

CRSP

Center for Revolutionary
Solar Photoconversion

update

Spring/Summer 2009

CRSP Research Profile

The Art and Science of Synthesizing New PV Materials

How does one begin to perform the basic research that's needed to produce low-cost, manufacturing-friendly PV products based on earth-abundant materials? In the case of this CRSP project, you start with two professors and a very talented graduate student.

There is a great need for inexpensive thin-film solar cells that can be manufactured on a massive scale. But first, two requirements must be met: the solar cells must be produced via a simple and cost-effective method and the component materials must be both inexpensive and abundant.

Copper zinc tin sulfide ($\text{Cu}_2\text{ZnSnS}_4$ or CZTS) is an emerging PV material that has the potential to satisfy both requirements based on its favorable bandgap (a required input energy that fits well within the solar spectrum), high absorption coefficient (much of the light that reaches the material is captured), and inexpensive elemental constituents.

The goal of this project is to produce an ink containing CZTS nanoparticles (typically 10 nanometers, or a hundred-millionth of a meter, in diameter) that can be "printed" onto inexpensive substrates and, with subsequent low-temperature annealing and contacting steps, be directly transformed into an efficient thin-film solar cell. A complementary goal is to grow bulk single crystals (many centimeters in diameter) of CZTS to evaluate and optimize the material's intrinsic semiconductive properties and to determine the practical limits of the efficiency of a PV solar cell made from this material.

The idea of making a CZTS nanoparticle ink that one could print with, using either spray techniques or silk-screening, is new. Once developed, this process could be analogous to mass production of newspapers as they roll off the presses. Think in terms of automated, speedy, and inexpensive. No other thin-film process can do that right now. With current



production methods, a vacuum process is usually involved, and that can be quite expensive.

The two professors, Bruce Parkinson, formerly of Colorado State University (CSU) and now at the University of Wyoming, and Amy Prieto of CSU, have been colleagues for several years. Dr. Parkinson has been in the "solar energy game" for more than 30 years; for a few of those years, he branched out into other fields because there was so little funding available in solar energy. Dr. Prieto is a fourth-year assistant professor with a background in synthesizing nanostructured materials.

The student is Shannon Riha, who just completed her third year of graduate studies at CSU. Such were her talents and work ethic that both Drs. Parkinson and Prieto sought an opportunity to put those qualities to work. That confidence has already been rewarded, because Shannon has succeeded in making the target CZTS compound as nanocrystals. This is a key step and a very promising result. The principals originally thought this was going to be difficult, because combining four different elements adds several layers of complexity.

"Shannon has taken to the work of both synthesizing and measuring PV materi-

CSU graduate student Shannon Riha, shown using a glovebox in the laboratory, is a key contributor to this CRSP project. Credit: Dan Bihn.

als. It's clear that she has natural chemical intuition," said Dr. Prieto.

"Synthesis is as much art as science, and she expresses both of those qualities," added Dr. Parkinson.

The project principals have submitted a proposal to the National Science Foundation to build on this work.

The Center for Revolutionary Photoconversion (CRSP)

is dedicated to the basic and applied research necessary to create revolutionary new solar energy technologies as well as educational and training opportunities. The research underpins renewable energy technologies, commonly called third-generation solar photon conversion, for the highly efficient and cost-competitive production of both electricity and fuels via direct solar processes. The CRSP participating research institutions are the National Renewable Energy Laboratory (NREL), University of Colorado at Boulder (CU), Colorado State University (CSU), and Colorado School of Mines (CSM).

Fast Track to Solar Cells Using Exotic Materials

Conventional wisdom holds that at least 15 to 20 years will elapse before a technology being developed in a laboratory is ready to make the leap to commercial production. And that's for the tiny percentage of promising technologies that make the leap at all.

As part of this CRSP project, the inventors of a new modified process to make solar cells from quantum dots (QDs) of silicon (Si) or germanium (Ge) are looking to challenge this norm. They plan to accelerate the development of their product by designing a technology in the laboratory that will be manufacturing friendly and can be produced cost effectively.

Dr. Conrad Stoldt of University of Colorado-Boulder led the team that invented the new approach for synthesizing Si and Ge QDs. He heads up the development work on this project, which focuses on the characterization of Si and Ge QDs used in prototype solar cell/photodetector devices. The goal is to identify optimal nanomaterial properties and post-processing protocols critical to advancing the next-generation renewable energy technologies.

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To inquire about CRSP membership and/or to receive a brochure and RFP packet, contact Managing Director Paul Nelson: paul.nelson@colorado.edu; 303-492-8025.

"We have a very exciting approach to making nanomaterials in large quantities—to my knowledge, the first example of being able to take an exotic process and talk about bridging bench-top science. It could become commercially viable in record time. The cost per watt could be a game-changer," said Dr. Stoldt.

This research project is built on the team's recent invention of a route to synthesizing freestanding, high-quality QDs of semiconductor materials that can be used for solar cells. The QDs are grown in a liquid aerosol solution. The initial invention developed the process parameters for Si and Ge QDs; this CRSP project will optimize the process for solar cell development, including an in-depth analysis of the Si and Ge thin-film optoelectronic properties.

Dr. Matthew Beard will perform optoelectronic evaluation to assess material performance, including QD thin-film electrical conduction and multiple-exciton generation measurements. Dr. Beard is a member of Dr. Arthur Nozik's team at NREL, which has been broadly recognized as a pioneer in the field of semiconductor QDs and multi-exciton generation (i.e., producing more than one electron-hole pair per absorbed photon of sunlight). This process has the potential to markedly increase the efficiency of solar cells.

The CU team believes they have a continuous, high-throughput method that will be readily scalable for industrial applications. And they are excited about expanding their work to photovoltaic applications. "Of all the different nanocrystalline materials, silicon will always be the cheapest and the most compatible with the solar industry," Dr. Stoldt said. "And I love that it's considered nontoxic."

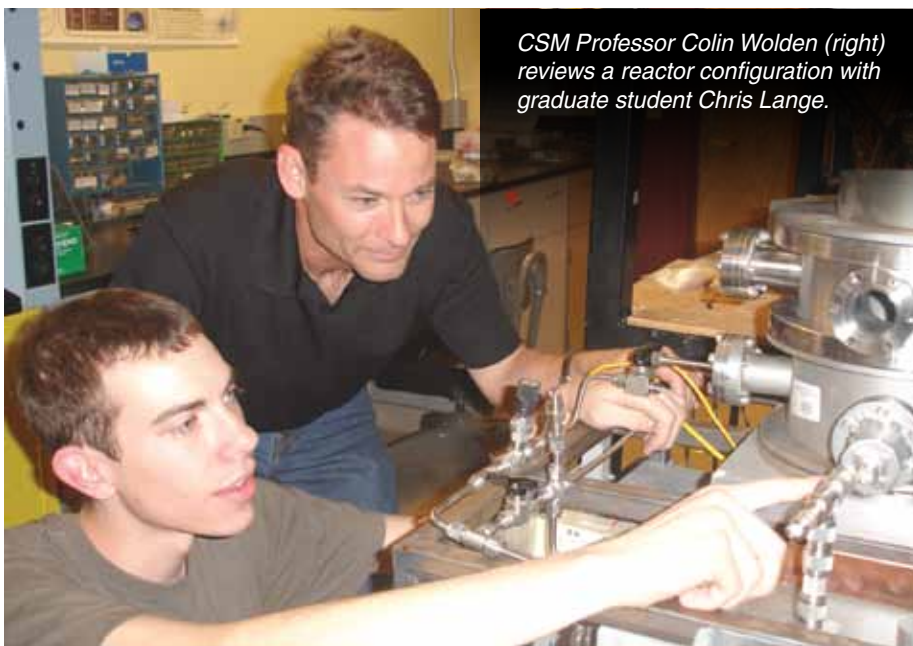
"We can produce the material and still maintain precise control of the nanocrystal size—which is a big challenge," said Dr. Stoldt. With nanomaterials, the ability to change the size of the QD allows the experimentalist to "tune" the color of light that is absorbed, as well as to achieve other desired material properties.

The most interesting part of this project lies in the attempt to maintain an ideal product (pure crystal with precise control of size) of the highest-possible quality. But this is also the biggest challenge. The goal of the CU team has always been to use the cheapest chemicals possible. Other chemicals that they know might do the job are too expensive and thus not an option for low-cost production.

"It's about working to demonstrate we can do it in a viable way. The current challenge is to maintain size control while ramping up throughput. We are shooting for producing a gram of material in a couple of hours," Dr. Stoldt said.



Dr. Conrad Stoldt of the University of Colorado-Boulder prepares a silicon nanocrystal sample for size analysis.



CSM Professor Colin Wolden (right) reviews a reactor configuration with graduate student Chris Lange.

CRSP Research Profile

Giving Due Respect to Photocatalysts

Scientific research that piggybacks on lessons learned from one set of technologies and applies them to a separate but related set has proven successful countless times in the past. Professor Colin Wolden and his team of students at the Colorado School of Mines are planning to mirror that approach, along with the successful result, in this CRSP project.

The CSM group is adapting a unique oxide-deposition technique that Professor Wolden developed initially for applications in the microelectronics industry. They are tailoring this technique and applying it to critically needed technologies that produce clean, low-cost energy from abundant solar sources. Oxides are critical to solar PV technologies for use as moisture barriers, passivation layers, antireflective (AR) and optical coatings, and transparent conducting oxides. The group is also engineering new oxide-based photocatalysts for renewable hydrogen production.

By using pulsed plasma-enhanced chemical vapor deposition (PECVD) to synthesize mixed metal oxide films, the team has nanoscale control over composition, thickness, and quality. The initial target materials include silicon dioxide (SiO_2), titanium dioxide (TiO_2), and their alloys, which are being evaluated as passivation and AR coatings for silicon PV. The pulsed PECVD technique retains the film qual-

ity demanded by the PV industry, but has been demonstrated in the laboratory to be an order-of-magnitude faster, and thus much cheaper, than the alternative (atomic layer deposition).

A second thrust of the project is to develop new photocatalysts with enhanced visible light absorption while maintaining efficient electron transport and stability against photocorrosion. Many candidate materials are stable, but do not absorb much light; others readily absorb light, but are not very stable. By engineering the surface properties of TiO_2 -based alloys, the CSM team is looking to achieve both objectives.

The CSM team is giving photocatalysts the respect they deserve by using semiconductor-grade fabrication techniques to produce them. This results in films that are conformal (i.e., can be applied evenly to textured surfaces and plastics) using a high-throughput, low-temperature process that lends itself to low-cost production. It also enables digital control and working at the nanoscale, depositing materials angstroms at a time and “dialing in” the thickness that is desired.

Professor Wolden brings to this project 12 years of experience as a chemical engineer, with a track record in semiconductor processing technologies. This CRSP project is a natural extension of that work. He divides his time between the laboratory and classroom, all while helping to build the skill sets of one postdoctoral student, three graduate students, and five undergraduates who contribute to this project and other work in his laboratory.

CRSP News & Events

International Laurels for Nozik—CRSP Scientific Director Arthur J. Nozik has won the 2009 Intergovernmental Renewable Energy Organization/United Nations Award for Science and Technology. This is Dr. Nozik's second major international award; in 2008 he received the Eni Award from the president of Italy.

DOE Energy Frontier Research Center (EFRC)—NREL, the lead CRSP institution, will partner with Los Alamos National Laboratory (LANL) and share in a \$19 million grant over 5 years for a joint EFRC named the Center for Advanced Solar Photophysics. Two universities that belong to CRSP, CU and CSM, will also participate in the new center and will receive EFRC support along with State of Colorado matching funds. This new center launches the CRSP Federally Funded Research Program.

Renewable Energy Materials Research Science and Engineering Center (REMRSEC)—The REMRSEC, sponsored by the National Science Foundation, is located at Colorado School of Mines. CRSP and REMRSEC recently formed an important affiliation, which will allow CRSP researchers to access key equipment and facilities at the REMRSEC and member companies in CRSP to receive briefings on the work being done.

Shared Research Program Awards RFP—On June 26, 2009, an RFP was sent to researchers at the four CRSP institutions for the second round of seed grants from funds provided by the CRSP membership fees plus dollar-for-dollar matching funds from the Colorado Renewable Energy Authority.

CRSP Annual Meeting—The meeting is scheduled for October 21–23, 2009, in Golden, Colo. On the agenda are tours of some CRSP participating research institution facilities, update presentations by CRSP 2008 shared research grant awardees, presentations by selected researchers proposing 2009 shared research projects, annual dinner, research proposal review/ranking committee meetings, poster session, REMRSEC and EFRC updates, and educational short courses.

Ascent Solar

Ascent Solar Technologies, Inc. (AST) is a manufacturer of flexible, lightweight, monolithically integrated thin-film PV based on a single-junction device using a copper-indium-gallium-diselenide (CIGS) absorber layer and deposited onto a polyimide substrate. A bare module weighs only about one-quarter of those using stainless steel; more importantly, the monolithic integration process significantly reduces assembly costs. The basic product, the “Premier,” has demonstrated 10.4% efficiency as measured by NREL. AST’s larger modules (up to 32 cm wide by 5 m long) generate 123 W and measured at 9.1% efficient. Both accomplishments are PV industry firsts. AST has achieved production status for its 1.5-MW line in Littleton, Colo. The new plant in nearby Thornton will begin production in 2010 and eventually will produce 30 MW annually and employ about 200 people.

AST is actively pursuing wider-bandgap material for better performance at the module level in normal operating conditions, as well as novel window layers for improved performance, reduced cost, and simplified plant operations. To reach the 15%–20% module efficiency level, AST researchers are pursuing the development of tandem and triple-junction flexible PV based on a bottom cell that is a variant of its standard CIGS device.

AST Web site: www.ascentsolar.com

DuPont

DuPont is a leading global materials and technology supplier to the PV industry, with more than 25 years of experience in PV materials development, manufacturing, and applications support. DuPont Photovoltaic Solutions (DPVS) today represents a broad and growing portfolio of innovations for the industry, developed by leveraging science from across

the company and working closely with strategic partners across the value chain. DPVS offerings are designed to increase the lifetime and efficiency of solar modules and improve the productivity of PV module makers.

DuPont products are used in the manufacture of both crystalline silicon and thin-film solar cells and modules. They include films, resins, encapsulation sheets, flexible substrates, and PV metallizations, as well as high-performance seals for solar cell manufacturing equipment, wet-etch additives for semiconductor texturing, and metallic sodium. The company invests in both capacity expansions to support the rapid industry growth and the development of innovative technologies to address different applications within the industry. DuPont has research sites in the United States, Switzerland, Japan, China, Taiwan, India, Belgium, and the United Kingdom.

DuPont Web site: www.photovoltaics.dupont.com



Colorado Senators Michael Bennet (left) and Mark Udall (right) inspect Ascent Solar Technologies’ 5-meter Flexible Monolithically Integrated CIGS Module while AST’s founder, Dr. Mohan Misra, looks on during a visit to the company’s new Thornton, Colo., facility on June 21, 2009.

CRSP Web site: www.ColoradoCollaboratory.org/crsp

CRSP Administration

Executive Board

Scientific Director: Dr. Arthur J. Nozik, Senior Research Fellow, NREL.
Co-Directors: Dr. David Jonas, CU; Dr. Mike Elliott, CSU; and Dr. Craig Taylor, CSM.
Managing Director: Paul Nelson, affiliated with both NREL and CU.

Advisory Panel

The panel includes one representative from each member company; these companies play a key role in identifying shared research thrust areas and selecting projects for funding.

Scientific Advisory Board

Dr. Thomas J. Meyer, University of North Carolina at Chapel Hill, chairs this board of external experts, whose role is to evaluate and monitor the quality of the science performed by CRSP researchers.

