories in the world with expertise in Si, CdTe and $CuInSe_2$–based solar cells. Throughout its history, IEC has worked with over 50 companies, either formally on a contract basis or informally on a researcher–to–researcher basis, in supporting their research efforts or transferring technology to start a new research program. Most recently, IEC has been providing the technology as a member of the Department of Defense consortium of five companies to develop a $CuInSe_2$ manufacturing facility. In 1996, IEC started an internal program on thin polycrystalline Si film for photovoltaic application to expand its expertise into this emerging technology.

The Institute has established collaborative efforts with many University groups, both nationally and internationally, working on the development of thin film photovoltaics. Probably one of the most important contributions IEC has made to the photovoltaic community is providing a training ground for people who have made important contributions to the photovoltaic technology. More than 105 students have received advanced degrees while performing their research at IEC along with numerous post-doctoral fellows and visiting scholars.

Over the years, the Institute has had a parade of colorful and extremely talented people, all of whom cared very much about what they were doing and were truly committed to the research and improvement of solar technology. There were bumps and turns along the way, but the personnel of the Institute always worked together as a team with a common goal.

We thank the editors and management of *Progress in Photovoltaics* for allowing us to capture this unique event in this special issue. The influence of IEC over its 25 year history, and the challenges faced by the industry, are preserved in these pages. This is an exciting and challenging time for thin film PV. Hopefully,

the interactions and information exchanged at this symposium will help smooth the transition from laboratory to manufacturing, and speed the growth of the thin film PV industry.

Robert W. Birkmire

Steven S. Hegedus