



CRSP

Center for Revolutionary
Solar Photoconversion

update

Summer 2011

CRSP Research Profile

Linking Laboratory Research to Large Scale Energy Production

Modern civilization is challenged by increasing population, increasing per capita energy use, and fossil fuel induced climate change. For civilization to succeed into the next century, humans must stabilize their population, stabilize per capita energy use, and transition from fossil fuels to sustainable energy systems – all by 2040.

Colorado School of Mines' (CSM) CdTe program, with funding from CRSP and other sources, has helped improve solar energy technology and has trained people who now work at commercial photovoltaic panel



CSM CdTe researchers in front of their Cd_2SnO_4 sputter machine. From back left to front right: Tim Ohno, Joe Beach, Bill Bradford, Jason Stoke, and Dani Sledz.

manufacturers, universities and national labs. These people work not only with CdTe, but also $Cu(In,Ga)Se_2$ and wafer Si technologies.

CSM CdTe program's recent work has focused on cadmium stannate (Cd_2SnO_4) processing. Cd_2SnO_4 is an outstanding transparent conductor that is used in high performance CdTe cells, but its processing involves a post-deposition contact anneal that isn't compatible with large area production. They have been working to understand how this anneal affects the film so they can develop non-contact anneal or a process as good as deposited films. Moving this material to commercial production will help increase the efficiency of CdTe modules by increasing their current and fill factor.

The program's participants have also engaged a broader group of researchers at CSM to examine CdTe absorber processing to increase cell voltage. This is perhaps the biggest challenge for CdTe solar cell research, and may enable 20% efficient lab cells and commercial module production cost near \$0.50/watt.

Long lifetime PV systems are critical for low electricity costs. Once the construction loan for a PV system is paid, its electricity cost can drop from \$0.15/kWh to \$0.015/kWh because of low O&M and zero fuel costs. CSM's researchers are assembling a vacuum laminator to enable

encapsulation of lab cells for stress testing. This will let them assess how changes to cell fabrication affect cell durability.

Through efforts in sustainable energy generation and sustainable fuels production, CSM's researchers are helping to develop the technologies and professionals to power humanity into the next century.

The Center for Revolutionary Solar 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).

CRSP Member Companies

- Abengoa Solar
- Applied Materials
- DuPont
- General Motors
- Sharp
- Tokyo Electron
- Total

CRSP Research Profile

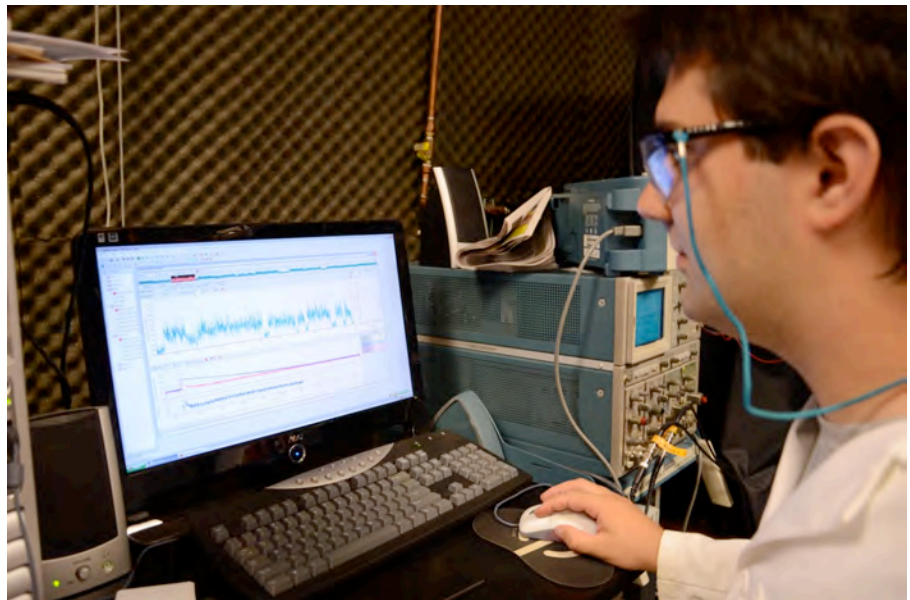
Studying a nanoscale solar cell to improve a macroscopic one

Imagine an operating solar cell only 10 billionths of a meter across. That's what the collaboration between the Alan Van Orden research group at Colorado State University (CSU) and the National Renewable Energy Laboratory (NREL) is trying to accomplish with the help of CRSP funding. The collaboration includes Dr. Jao van de Lagemaat and Dr. Justin Johnson of NREL.

What use could such a small solar cell be? Several solar cell architectures have been developed utilizing nanometer sized semiconductor particles called quantum dots in close packed arrangements. These nanometer scale particles have optical properties that can be tuned so they efficiently absorb the light from the sun. In addition, under some conditions quantum dots can generate multiple charge carriers for each photon of light absorbed, which could dramatically boost the efficiency over conventional solar cells.

However, there are several unknowns in using quantum dots for solar energy. For example, quantum dots exhibit interesting fluorescence behavior in which the emitted light "blinks" on and off. The effect of this blinking on the performance of quantum dot solar cells is unknown. Also, while the properties of individual quantum dots have been well studied, the interactions between quantum dots in close proximity are not well understood.

The Van Orden group has recently studied the fluorescence



CSU graduate student Kevin Whitcomb of the Van Orden research lab analyzes a single molecule fluorescence time trace from an individual quantum dot.

properties of small clusters of quantum dots containing up to ten particles using single molecule fluorescence spectroscopy techniques. They found evidence that the clustered quantum dots undergo inter-quantum dot electronic energy transfer. Here again, the effect of these interactions on the performance of solar cells is not well understood. "The next step is to see how these clusters behave in a solar cell," said Dr. Van Orden. "The inter-particle fluorescence blinking behavior is only observable in the small scale. A bulk measurement would not detect this altered behavior."

Making a solar cell out of one of these clusters would allow researchers to observe the effects of clustering and blinking on photocurrent in an actual solar cell environment. The optical measurements would allow for researchers to correlate this photocurrent with blinking, something a bulk measurement couldn't do.

To make this solar cell, the collaboration intends to use the Scanning Tunneling Microscopy (STM) expertise of the van de Lagemaat group at NREL combined with the optical excitation and detection expertise of the Van Orden group. Small clusters of quantum dots will be spread out on a flat gold surface and probed with the STM and single molecule spectroscopy measurements simultaneously. The holes, or positive charge carriers, will be drawn out of the optically excited cluster by the gold substrate, and the electrons will be collected by the microscope tip. With this method, photocurrent can be collected and measured to observe the effects of blinking and quantum dot interactions on the cell's ability to generate current.

Dr. Van Orden said, "we hope this experiment will give us new insight into how quantum dots behave in a solar cell so we can improve solar cell devices."

CRSP Research Profile

Atomic Level Control Could Enhance Feasibility of Thin Film Solar PV Devices

Consider constructing a thin-film material in a manner like building a brick wall except the bricks are atoms or molecules and the final thickness is determined at angstrom-level accuracy. That's atomic layer deposition (ALD) and scientists at the University of Colorado at Boulder (CU) with CRSP funding are investigating how to use this technique under conditions that are cost competitive with less effective alternatives such as chemical vapor deposition.

Dr. Steve George and his research group at CU have been at the forefront of developing ALD methods and systems for a number of years. Currently, they are conducting research on how to best use ALD to create flexible, thin and protective inorganic films that provide gas diffusion barriers on thin film photovoltaic cells like CIGS, DSC and OPV. These PV cells are typically built on a polymer substrate that maintains flexibility but allows gases like water vapor and oxygen to permeate the cell over time – resulting in corrosion with reduced efficiency and lifetime of the cell.

The key metric for gas diffusion barriers is the gas transmission rate from atmosphere into the cell material. ALD techniques are being developed in order to build an appropriately thin protective film that meets transmission rate limits. For water vapor transmission rates, that limit is $\leq 1 \times 10^{-6}$ g/m²/day. This may seem like a high standard for a material to meet but is critical when

considering that solar PV devices must exhibit a lifetime of a decade to multiple decades to be cost competitive.

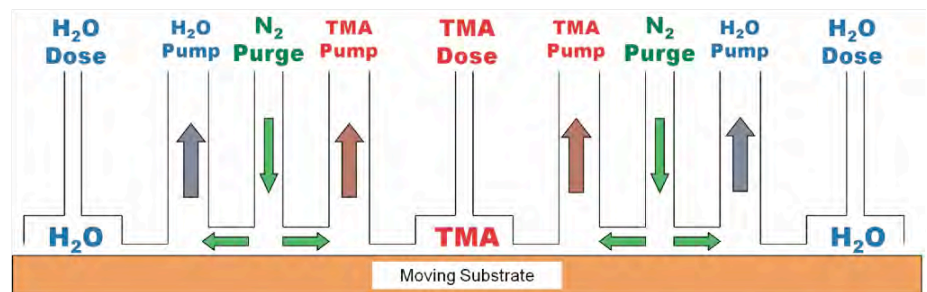
Oxides and nitrides, such as Al₂O₃ and SiN_x, are the molecular materials of choice for ALD protective films and are formed at the film surface. ALD techniques deliver the precursors to these inorganic materials (e.g., trimethyl aluminum (TMA) and water to form Al₂O₃) sequentially to control molecular level morphology of the film, avoiding gas phase reactions. Slow ALD processes using chambers have been the traditional approach to deposit layers of the inorganic molecules to their desired thickness and conformation. For ALD to be commercially relevant with solar PV cells, a new process needs to be developed and refined.

Dr. George and two researchers in his group, Dr. Ryan Fitzpatrick and Zachary Gibbs, are conducting experiments on atmospheric ALD methods as a viable approach to applying the protective film during commercial roll-to-roll continuous manufacturing of thin film solar PV cells. Atmospheric ALD is chamberless with the small gap between the chamber and gas head acting as the chamber environment. Various research groups around the globe are working on atmospheric ALD designs including gas source

head with reactant slits, gas bearings, rotating sample cylinder, and moving through spatially separated reactants. The George group chose a gas source head approach and then tested key design variables including gap between the head and substrate, precursor gas flow rates, and the pressure between gas channels in the head.

Research results to-date have generated a model for determining the optimal pressure beneath the gas head for consistent film properties and identified challenges around control of gap spacing. A spacing of 30 μ m was determined to be outside the mechanical tolerances of the system, so a 100 μ m gap was used for the atmospheric ALD experiments. Exhaust channel speeds were found to be central to isolating the precursors, although the group was unable to reproducibly produce consistent films. The next step will be to refine their design, e.g., greater spacing between the channels or a hybrid gas source head with gas bearings.

“If we solve the system design parameters to produce consistent protective films with atmospheric continuous ALD, then the resulting longer lifetime of low cost thin film PV devices will enhance the role of solar power in the world's energy mix,” said Dr. George.



Cross-section view of channels in model gas source coating head

CRSP Member Company Profile

Abengoa Solar Developing CSP & CPV Technologies

Abengoa Solar develops and applies technologies to generate electricity from the sun. Through their solar technologies, the company works to limit climate change and develop local communities using mostly concentrating solar thermal, but also photovoltaic technologies.

For twenty years, Abengoa Solar has been committed to both concentrating solar power (CSP) and concentrating photovoltaic (CPV) technology development. Through this commitment, the company has reinforced its strategic position in the solar industry and holds a portfolio of over 3 gigawatts of solar power as of the end of the 2010 fiscal year.

In addition to their current technologies in the area of CSP (using parabolic trough and tower technology), Abengoa Solar has

added CPV technology to its successful portfolio and now offers supply modules and complete systems to its customers and has more than 1 megawatt of CPV solar power (using III-V cell technology) in operation.

Abengoa Solar has designed and commercialized a new CPV technology to maximize collection of the solar resource, achieving concentrations of 500 to 1,000 suns. Abengoa Solar's high concentration photovoltaic (HCPV) system includes a solar tracker and concentrating module.

Currently, the company's research activities are focused on low and high concentration photovoltaic technologies. Abengoa Solar continues to work in this area to develop high efficiency modules with excellent thermal characteristics.

Abengoa Solar website:
<http://www.abengoasolar.com/>



High Concentration Photovoltaic System from Abengoa Solar

CRSP Administration

Executive Board & Management

Scientific Director: Dr. Craig Taylor, Renewable Energy MRSEC, CSM.

Co-Directors: Dr. C. Michael Elliott, CSU; Dr. David Jonas, CU; Dr. Colin Wolden, CSM.

Managing Director: Kaitlyn VanSant, NREL

Senior Scientific Advisor: Dr. Arthur Nozik, NREL

Senior Advisor: Paul Nelson

Company Advisory Panel

The panel includes one representative from each member company, who play a key role in identifying shared research thrust areas, selecting projects for funding, and in other functions of CRSP.

Scientific Advisory Board

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

For more information

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