QESST

newsletter ▪ spring 2015, volume 3

Quantum Energy and Sustainable Solar Technologies

AN NSF-DOE ENGINEERING RESEARCH CENTER

research highlights

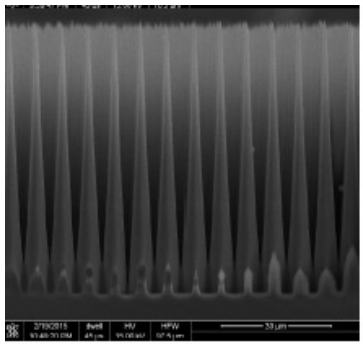
III-V and Si PV Absorbers via Epitaxy-Free Etch/Liftoff Methods

QESST researchers at Caltech have demonstrated a method for fabrication of arrays of both indium phosphide and silicon wires in which wires are defined by etching high aspect ratio structures in single crystal InP and Si wafers, respectively. The wire arrays are subsequently embedded in a polymer film and removed from their substrates by a mechanical peeling process. InP nanowires exhibit efficient light absorption and even in sparse arrays, and the process does not require epitaxial growth. This enables synthesis of many III-V solar cell absorber layers per InP wafer, and results to date indicate optoelectronically active InP wire arrays can be achieved with simple non-vacuum processing methods.

A challenge in future low-cost tandem solar cell manufacturing is to simultaneously reduce the cell cost and increase the cell efficiency. Peeled wire arrays enable the synthesis of single crystal photovoltaic active layer building blocks for tandem cells without epitaxy or consumption of an entire wafer. The epitaxy-free etch/peel fabrication approach enables synthesis, for both III-V materials and Si, of multiple highly flexible solar cell absorber layers from a single wafer, and thus has potential to dramatically lower the fabrication costs of both III-V and Si photovoltaic absorber layers in future III-V/Si tandem solar cells.

Atwater Elected to NAE

QESST Deputy Director Harry Atwater, the Howard Hughes Professor of Applied Physics and Materials Science at Caltech, was elected into the National Academy of Engineering for his contributions to plasmonics—the study of plasmons, coordinated waves of electrons on the surfaces of metals. Dr. Atwater is developing plasmonic devices for controlling light on a nanometer scale. Such devices could be important for the eventual creation of quantum computers and more efficient photovoltaic cells in solar panels.



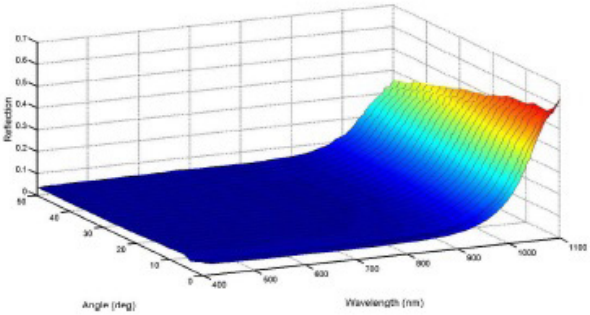


Figure: At left, very high aspect ratio tapered Si wires prior to peel off. At right, reflective vs. wavelength for etched Si microwire arrays

important dates

May 1-August 7, 2015
QESST Research Experience for Undergraduates

May 2-3 2015
QESST Scholar Retreat

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

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

June 1, 2015
QESST Year 5 Internal Research Proposals due for Consideration

June 1-July 3, 2015
QESST Research Experience for Teachers

June 14-19, 2015
42nd IEEE Photovoltaics Specialists Conference (PVSC), New Orleans, Louisiana

June 18, 2015
Due Date for Paper Submission for 2015 Fall MRS Meeting

June 19-25, 2015
2015 Hands-On PV Experience (HOPE) Workshop hosted by NREL

June 26-29, 2015
25th Annual Crystalline Silicon Workshop in Keystone, Colorado sponsored by NREL and QESST Industry Member Sinton Instruments

QESST Advances Spectrum Splitting for PV

QESST researchers have developed a novel expansion of the Gerchberg-Saxton iterative algorithm which has enabled a new design for a Diffractive Optical Element (DOE) for spectrum splitting photovoltaics (PV). Spectrum splitting is an optical technique that will enable development of novel multijunction photovoltaic systems that are not constrained with the requirement of lattice or current matching of the current generation of layered multijuction PV devices. However, spectrum splitting devices do have the requirement of high optical efficiency and rectangular spectral filtering properties at reasonable costs. A surface relief DOE has the potential to succeed in all of these areas.

A prototype DOE has been fabricated using grayscale lithography and the resulting spectral separation has been verified with a scanning spectrometer. The results for the prototype DOE for a two-cell multijunction PV system are shown below. The high optical efficiency and the nearly rectangular spectral transitions at 800 microns show tremendous promise for integration into a commercial system. The next steps for the QESST spectrum splitting team – which includes Ray Kostuk, Yuechen Wu, Juan Russo, Shelby Vorndran and Silvana Ayala Pelarez at the University of Arizona and Harry Atwater and Carissa Eisler at Caltech – is to design and fabricate candidate spectrum splitting demonstration systems to test the DOE prototype and to develop more accurate system cost and scalability estimates.

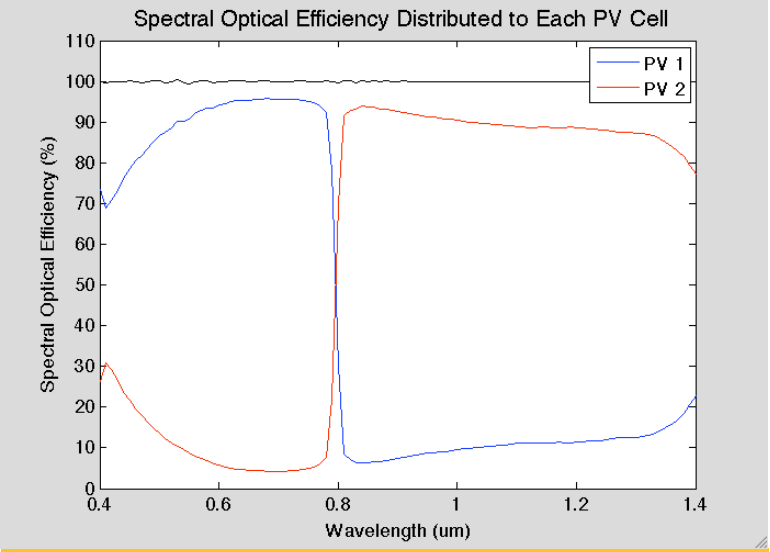


Figure: Filter function obtained with a prototype diffractive optical element developed using grayscale lithography and based on a novel expansion of the Gerchberg-Saxton iterative algorithm.

QESST Scholar wins IMAPS Conference Award

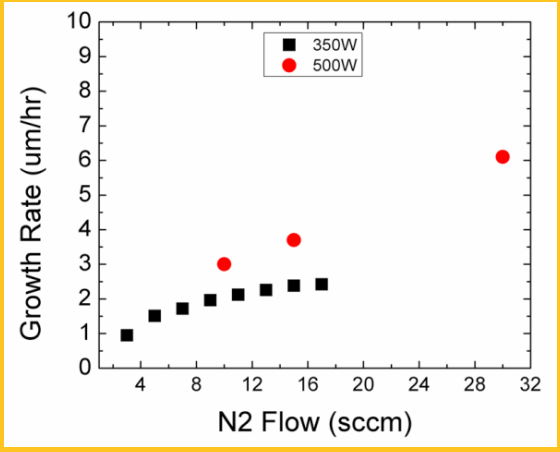
Pradyumna Muralidharan, a QESST Scholar working with Professors Dragica Vasileska, Stephen Goodnick and Stuart Bowden, won a student award in March for his presentation, "A Kinetic Monte Carlo Approach to Study Transport in Amorphous Silicon HIT Cells," at the 2015 International Microelectronics Assembly and Packaging Society (IMAPS) Conference on Device Packaging.

Gunning wins award for research on high growth rate MBE for III-nitride materials

Brendan Gunning (right) receiving his award at WOCSEMMAD 2015.

QESST Scholar Brendan Gunning (Georgia Tech) received the Most Valuable Contribution award at the oldest running compound semiconductor conference in the USA, WOCSEMMAD 2015. Brendan was presenting research sponsored by QESST that demonstrated record-high growth rates for molecular beam epitaxy (MBE) of III-Nitride semiconductors.

While indium gallium nitride (InGaN) alloys are promising candidates for full-solar-spectrum photovoltaic applications, these alloys exhibit major challenges such as the growth of thick, high-quality InGaN layers. The high growth rate demonstrated by Georgia Tech researchers will enable the growth of thick InGaN layers required for high-efficiency nitride-based solar cells. This improvement in growth technology will have great impact for the commercialization of low-cost nitride solar cells. By varying both the RF power and the N2 flow, researchers at Georgia Tech have been able to achieve growth rate ranging from 950nm/hr to ~8um/hr with excellent uniformity over a 2" wafer.



Growth rate of GaN as a function of the N2 flow for various RF power conditions.

QESST Outreach at Night of the Open Door

QESST Scholars, faculty and staff participated in ASU's annual Night of the Open Door event on February 28, 2015. The QESST activities were designed to engage students of all levels in learning about solar energy and to excite the next generation of PV engineers. Hundreds of community members stopped by to learn about QESST and the Terawatt Challenge. In the photo, QESST Scholar Apoorva Srinivasa helps teach the next generation of PV engineers about harnessing light to generate energy.

Photo credit: Jessica Hochreiter/ASU.

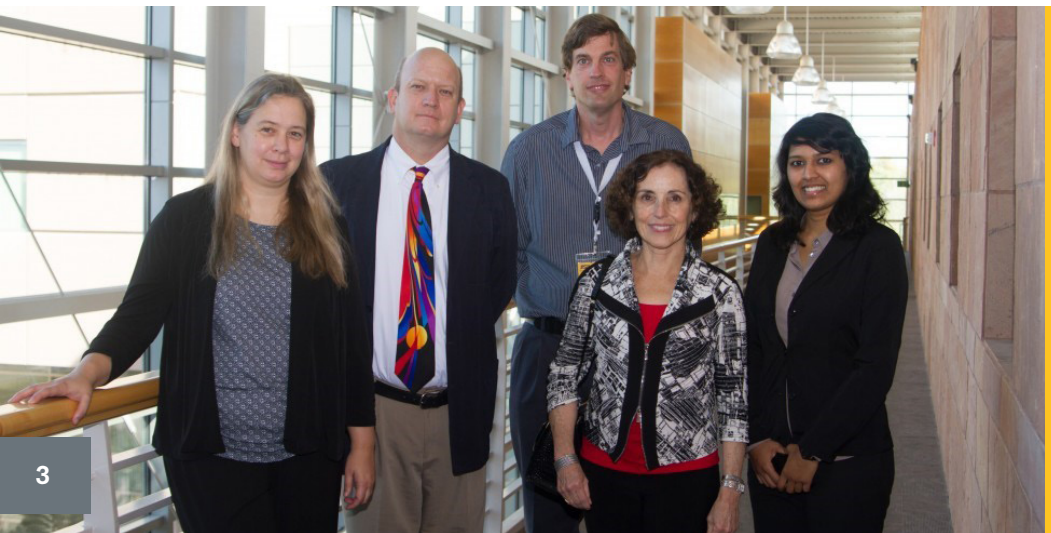
QESST Annual Report Submitted

QESST's Fourth Year Annual Report was completed and submitted to NSF in advance of the upcoming site visit. Thanks to everyone who uploaded information, wrote content and edited the document. We especially want to acknowledge the QESST staff at ASU – Regina Sanborn and Michelle Iafrat – who went above and beyond the call of duty to assemble and format the document.

The covers of the annual report this year feature Professors Mariana Bertoni and Zachary Holman working with students in their labs in recognition of their contributions to the success of QESST.

While the impacts of QESST are detailed extensively in the annual report, we'd like to report some key impact metrics here:

- QESST Scholars and faculty published 26 articles in peer-reviewed journals and 31 articles in peer-reviewed conference proceedings during the fourth reporting year (February 1, 2014-January 31, 2015).
- Across the eight campuses, 46 ongoing courses were offered with QESST-related content during Year 4.
- QESST participated in 36 different educational outreach events targeting K-12 students. Those events were attended by 4575 students and 376 teachers during Year 4.
- Over the lifetime of QESST, four start-up companies have been formed to commercialize QESST technologies.
- QESST actively engaged with 125 graduate students and 63 undergraduates during Year 4.
- In addition to the core support from NSF, DOE, industry partners and university cost-sharing, QESST research attracted over $5.6 million in funding for Associated projects during Year 4.



Dr. France Córdova, Director of the National Science Foundation, visited ASU's Solar Power Lab (SPL) on Wednesday, February 18th, and met with faculty, students and staff of the QESST Engineering Research Center. Six QESST Scholars from ASU – including Eva Pettinato, Apoorva Srinivasa, Aymeric Maros, Peter Firth, Brad West and Mike Minjares – gave "Perfect Pitch" presentations to illustrate the breadth and depth of research, education and industrial engagement efforts at QESST. QESST Director Christiana Honsberg and Executive Director Matt Fraser discussed the QESST strategic plan and engineered system vision for QESST, followed by a tour of the SPL facilities led by Process Lab Manager Bill Dauksher.

From left to right, QESST Director Christiana Honsberg, QESST Executive Director Matt Fraser, SPL Process Lab Manager Bill Dauksher, NSF Director Dr. France Córdova and QESST Scholar Apoorva Srinivasa

education & outreach

Honsberg Named Outstanding Faculty of the Year

QESST Director Christiana Honsberg was presented the Outstanding Faculty Award for 2014 by the Phoenix Section of the Institute of Electrical and Electronic Engineers (IEEE) at a banquet on February 7, 2015. The award recognized Honsberg's contributions as a university faculty member developing new courses and degree programs designed to educate students on photovoltaics technology and to advance renewable energy technologies through research on high performance photovoltaic systems.

QESST Supports MESA Day

QESST has designed and implemented a solar car challenge for Arizona's Mathematics, Engineering, Science, and Achievement (MESA) Day Competition. On March 7, 2015, QESST Scholars from Arizona State University and the University of Arizona partnered to volunteer their time at the MESA Day competition. MESA is aimed at promoting STEM education and careers among underrepresented minority, low income, and first-generation college-bound students. Through the solar car challenge, students have the opportunity to use creativity and innovation as well as engineering practices as they work together to tackle the challenge of building a solar car using recycled materials. QESST provides the necessary equipment to forty Title 1 schools around Arizona. QESST Scholars spend the day judging the car races and providing feedback to middle school and high school students.

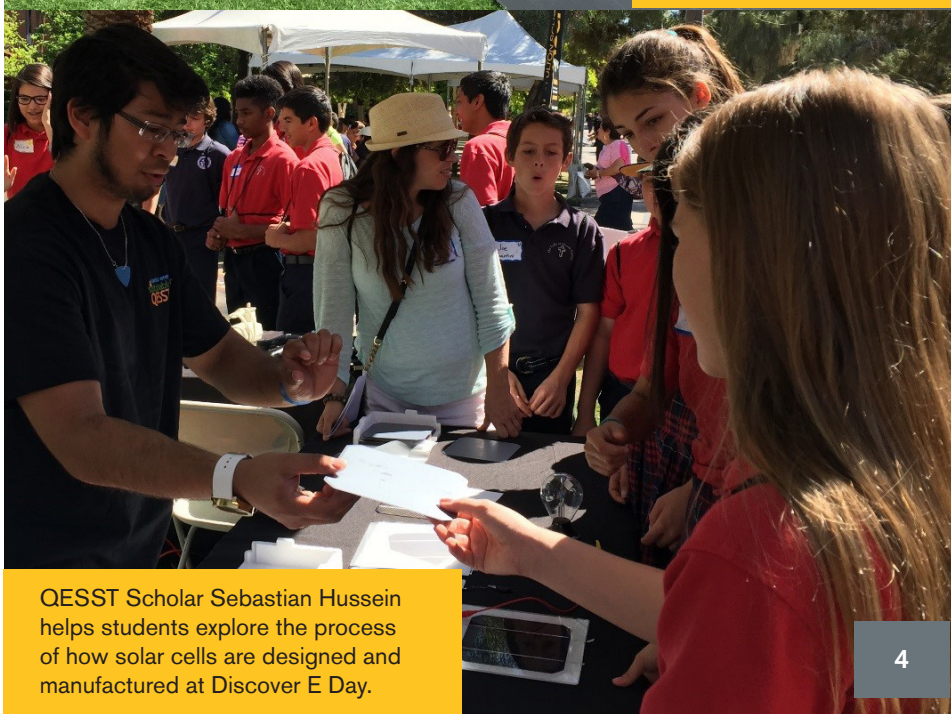
QESST Scholars Participate in Annual "Discover E Day" at Arizona State University

Approximately 1,500 students, teachers and chaperones from 3rd to 8th grade classrooms attended Discover E Day at ASU. QESST participated in the event by hosting a booth which led students through a series of interactive hands-on lessons consisting of "How to Make a Solar Cell," "How to Reduce Our Energy Consumption," and "How Solar Energy Solves Social Problems by using a Solar Water Pump." The hard work and dedication of our volunteers helped teach the students and teachers that science and engineering can be fun and exciting.

Professor Honsberg uses a hands-on display to illustrate photovoltaics.

Photo credit: Jessica Hochreiter/ASU.

U of A QESST Scholar Shelby Vorndran assists a student prior to the start of the race at the MESA day competition.



QESST Scholar Sebastian Hussein helps students explore the process of how solar cells are designed and manufactured at Discover E Day.

University Education - A Global Perspective

Steve Limpert

Steve Limpert is a QESST Scholar pursuing his PhD on hot carrier solar cells at the University of New South Wales, in Sydney, Australia. Steve won a Fulbright scholarship, which provides financial support for his studies abroad, and was interviewed by the QESST University Education Director Jeff Cotter.

Jeff: UNSW has a very impressive PV research team and research facilities. What's it like to study and work in and around some of the "giants of PV"?

Steve: It's very inspiring. Knowing that the research done at UNSW has a substantial global impact motivates me to bring my best to the table every day.

Jeff: Have you been able to develop any new research collaborations and/or build your network of colleagues and friends while at UNSW?

Steve: Yes, I have. I've met many people here at UNSW who are working on interesting photovoltaic projects in areas like photoluminescence, perovskites, back contacting, high efficiency silicon cells, and III-V material growth, characterization and device development to name a few. The community of people at UNSW is really great. It has been a pleasure to be a part of it at both work and outside of it. As a major research university, UNSW often hosts visiting researchers from other universities around the world. One particularly fruitful collaboration that I've been a part of was initiated when I met a professor from Lund University after he gave a seminar on thermoelectrics in the physics department.

Jeff: Give us the 'elevator pitch' for your own research project. What's the coolest or most interesting thing you've learned while working on your project?

Steve: Recently, I got a chance to visit Lund University and investigate single nanowire III-V optoelectronic devices there. Working on this project gave me a chance to learn about nano-device fabrication and characterization techniques, and to learn about the unique light absorption and electron transport properties of nanowires. As single nanowires are commonly gated to control conductance, it also served as an opportunity for me to combine content about MOSFETS that I'd learned during my coursework at ASU with content about solar cells that I'd learned during my research with QESST. In the end, the devices showed very unique photodetection characteristics that have prompted me to learn more about how currently used photodetectors work and to investigate what would be substantial contributions to this field.

Jeff: Was it difficult to win your Fulbright scholarship? What tips would you give to other prospective students who wanted to apply for a Fulbright, or other, scholarship?

Steve: The process for applying for the Fulbright scholarship was lengthy, but I would not say difficult. It consisted of preparing a personal statement, a research proposal, gathering letters of recommendation and a letter of affiliation from the host institution, filling out forms and going through an internal interview process at ASU before being approved to submit nationally. ASU provides a wealth of resources for students who want to apply for scholarships like the Fulbright. I would say that if you want to apply for a scholarship like the Fulbright, the first step it to develop a detailed plan of where you want to go and why. Being able to make a strong case for why you should be given the money to do your project is key to a successful application, I think. And remember, it's not only people in the US that will be reading and judging your application, but also people in your intended host country. It seems that the success of my application stemmed from, in part, its resonance with the Australian reviewers, who related to my story of observing the environmental degradation caused by the coal mining in northeastern Pennsylvania.

Jeff: Did you get any help from QESST/ASU faculty when preparing your scholarship application?

Steve: Yes, Professors Stuart Bowden and Stephen Goodnick provided me letters of recommendation for my Fulbright scholarship application. Additionally, my research proposal was based on work that I had begun as part of the FURI program working with Professors Bowden and Goodnick.

Jeff: What do you do for fun in Sydney when you're not working on your PhD project?

Steve: Get outside mainly. Sydney has tons of great beaches and is surrounded by state and national parks perfect for hiking or camping. Besides that, there's a wealth of cultural options in the city. I'm a big music fan, so I've enjoyed visiting some of Sydney's jazz clubs and taking in shows at the Opera House.

Jeff: Last question: What's a Vegemite sandwich and what the heck does 'chunder' mean?

Steve: Well, a Vegemite sandwich is a thin layer of brown yeast paste spread on a piece of bread perhaps with a slice of cheese on top - not exactly my cup of tea, but definitely a cultural experience. You've got me on 'chunder.' I'm going to have to look that one up.

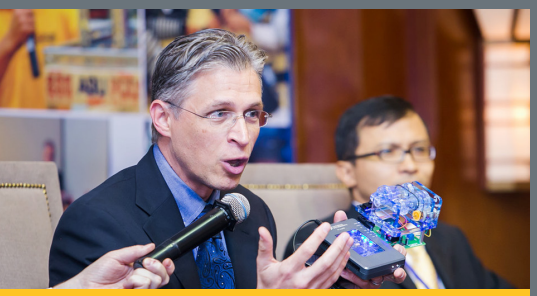
Steve can be reached at steven.limpert@gmail.com. QESST students interested in applying for travel-related scholarships can contact Jeff Cotter (jecotter@asu.edu) or Jenefer Husman (jenefer.husman@asu.edu) for help and guidance.

Steve Limpert enjoying a bit of fun in the sun

industrial engagement

Industry and Innovation Program

During the first quarter of 2015, QESST participated in and presented at the Vietnam Engineering Education Conference, along with QESST Industry Member National Instruments in Da Nang, Vietnam.



Dave Wilson, Academic Program Director, National Instruments

ASU hosted the event along with Intel, National Instruments, Mekong Technologies and Pearson. The event brought together industry, government and academe to discuss transformative ideas and solutions to engineering and technical education programs in Vietnam. The theme was "Engineering Education as a Catalyst for Innovation and Entrepreneurship in Vietnam." A few of the topics included:

- How the Maker Movement can transform STEM and Higher Engineering Education
- Inspiring the undergraduate engineer's entrepreneurial and innovative mindset
- Academic-Government-Industry Partnerships: A Toolkit for Development – This presentation **featured the QESST ERC as an example model**
- Building Bi-Lateral Technology and Economic Development Partnerships – **presented by NSF Program Director, Dr. Sonia Ortega**

QESST's presentation and presence at the event helped create interest from the USAID Mission Director, Joakin Parker. QESST Industrial Liaison Officer John Mitchell is pursuing potential collaborations as a follow-up to this meeting. If you have interest, please contact John Mitchell at john.j.mitchell@asu.edu, or call John at 480-727-2048.

NSF Program Director, Dr. Sonia Ortega (left) and University Dean and Vice President, Entrepreneurship and Innovation, Arizona State University, Dr. Mitzi Montoya (right)

recent publications

Below are a selection of recent publications from QESST Scholars and faculty illustrating the breadth and depth of QESST research activities.

J. Byrne, J. Taminiau, L. Kurdgelashgvili, K. N. Kim "A Review of the Solar City Concept and Methods to Assess Rooftop Solar Electric Potential, with an Illustrative Application to the City of Seoul" Renewable & Sustainable Energy Reviews, Vol, 41, pp: 830-844, 2015.

C. Fabien, W. A. Doolittle "Guidelines and limitations for the design of high-efficiency InGaN single-junction solar cells" Solar Energy Materials and Solar Cells, doi: 10.1016/j.solmat.2014.07.018, 2014.

B. P. Gunning, C. A. M. Fabien, J. J. Merola, E. A. Clinton, W. A. Doolittle, S. Wang, A. M. Fischer, F. A. Ponce "Comprehensive study of electronic and optical of highly degenerate p-type Mg-doped GaN and AlGaN" Journal of Applied Physics vol. 117, doi: 10.1063/1.4906464, 2015.

J. Hofstetter, D. Fenning, D. Powell, A. Morishige, H. Wagner, T. Buonassisi "Sorting Metrics for Customized Phosphorus Diffusion Gettering" IEEE J. of Photovoltaics, Vol. 4, No. 6, 2014.

M. Kivambe, D. Powell, S. Castellanos, M. Jensen, A. Morishige, K. Nakajima, K. Morishita, R. Murai, T. Buonassisi "Minority-carrier lifetime and defect content of n-type silicon grown by the noncontact crucible method" Journal of Crystal Growth, v 407, p 31-36, 2014.

C. A. Miller, C. Altamirano-Allende, N. Johnson, M. Agyemang "The Social Value of Mid-Scale Energy in Africa: Redefining Value and Redesigning Energy to Reduce Poverty" Energy Research and Social Science, doi: 10.1016/j.erss.2014.12.013, 2015.

K. Nelson, J. Husman "Student approaches to learning in a foundational engineering course: A motivational and self-regulated learning profiles perspective" Journal of Engineering Education, doi: 10.1002/jee.20066, 2014.

O. S. Romero, A. A. Aragon, N. Rahimi, D. Shima, S. Addamane, T. J. Rotter, S. D. Mukherjee, L. R. Dawson, L. F. Lester, and G. Balakrishnan "Transmission Electron Microscopy-Based Analysis of Electrically Conductive Surface Defects in Large Area GaSb Homoepitaxial Diodes Grown Using Molecular Beam Epitaxy" Journal of Electronic Materials, doi: 10.1007/s11664-014-3070-0, 2014.

J. Russo, D. Zhang, M. Gordon, S. Vorndran, Y. Wu, R. K. Kostuk "Spectrum Splitting Metrics and Effect of Filter Characteristics on Photovoltaic System Performance" Opt. Express, vol. 22, A528-A541, 2014.

B. Wender, R. Foley, V. Prado-Lopez, D. Eisenberg, D. Ravikumar, T. Hottle, J. Sadowski, W. Flanagan, A. Fisher, L. Laurin, T. P. Seager, M. P. Fraser, D. H. Guston "Illustrating anticipatory life cycle assessment for emerging photovoltaic technologies" Environ. Sci. Tech. vol. 48, 10010-10018, doi: 10.1021/es502542a, 2014.

J. Williams, T. Williamson, M. Hoffbauer, Y. Wei, N. Faleev, C. Honsberg "Growth of high crystal quality InN by ENABLE-MBE" Physica Status Solidi (c), doi: 10.1002/pssc.201300693, 2014.

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

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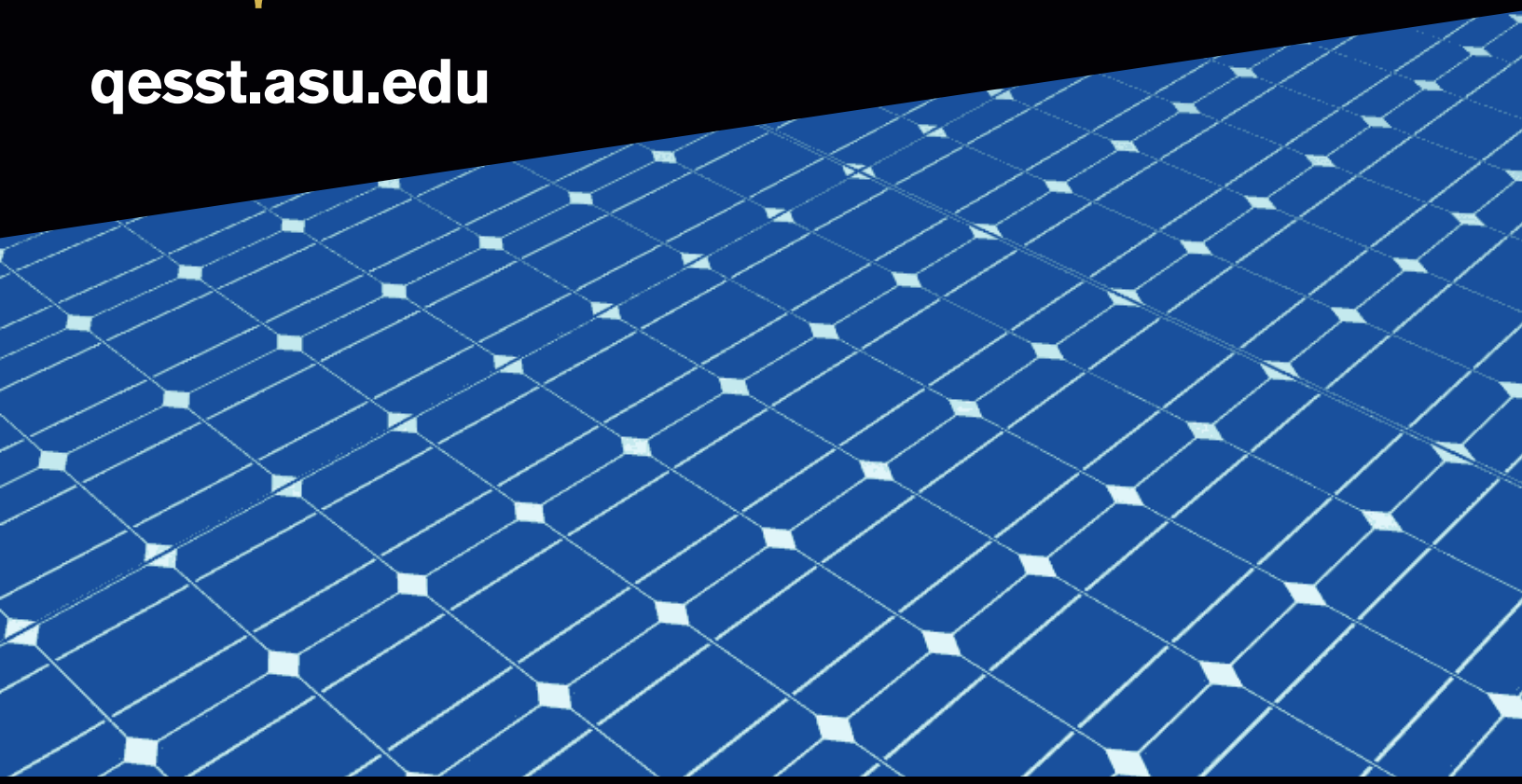

IRA A. FULTON SCHOOLS OF engineering

ARIZONA STATE UNIVERSITY