QESST

newsletter ▪ winter 2015, volume 2

Quantum Energy and Sustainable Solar Technologies

AN NSF-DOE ENGINEERING RESEARCH CENTER

research highlights

UNM Pioneers Antimony Based Solar Cells

QESST researchers at the University of New Mexico are capitalizing on over two decades of experience at the UNM Center for High Tech Materials (CHTM) in antimonide based narrow gap compound semiconductor devices to advance solar technologies. The epitaxial laboratory at CHTM has four molecular beam epitaxy reactors dedicated to the technology, including a fully automated, state of the art, Veeco GEN 10 reactor. QESST Researcher Professor Gunny Balakrishnan has been working towards the realization of novel high-efficiency multi-junction solar cells through the demonstration of III-Sb/Silicon and GaSb/GaAs dual junction solar cells and the development of lattice matched large area antimonide cells. The QESST research at CHTM is vertically integrated with the ability to design the solar cell devices, grow the devices, process the devices, and conduct a variety of characterization studies on the semiconductors. The effort to date has involved five graduate students and three undergraduates.

All silicon solar cells absorb the ultraviolet (UV), the visible and part of the near infrared (IR) solar spectrum. However, a sizable percentage of the IR spectrum consists of photons that have energy below the bandgap of silicon and thus are not absorbed by the solar cell. Subsequently, these photons are not converted to electricity. The ability to absorb these IR photons by creating a second narrow-bandgap sub-cell in series with the silicon solar cell could lead to substantial improvement in the efficiency of the silicon solar cell. Gallium Antimonide (GaSb), with a bandgap of 0.72 eV, grown on silicon is an excellent candidate for this application.

The effort at the UNM has been focused on the development of such a dual junction cell using a GaSb based sub-cell as the IR absorber and silicon as the visible/near-IR absorber. The effort has resulted in numerous breakthroughs, including the demonstration of high quality single domain GaSb grown on silicon and the demonstration of diodes on silicon. The key research thrust of this project is to address the high lattice mismatch between the GaSb and the silicon substrate. This is being achieved by inducing arrays of interfacial misfit dislocations between the two materials. The misfit dislocation arrays are a result of advanced epitaxial recipes that allows for the GaSb alloy to relax on the silicon substrate by periodically skipping silicon atoms.

In parallel, GaSb/GaAs base ultra-thin solar cells are also being developed. The GaSb is grown on the GaAs substrate using the same interfacial misfit array growth mode; however in this case, they also are lifting off the device from the GaAs substrate such that the substrate can be reused. The development of such a process can help realize GaSb/GaAs tandem devices with up to 28% efficiency with a thickness of ~5 µm.

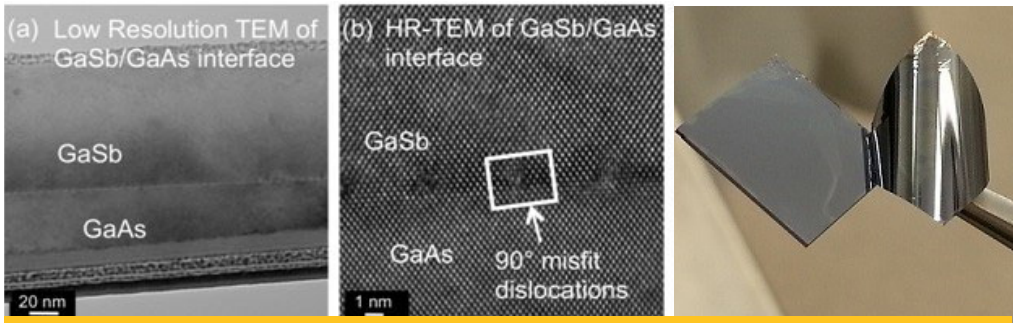


Fig. 1: High-resolution transmission electron microscopy images of GaSb on GaAs showing the presence of interfacial misfit dislocation arrays (images on the left) and complete delamination of a GaSb/GaAs solar cell from the substrate achieved by the use of lateral etch techniques (photo on right).

important dates

January 23, 2015
42nd IEEE Photovoltaics Specialists Conference Abstracts Due

February 2-6, 2015
Liberty Classroom Implementations

February 9, 2015
Building an Inclusive Environment in QESST - Workshop II

February 17, 2015
Deadline for Project Center Entries for QESST Annual Report

February 20, 2015
Liberty STEM Showcase

February 28, 2015
Night of the Open Door

February 28, 2015
STEM Saturday

March 31, 2015
QESST Annual Report due to NSF/DOE

April 6-10, 2015
MRS Spring Meeting & Exhibit, San Francisco

April 7, 2015
Deadline to Register at Residence Inn Downtown Tempe\University Hotel for Site Visit

April 18, 2015
MESA Championship Competitions, Tucson

April 25, 2015
STEM Saturday

May 4, 2015
Rehearsal Day for NSF/DOE Site Visit to QESST ERC

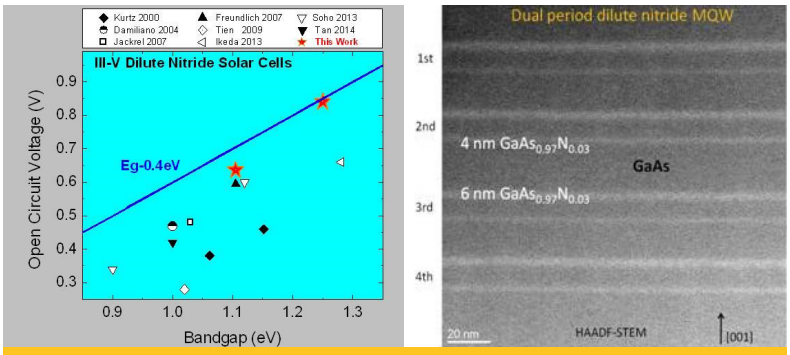
May 5-6, 2015
NSF/DOE Site Visit to QESST ERC

Quantum-Engineering for Pushing Tandem Solar Cells Conversion Efficiencies toward 50%

Tandem devices based on III-V semiconductors have shown excellent promise for boosting solar cell conversion efficiencies. In particular, the use of a bottom subcell made with dilute nitrogen alloys of these semiconductors in a 3-cells series-connected tandem configuration already has shown practical conversion efficiencies in the range of 44%.

Nevertheless, thus far access to higher efficiencies in this material system has been limited by the relatively poor voltages associated with dilute nitride solar cells. QESST researchers, lead by Dr. Alex Freundlich from the University of Houston, recently have demonstrated 1.1 eV devices with open circuit voltages that exceed the prior art by nearly 10%. To make this breakthrough possible, the team has designed a device that incorporates sets of carefully crafted ultra-thin nanostructures - resonantly coupled multi-quantum wells - of dilute nitrides. The device allows for a near ideal conversion of sunlight into electricity, and the QESST team expects that the integration of these devices in tandems would lead to devices with practical conversion efficiencies of close to 50%.

The results on the 1.1eV cell were presented at the 40th IEEE PVSC in Denver by QESST scholars Gopi Vijaya (UH) and Dinghao Tang (ASU), along with their advisors, Alex Freundlich (UH) and David Smith (ASU). This poster was awarded one of the Best Poster Presentation awards. The work has been submitted for publication.



Open circuit voltages as a function of the bandgaps for solar cells where the absorber incorporates dilute nitrogen alloys of III-V compound semiconductor (left). Red stars show record open circuit voltages obtained by the QESST researchers, while the blue line represent near ideal (Eg-0.4 eV) limit. On the right, transmission electron micrograph representing a cross sectional view of the quantum-engineered region of the device.

Jen Fuller, a QESST ERC and CSPO (Consortium for Science, Policy and Outcomes) scholar has been awarded a Graduate Education Completion Fellowship for Spring 2015 in the School of Human Evolution and Social Change (SHESC) at Arizona State University (ASU).

Completion Fellowships are awarded to support a student's degree completion of a PhD, and are made on the basis of a demonstrated ability to complete research/projects of high quality, along with the assurance that a semester of full-time effort will allow the student to complete their dissertation. Jen is expected to graduate in May 2015 with a PhD in Environmental Social Science.

Her research focuses on the connections between energy and communities in Treviso, Italy and Flagstaff, Arizona. She is particularly interested in how community solar projects promote their endeavors as changing not only technical energy systems, but also social systems in the ways that people relate to each other. Jen uses sociotechnical imaginaries theory from science and technology studies (STS) and scholarship on community electricity from Human Geography to anchor her work. She is most interested in the connections between the way that energy is imagined in the public sphere, and how that connects to both the everyday and policy implications.

QESST International Partner UNSW Reaches 40% Efficiency

Ry Crozier, UNSW Media Office

UNSW's solar researchers have converted over 40% of the sunlight hitting a solar system into electricity, the highest efficiency ever reported.

The world-beating efficiency was achieved in outdoor tests in Sydney, before being independently confirmed by the National Renewable Energy Laboratory (NREL) at their outdoor test facility in the United States.

The work was funded by the Australian Renewable Energy Agency (ARENA) and supported by the Australia–US Institute for Advanced Photovoltaics (AUSIAPV)

"This is the highest efficiency ever reported for sunlight conversion into electricity," UNSW Scientia Professor and Director of the Australian Centre for Advanced Photovoltaics (ACAP) Professor Martin Green said.

The 40% efficiency milestone is the latest in a long line of achievements by UNSW solar researchers spanning four decades - Dr. Mark Keevers.

"We used commercial solar cells, but in a new way, so these efficiency improvements are readily accessible to the solar industry," added Dr. Mark Keevers, the UNSW solar scientist who managed the project.

The 40% efficiency milestone is the latest in a long line of achievements by UNSW solar researchers spanning four decades. These include the first photovoltaic system to convert sunlight to electricity with over 20% efficiency in 1989, with the new result doubling this performance.

"The new results are based on the use of focused sunlight, and are particularly relevant to photovoltaic power towers being developed in Australia," Professor Green said.

Power towers are being developed by Australian company, RayGen Resources, which provided design and technical support for the high efficiency prototype. Another partner in the research was Spectrolab, a US–based company that provided some of the cells used in the project.

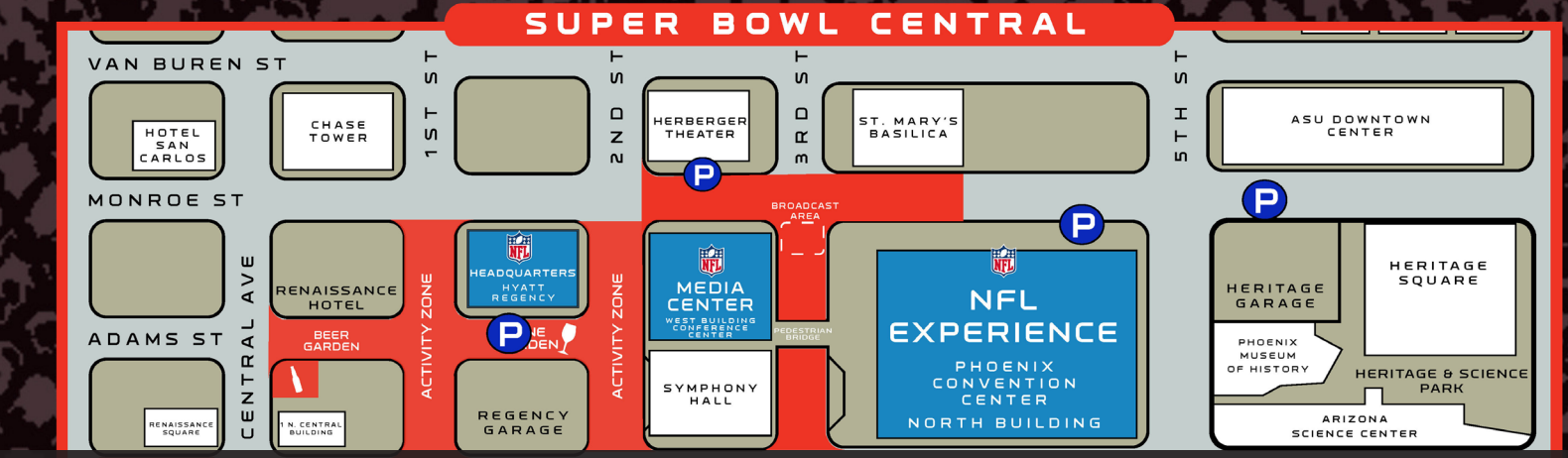
A key part of the prototype's design is the use of a custom optical bandpass filter to capture sunlight that normally is wasted by commercial solar cells on towers, and convert it to electricity at a higher efficiency than the solar cells themselves ever could.

Such filters reflect particular wavelengths of light while transmitting others.

ARENA CEO Ivor Frischknecht said the achievement is another world first for Australian research and development, and further demonstrates the value of investing in Australia's renewable energy ingenuity.

"We hope to see this home grown innovation take the next steps from prototyping to pilot scale demonstrations. Ultimately, more efficient commercial solar plants will make renewable energy cheaper, increasing its competitiveness."

The 40% efficiency achievement is outlined in a paper expected to be published soon by the Progress in Photovoltaics journal.



QESST to participate in Super Bowl Central, January 28th - February 1st

QESST will join ASU in presenting its solar energy research at the Verizon Super Bowl Central. This family-friendly event will take place on January 28 - February 1, 2015, in downtown Phoenix. The event hours are Wednesday - Saturday, noon to 10 p.m.; Sunday 10 a.m. to 3 p.m. Admission is free to the public. For more information, go to https://azsuperbowl.com/verizon-super-bowl-central-2/

QESST Presenters at the Materials Research Society (MRS) Fall 2014 Meeting and Exhibit

The Materials Research Society Fall 2014 Meeting and Exhibit was held in Boston the first week of December. Research presentations by QESST students and faculty at this important conference included:

"Surface Passivation of Inorganic Substrates by Multifunctional Polymeric Interfaces" B. Reeja-Jayan, A. Ugur, M. Lizet Castillo, T. Buonassisi, K. K. Gleason

"Multifunctional Materials via Photolithographic Olefin Metathesis Polymerization" R. A Weitekamp, R. H. Grubbs, H. A. Atwater

"2π Phase Shifts in Double Layer Graphene Nanoresonators" M. C. Sherrott, V. W. Brar, P. W. Hon, L. A. Sweatlock, H. A. Atwater

"Gate-Tunable Conducting Oxide Plasmonic Lightwave Circuits: Modulators and Multistate Logic in Guided Wave Networks" H. W. Lee, G. Papadakis, A. Kriesch, S. Burgos, K. Chander, U. Peschel, H. A. Atwater

"Graphene Plasmon-Modulated Infrared Radiation via Emissivity Control" V. W. Brar, M. C. Sherrott, L. A. Sweatlock, M. S. Jang, L. Kim, M. Choi, H. A. Atwater

"Room Temperature GaN Film Growth by UV Surface Plasmon-Mediated N2H4 Decomposition" S. Peng, M. T. Sheldon, H. A. Atwater

"Quantum Interference and Path Entanglement of Surface Plasmons" J. S. Fakonas, A. Mitskovets, H. A. Atwater

"Broadband Negative Refraction Due to Discrete Plasmon Diffraction" A. Kriesch, H. W. Lee, D. Ploss, S. P. Burgos, H. A. Atwater, U. Peschel

"Field Effect-Induced Transition from Elliptical to Hyperbolic Dispersion in Metamaterials" G. T. Papadakis, H. W. Lee, H. A. Atwater

"Systematic Determination of the Efficiency Limiting Factors to Accelerate the Development of Photovoltaic Materials" N. M. Mangan, R. E. Brandt, V. Steinmann, R. Jaramillo, J. R. Poindexter, K. Hartman, C. Yang, R. G. Gordon, T. Buonassisi

"Minority Carrier Lifetime Measurements on SnS Thin Film" R. Jaramillo, M. J. Sher, B. Ofori-Okai, S. Teo, J. Poindexter, A. Polizzotti, V. Steinmann, K. Hartman, K. Nelson, A. Lindenberg, T. Buonassisi

"A 3.88% Efficient Tin Sulfide Solar Cell - A Loss Analysis and Optimization Steps to Approach the 10% Efficiency Hurdle" V. Steinmann, R. Jaramillo, R. Chakraborty, K. Hartman, R. E. Brandt, C. Yang, J. Hofstetter, N. Mangan, J. R. Poindexter, A. Polizzotti, R. G. Gordon, T. Buonassisi

"Two-Step Annealing of SnS Thin Films for Controlled Morphology and Carrier Concentration" K. Hartman, R. Jaramillo, V. Steinmann, R. Chakraborty, A. Polizzotti, J. Hofstetter, J. Poindexter, C. Yang, R. G. Gordon, T. Buonassisi

"Separating the Contributions of Bulk and Interface Recombination in Thin-Film Photovoltaics" R. Brandt, N. M. Mangan, J. V. Li, R. Jaramillo, V. Steinmann, S. C. Siah, J. Poindexter, T. Buonassisi

"Plasma-Assisted Molecular Beam Epitaxial Growth of Cu2O Layers for Photovoltaics" Y. Tolstova, S. S. Wilson, H. A. Atwater

"Bottom-Cell Design Considerations for 2- and 4-Terminal Perovskite-Silicon Tandem Solar Cell" J. P. Mailoa, C. D. Bailie, M. G. Christoforo, E. T. Hoke, Z. Ren, H. Liu, Z. Liu, A. Bowring, W. Nguyen, J. Z. Lee, I. M. Peters, A. Salleo, M. D. McGehee, T. Buonassisi

"X-Ray Absorption Spectroscopy Elucidates the Impact of Structural Disorder on Electron Mobility in Amorphous Zinc-Tin-Oxide Thin Films" S. C. Siah, S. W. Lee, Y. S. Lee, J. Heo, T. Shibata, C. U. Segre, R. G. Gordon, T. Buonassisi

"The Effect of Atom Location and Residual Strain on the Optical Absorption of Silicon Hyperdoped with Gold" W. Yang, J. P. Mailoa, A. J. Akey, D. Recht, M. J. Aziz, T. Buonassisi, J. S. Williams

ASU hosted a visit from US Secretary of Energy Ernest Moniz

On December 11, 2014, ASU hosted a visit from US Secretary of Energy Ernest Moniz. QESST Executive Director, Dr. Matt Fraser, briefly discussed QESST research with Dr. Moniz during a tour of research facilities at ASU. During a poster session and reception, QESST Scholars Mike Minjares, Tim Reblitz, Apoorva Srinivasa and Travis Stowers (left to right) discussed their project - installing residential PV systems on the Navajo Nation in northern Arizona - with Secretary Moniz.

education & outreach

QESST RET Teacher Wins Teacher of the Month

Teacher of the Month winner, Joni Hood

Joni Hood teaches 7th grade at Wingate Elementary School, a Bureau of Indian Education school, in New Mexico, and has participated in the QESST Research Experience for Teachers (RET) at UNM the last two years. She uses the stipend she receives from the QESST RET program to purchase Raycatcher cars to use in her classroom from Pitsco Educational. Unfortunately, someone broke into her classroom and stole the cars; the smashed cars were found on the school playground. The QESST team at UNM worked to replace the cars, and decided to nominate Joni for the Teacher of the Month competition sponsored by Pitsco, and she won! In support of her efforts, Pitsco is sending her a new classroom set of solar cars! Congratulations Joni!

http://www.pitsco.com/Content/?art=7655

QESST at South Valley Academy

For the second year in a row, the QESST team at UNM talked up photovoltaics to the entire 6th grade class at South Valley Academy on October 22, 2014. South Valley is a Title 1 school that serves a heavily Hispanic community. Most students from South Valley will be the first in their families to attend college.

The outreach event used solar car kits to build and race vehicles to get students excited about solar energy as one part of the UNM outreach team's long-standing engagement with South Valley.

QESST Outreach Coordinator, Stefi Weisburd, is one of South Valley's mentors in the Big Brother Big Sister Mentor 2.0 program. This program has "adopted" the entire ninth grade class from last year with a 4-year commitment to mentor them all the way into college. UNM also puts on a Family Engineering Night at South Valley Academy every spring in collaboration with their head science teacher, as well as hosting South Valley Academy teachers in RET programs, one of whom is working with QESST faculty on solar energy. There also are currently six South Valley high school students enrolled in UNM research internship program and camps.

QESST Participates in Houston Energy Day

The Houston Energy Day on October 18, 2014, attracted over 15,000 people, including students, educators, families and business leaders. QESST team members from University of Houston were one of the more than 70 interactive demonstrations and exhibits teaching students and their families about solar energy technology.

QESST Installs Solar PV System in Monument Valley

On November 1, 2014, QESST Scholars and faculty completed the first phase of a solar PV system on a residence in the Monument Valley Navajo Tribal Park. The residence has no connectivity to grid electricity and thus has few options for electricity. The installed system ultimately will provide lighting in each room, as well as powering small appliances, including a television and a coffee maker. The goal of this ongoing project is to educate the community about how solar energy works and its benefits to the community.

Wingate Elementary School 7th graders show their enthusiasm while learning about their solar cars.

UH-QESST Scholars demonstrate how solar energy impacts everyday life

QESST Scholars and faculty install solar PV system in Monument Valley, Navajo Tribal Park

industrial engagement

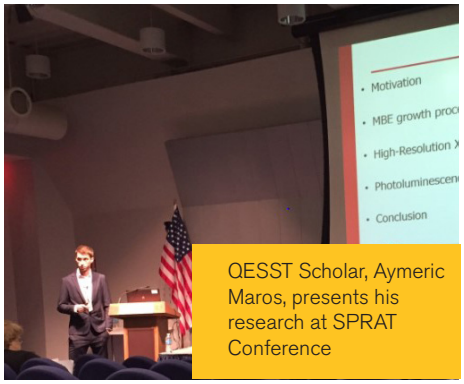
Industry and Innovation Program

During the fourth quarter of 2014, two QESST Scholars, Eva Pettinato and Aymeric Maros, along with QESST Industry Member CFD Research Corporation, presented at the NASA Space Photovoltaic Research and Technology (SPRAT) Conference.

A project recently started at Arizona State University in collaboration with several partners, including the Jet Propulsion Lab, was presented by the two scholars. The project aims at designing and developing a 10 × 10 × 5cm picosatellite with a mass of 0.5 kg to explore the surface of the potentially hazardous asteroid, Apophis. This student-based project was initiated by the School of Space and Earth Exploration at ASU, and is being conducted in a 2-semester class format. Each team of students is responsible for the choice of the mission, which should address either a science or engineering problem, as well as the design, development and testing of the spacecraft. The first semester was dedicated to the design of the picosatellite, while the second semester will consist of building a first prototype. These miniature versions of conventional satellites have recently shown a lot of interest from the space community for several reasons, the one and the foremost being reduced launch costs.

In addition, Aymeric also presented his recent results on InGaAs and GaAsSb grown on GaAs with low lattice-mismatch to study the formation of crystalline defects and their affect on physical properties of the materials. The ultimate goal of his project is to grow dilute nitrides alloys (InGaAsN and GaAsSbN with N < 3%) lattice-matched to GaAs with a band gap of 1 eV for use in multi-junction solar cells targeted for space applications.

The QESST team and CFD Research Corporation are now pursuing funding for this research.



QESST Scholar, Aymeric Maros, presents his research at SPRAT Conference

Collaborations Aim to Boost Solar Technology

Dr. Mariana Bertoni, QESST Thrust 1 Co-Lead, and Dr. Stuart Bowden, QESST Testbed 1 Lead, will have roles partnering with industry as part of an effort by the U.S. Department of Energy to aid photovoltaic manufacturing and supply-chain companies in advancing their technologies. Their projects aim to develop technology that will reduce costs and increase efficiency.

Dr. Bertoni will identify the most detrimental defects present in the new crystals grown by SolarWorld and analyze the impact of the crystals on the performance of solar cells. The results will help SolarWorld optimize growth conditions to minimize as-grown defects and maximize the power-conversion efficiency of the final solar cells.

Dr. Bowden will work with Technic Inc. to eliminate the use of silver in the manufacturing of solar energy cells, and replace it with copper, a more abundant and less costly material. The goal is to develop a copper-plating technique that will reduce the cost of making solar cells without a decrease in performance quality.

For more information, please go to https://asunews.asu.edu/20150113-bertoni-bowden-solar-research%20?j=36964&e

out and about

Valentina Prado, a QESST Scholar, presented her research and chaired a session at the American Center for Life Cycle Assessment XIV Conference in San Francisco, California, October 6-8, 2014.

Dr. Jeff Cotter, QESST University Education Director, visited with faculty and students at the Massachusetts Institute of Technology, one of QESST's partner universities, on October 14-16, 2014, to discuss ongoing development and communication of QESST university education programs.

QESST Scholar, Dwarak Triplican, visited the First Solar Recycling Plant in Rossford, Ohio on October 16, 2014, to learn more about their operation and how it relates to his doctoral work.

Dr. Christiana Honsberg, QESST ERC Director, and John Mitchell, QESST Industrial Liaison Officer, participated in the Solar Power International Conference in Las Vegas, Nevada on October 20-23, 2014.

Dr. Christiana Honsberg (QESST ERC Director), Dr. Matt Fraser (QESST Executive Director), Dr. Zak Holman (QESST Thrust 2 Co-Lead), Dr. Harry Atwater (QESST Deputy Director), Dr. Alex Freundlich (QESST Thrust 3 Co-Lead), and QESST Scholar, Aymeric Maros, participated in the 6th World Conference on Photovoltaic Energy Conversion (WCPEC-6) in Kyoto, Japan, November 23-27, 2014, as plenary speakers and session/poster presenters.

Dr. Matt Fraser participated in the Renewable Energy World North America Conference in Orlando, Florida on December 8-9, 2014.

Upcoming Solar Energy Research Experiences:

for undergraduates
program dates: May 1 - August 7, 2015
application deadline: March 15, 2015

for teachers
program dates: June 1 - July 3, 2015
application deadline: March 15, 2015

For more information, please go to http://qesst.asu.edu/education-and-outreach

all QESST vidyo conference dates

February 2, 2015
Testbed 1 Presentations, Announcement of New Student Design Contest

February 16, 2015
Testbeds 2 and 3 Presentations

March 2, 2015
Discussion of QESST Year 4 Annual Report and Deadlines

March 16, 2015
Sustainability Presentations

April 6, 2015
Discussion of NSF/DOE Site Visit and Deadlines

April 20, 2015
Student Presentations and Semester Wrap-up

recent publications

Below are new publications representing a selection of journal publications by QESST Scholars and faculty, that illustrate the range and depth of research conducted at QESST. A more extensive publication list can be found on our website at qesst.asu.edu. We encourage all QESST participants to submit recent publications through the Project Center at www.qesst.net.

Lee, J.; Honsberg, C. B. "Limiting Efficiencies of Multijunction Solar Cells with Multiple Exciton Generation" IEEE Journal of Photovoltaics, 4, 3: 874-880, doi: 10.1109/JPHOTOV.2014.2307156

Marconi, M.; Monserud, N.; Malm, E.; Wachulak, P.; Huiwen, X.; Balakrishnan, G.; Chao, W.; Anderson, E. "Extreme Ultraviolet Fourier Holography of Nano-scale Objects" Bulletin of the American Physical Society, 59(1)

Miller, C. A.; Richter, J.; O'Leary, J. "Socio-energy Systems Design: A Policy Framework for Energy Transitions" Energy Research & Social Science, 6: 29-40, doi:10.1016/j.erss.2014.11.004

Russo, J. M.; Vorndran, S.; Wu, Y.; Kostuk, R. K.; "Cross-correlation Analysis of Dispersive Spectrum Splitting Techniques for Photovoltaic Systems" SPIE Journal of Photonics for Energy, 5(1): 054599, doi: 10.1117/1.JPE.5.054599

Wang, W.; Freundlich, A. "Design of Sub-wavelength Dielectric Antireflective Grading for Multijunction Concentrator Photovoltaics" SPIE Proceedings, 8981, doi: 10.1117/12.2040431

Building an Inclusive Environment at QESST - Workshop II

Monday, February 9, 2015
11:30 a.m. - 1:30 p.m.
ERC 189

Dr. Delia Saenz, QESST Diversity Director, will be hosting Michael Begaye, Executive Director, ASU American Indian Student Support Services (AISSS), and Annabell Bowen, Coordinator of American Indian Initiatives, Office of University Provost, who will be presenting information to QESST faculty and scholars regarding how they recruit and retain Native American students, and ways in which to engage more Native American students, especially in STEM.

For information, please contact Regina Sanborn at rsanborn@asu.edu.

partner universities

Arizona State University

Caltech

University of Delaware

Georgia Institute of Technology

University of Houston

The University of Arizona

Massachusetts Institute of Technology

The University of New Mexico

UNSW The University of New South Wales

Imperial College London

東京大学 The University of Tokyo

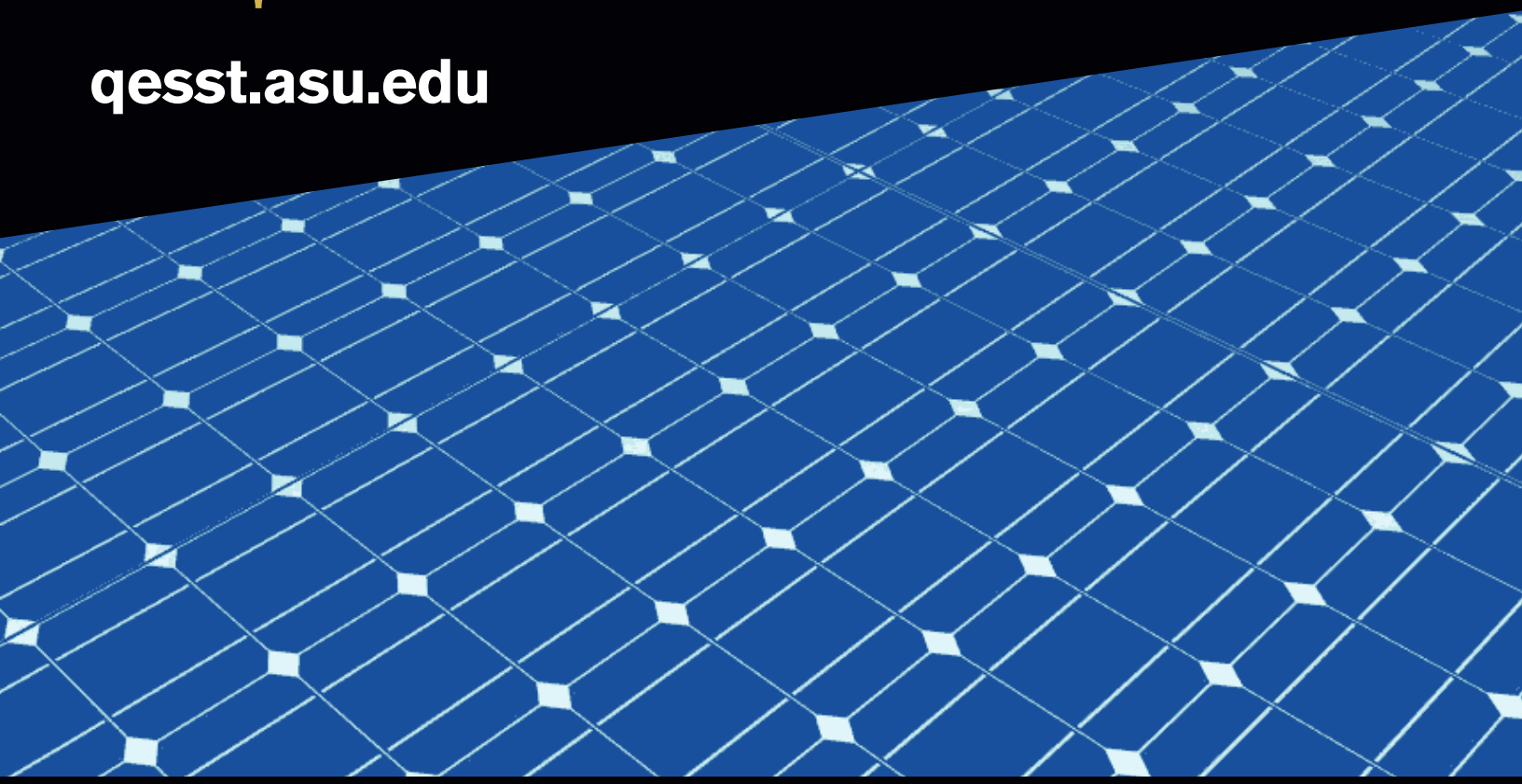
accepting the challenge

Electricity is the lifeblood of modern society, powering everything from cities to pacemakers. With demand increasing, the electricity generating system faces challenges. These include harmful environmental impacts, threats to national security, resource supply problems, difficulties in powering autonomous applications, and over a quarter of the world's population without access to electricity. These all indicate the need for a new electricity generation system. QEEST addresses these challenges by supporting a system of photovoltaic science and innovation—a system that breaks away from the waste and inefficiencies of unsustainable fossil fuels and generates power using our favorite sustainable and unlimited resource: the Sun.

QESST is an NSF/DOE Engineering Research Center funded in 2011 under cooperative agreement EEC-1041895 and headquarted at Arizona State University

U.S. DEPARTMENT OF ENERGY

qesst.asu.edu



IRA A. FULTON SCHOOLS OF engineering

ARIZONA STATE UNIVERSITY