QESST

newsletter ▪ fall 2015, volume 5

Quantum Energy and Sustainable Solar Technologies

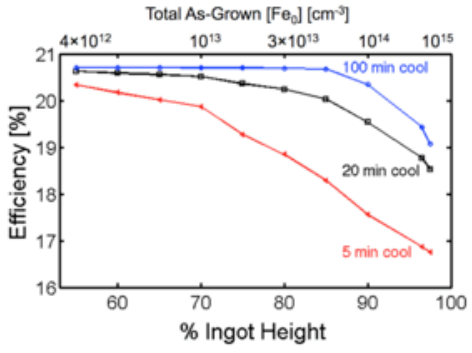
AN NSF-DOE ENGINEERING RESEARCH CENTER

research highlights

Simulating Trace Metal Impurity Engineering for Crystalline Silicon Photovoltaics

Ashley Morishige, a QESST Scholar at MIT, has developed new simulations of trace metal impurity evolution during crystalline silicon solar cell processing. Morishige collaborated with colleagues at Synopsys, Inc. to couple numerical process and device simulations in state-of-the-art Sentaurus TCAD software. The tool enables the development of optimal cell processing that is tailored to the quality of the Si wafer. This approach also accounts for the detrimental electrical effect of impurities in both the atomic point defect form as well as in clustered precipitates, which are common in wafers made from lower cost feedstocks. The results of Ashley's work show that cooling more slowly after phosphorus diffusion can significantly increase final solar cell efficiency even for highly impure Si wafers (Figure 1). The code they developed is available freely online at http://pv.mit.edu/impurity-to-efficiency-i2e-simulator-for-sentaurus-tcad/.

Morishige also collaborated with colleagues at Aalto University, Fraunhofer ISE, and the Instituto de Energía Solar to review existing crystalline silicon solar cell processing models. The in-depth review enables scientists and engineers to choose an appropriate level of model complexity based on wafer type and quality, process conditions, and available computation time. Additionally, their analysis provides new physical intuition that informs development of process simulation tools, improved silicon materials, and solar cell processes. Figure 2 shows post-gettering interstitial iron concentration as a function of initial total iron concentration predicted by the different models.



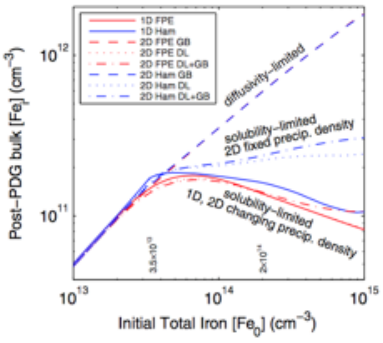


Figure 1 (left): Impact of cooling rate on final solar cell efficiency from A.E. Morishige, et al. "Combined impact of heterogeneous lifetime and gettering on solar cell performance," Energy Procedia 77 pp. 119-128 (2015). Figure 2 (right): Simulated final interstitial iron concentration as predicted by different modeling approaches from A.E. Morishige, et al. "Building intuition of iron evolution during solar cell processing through analysis of different process models," Appl. Phys. A 120 pp. 1357-1373 (2015).

important dates

All QESST Vidyo Conferences
November 2nd
November 16th
December 7th
January 4th
February 1st
February 15th
March 21st
April 4th
April 18th

Industrial Advisory Board Meeting
October 22, 2015
ASU Tempe Campus

30th Anniversary of ERC Program Event
October 28, 2015
Washington, DC

ASU Homecoming
November 14, 2015
ASU Tempe Campus

Deadline to Enter Information into Project Center
February 16, 2016
qesst.net

Night of the Open Door
February 27, 2016
ASU Tempe Campus

Annual Report Due to NSF
March 28, 2016

MRS Spring Meeting
March 28 - April 1, 2016
Phoenix, Arizona

QESST Focuses on CIGS Thin Film Processing

$CuInSe_2$-based materials have achieved the highest efficiency of any thin film PV cell due to their high optical absorption, tunable electronic properties, and ease-of-manufacturing. Further, their tunable properties mean that they can be used in advanced high efficiency devices such as tandem cells which are predicted to produce efficiencies exceeding 25%.

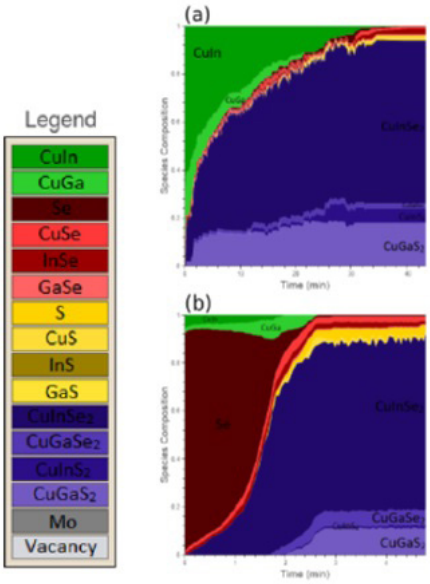


Figure caption: time evolution of molecular composition for (a) the simultaneous Se and S reaction and (b) the selenium-capped reaction in CIGS growth. From Lovelett et al. "A stochastic model for Cu(InGa)(SeS)2 Absorber Growth During Selenization/ Sulfization" Proc. IEEE Photovoltaic Specialists Conference (2015).

In particular, one of the advantages of $CuInSe_2$-based materials is the capability to adjust its properties through the depth of the films by alloying with other elements including gallium and sulfur. Most of the high efficiency solar cells made with $CuInSe_2$-based materials optimize the composition depth profiles to improve performance but there is a limited understanding of how to control the depth profile of composition of the alloys, especially when using selenization reactions.

QESST Scholar Robert Lovelett and others at the Institute of Energy Conversion of the University of Delaware developed a new model to simulate $CuInGaSe_2$ (CIGS) growth during the selenization process. The model is designed to predict the composition profile of the film and to help researchers understand the forces that control this profile, such as reaction rates (how fast the film is converted to a final product) and diffusion coefficients (how fast the materials tends to intermix). The model is "stochastic", which means that it is based on probabilities instead of fixed, deterministic equations.

QESST researchers have shown that the model is able to predict some prominent features seen in selenized $Cu(In,Ga)Se_2$, such as the accumulation of gallium near the back of the film and the improved intermixing that occurs with a sulfur treatment. The next steps are to use the model to get better estimates of physical properties, which will aid in designing a process that produces higher efficiency solar cells, and to study how this model can be applied to other reaction systems, such as in the multi-source evaporation method to produce $Cu(In,Ga)Se_2$.

Ganesh Wins 2015 NAMBE Young Investigator Award

The North American Molecular Beam Epitaxy Advisory Board selected Professor Ganesh Balakrishnan to be the recipient of the 2015 NAMBE Young Investigator Award. The award is "for contributions towards the growth and characterization of lattice matched and mismatched antimonide semiconductors." The award was presented to Professor Balakrishnan at the North American MBE conference, which was held in Cancun, Mexico, at the conference banquet on October 8, 2015.

Professor Ganesh Balakrishnan is an associate professor and regents lecturer in electrical and computer engineering at the University of New Mexico. He has been involved in the growth of antimonide based semiconductors using molecular beam epitaxy for over fifteen years. During this time, he has conducted seminal work on the growth mechanisms for highly mismatched antimonides on a variety of substrates including GaAs and Silicon. Ganesh has a highly cited body of work on the formation of Lomer dislocations between GaAs substrates and GaSb epilayers. He also proceeded to demonstrate such growth modes for antimonides on Silicon resulting in several communications wavelength lasers. The technique of inducing such a spontaneous relaxation in the growth of highly mismatched semiconductors has since been used by numerous research groups to demonstrate high performance antimonide lasers, solar cells, detectors and transistors on GaAs and Silicon.

QESST Featured in Science Nation

QESST researchers recently were highlighted in the Science Nation video series. The Science Nation team spent the day filming at the Solar Power Lab at the ASU Research Park, and produced a video highlighting QESST's work to meet the terawatt challenge.

Science Nation is a video series commissioned by the NSF Office of Legislative and Public Affairs. The series is distributed throughout the world, including to LiveScience.com and other media outlets on the internet, local community TV stations in the U.S. via TelVue Connect Media Exchange, Voice of America for international broadcast distribution, the NSF STEM video portal Science360, the Knowledge Network video stream and Roku channel, and K-12 content distributors in the U.S. and abroad.

The video can be found on the QESST website at: http://qesst.asu.edu/qesst-for-solar-power-to-feed-an-energy-hungry-world

ASU Homecoming, November 14th

Stay tuned for more information about ASU Homecoming, which will take place on November 14, 2015! QESST again will participate in activities leading up to kick-off at ASU Sun Devil Stadium. Homecoming is one of ASU's largest signature events. It features activities for the whole family, including interactive displays, games and activities. This year, QESST will be hosting a booth outside the Engineering Research Center. We will be featuring solar cells made by QESST Scholars, solar cars, poster designs, a clean room wardrobe, and many other fun activities.

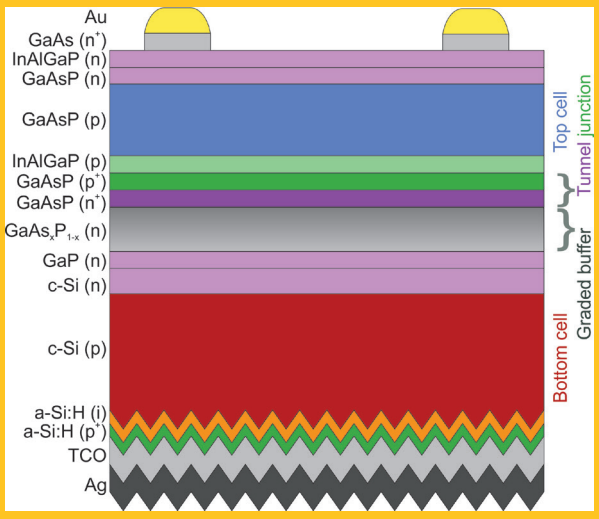
ASU to Establish Clean Energy Partnership Center in Pakistan

QESST researchers, including Sayfe Kiaei (the project PI and academic lead), G. (Mani) Tamizhmani (in charge of solar PV testing) and Zachary Holman (in charge of materials research), have received a new grant for $18M funded by the U.S. Agency for International Development (USAID). The ASU-led "Partnership Center for Advanced Studies in Energy (PCASE)" will develop two new energy centers in Pakistan in partnership with Pakistan's National University of Science and Technology (NUST) in Islamabad and the University of Engineering and Technology (UET) Peshawar. PCASE will need to develop the new centers to focus on energy including governance, policy, curriculum, applied research, exchanges and scholarships, and institutional sustainability. The goal is to engage over 200 Pakistani researchers and graduate students over the next five years with each spending one semester at ASU working in energy research labs to learn the latest technologies. The research foci for the new centers will include Photovoltaics and Solar Energy, Materials, Thermal Energy, Power Systems and Policy, Governance, and Entrepreneurship.

The project was launched with events in Pakistan in June and Tempe in August. At the Tempe event, Senator John McCain (R-Az) spoke of the tremendous return on investment for development projects that focus on expanding capacity in education.

Holman Begins New Associated Project on III/V Integration with Silicon

QESST Faculty Zachary Holman and Minjoo (Larry) Lee of Yale University were awarded a grant under the NSF Energy for Sustainability program, which focuses on integrating III/V with silicon in tandem solar cells. The ultimate goal of the work is to develop two-terminal tandem solar cells through controlled growth of Group III-V materials on silicon. The research will include fundamental studies of materials growth to minimize defect formation in the top cell, optimization of the silicon bottom cell for the infrared spectrum, and integration of the sub-cells to achieve 30% solar energy conversion efficiency. The initial material selected for the top cell is GaAsP, since it has a direct and tunable bandgap and can be grown on a transparent, compositionally graded buffer on a GaP/Si template. The bottom cell of the tandem device will be based on an amorphous silicon/crystalline silicon heterojunction solar cell, where the front amorphous silicon layers will be replaced with the GaP template layer upon which the top cell is grown.



education & outreach

QESST Hosts Delegation from Tec de Monterrey

On September 23-24, 2015, QESST Faculty and Scholars taught 21 architectural undergraduate students and 2 faculty members from Tecnologico de Monterrey how to design their own photovoltaic module. The visiting undergraduates worked with sixteen QESST Scholars during the two-day workshop, which was hosted by the Solar Power Lab in the ASU Research Park (Tempe, Arizona).

Beginning with an interest, but very little knowledge about solar energy, the Tecnologico de Monterrey students ended the workshop having built and tested their own silicon cell modules. In addition to mastering the processes needed to build and test a module, each student had an opportunity to explore every aspect of a photovoltaic system, at the level of individual cell performance to solar installation design.

A large cadre of QESST Scholars, faculty, and staff were required to provide this intense two-day workshop. QESST Director, Dr. Chris Honsberg, provided an introduction to photovoltaics for the novice students. Dr. Harvey Bryan from the ASU Design School discussed the influence of utility costs, location of solar panels, usage amounts based on demographics, as well as aesthetics of solar installation design. Dr. Mariana Bertoni brought it all home, ensuring students left with confidence in their new knowledge and a passion for photovoltaic design.

QESST REU/REV/RET/YS Wrap-up

QESST celebrated a successful end to the 2015 summer REU, REV, RET, and Young Scholar programs on August 8th. Undergraduate students and teachers from the states of Arizona, Delaware, Maryland, and New Mexico met at the ASU Engineering Research Center and shared their research during a poster presentation.

QESST hosted a luncheon that included industry members from Ameresco, APS, First Solar, Soitec and NRG. All participants presented their summer research to QESST faculty, post-doctoral scholars, graduate students, and industry members.

The day ended with the presentation of certificates to the REU, RET, REV participants, and Young Scholars in recognition of their outstanding efforts in the lab.

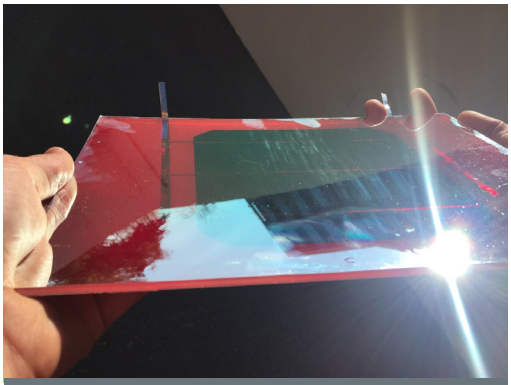
Tec de Monterrey visitors in Solar Power Lab

Tec de Monterrey students show off their solar cell modules

REU students and Young Scholars celebrate a successful summer program held at the Solar Power Lab

QESST Engages in I-Corps Program

QESST Researchers Kathryn Fisher, Charlie Gay, and Zachary Holman completed an NSF Innovation Corps (I-Corps) summer program designed to train academic scientists and engineers in entrepreneurship.



Cell produced by the PVMirror project that combines a concave reflective mirror for concentrating solar thermal power with a thin silicon photovoltaic cell.

With the ultimate goal of broadening the impact of basic research, I-Corps combines mentoring and guidance from established entrepreneurs with a targeted curriculum to identify valuable product opportunities that can emerge from basic research projects.

The QESST I-Corps team interviewed 80 solar power experts over the course of six weeks in the course of the customer discovery process to learn about market opportunities for their technology that combines photovoltaic and concentrating solar thermal power. This technology has been developed under the QESST Associated Project "PVMirror: A Solar Concentrator Mirror Incorporating PV Cells" funded by ARPA-E. Professor Holman is the PI of the PVMirror project, results of the PVMirror project at the recent PVSC conference.

To learn more, http://spie.org/x115400.xml?ArticleID=x115400

QESST Participates in HOPE Workshop

The National Renewable Energy Laboratory (NREL), a Department of Energy research center, with input from QESST faculty and Educational program leaders, conducted a one week Hands-On Learning Education (HOPE) workshop.

The goal of this program was to accelerate graduate students learning in photovoltaic research. The July 19-25, 2015 workshop involved 13 students, 12 professors (the students' advisors) and about 35 NREL staff members. HOPE provided professors and graduate students with the opportunity to interact with NREL scientists and engineers and PV researchers from universities across the United States.

The students learned about PV technology in a small-group research setting. They observed solar cell fabrication, conducted device characterization, learned about modeling device performance, and discussed the PV industry and where it may be heading in the future.

The small size of the group and extensive involvement by NREL staff provided students with an actively learning environment, which allowed them to explore cutting edge of photovoltaics research.

The HOPE workshop, designed and organized by QESST Science Advisory Board Member, Dr. Sarah Kurtz, is in its 4th year. Each of the 12 students live, learn and work together for the week on the NREL campus, creating a community of scholars from universities around the country. Their faculty advisors provide content, organizational support, and learn from each other about the state of the art of research being conducted at NREL and University laboratories. Each year QESST Faculty and Scholars, and provide support for and participated in the workshop.

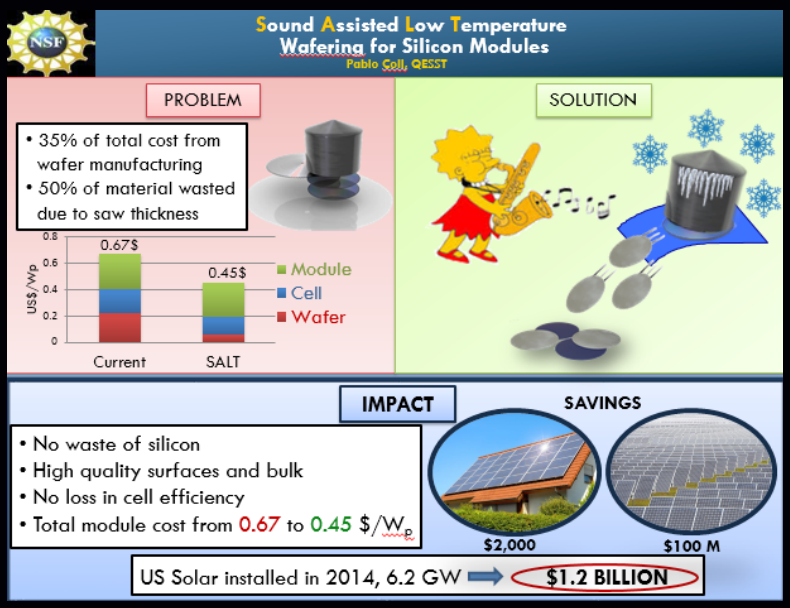
industrial engagement

Industry and Innovation Program

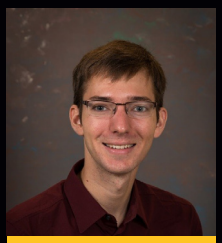
Perfect Pitch Competition

During the September 21st semi-monthly vidyo conference with all QEEST universities and members of the Industrial Advisory Board, QESST held the annual Perfect Pitch competition.
The top three QESST competitors elected by the Industry Advisory Board are: Pablo Guimerá Coll, Jimmy Hack, and Cristofer Flowers. The first place winner, Pablo Guimerá Coll, now qualifies for the ERC-wide competition being held in Washington, DC in October. Pablo's concept is to use sound assisted low temperature wafering to help reduce kerf loss during the wafer manufacturing process.
The Perfect Pitch competition was established by the NSF as a friendly competition between all ERC Centers across the country.

By asking students to answer the following three questions in 90 seconds—what real-life problem their research addressed, how they solved it in a unique way, and what impact it would have for society and in achieving their Center's mission—students learn a succinct way of talking about their research in the context of societal needs and the broader impact of their success. The top three placers in the ERC wide competition will present their pitch to members of Congress.



QESST Scholar Pablo Guimerá Coll (ASU)



QESST Scholar Jimmy Hack (UDel)

QESST Scholar Cristofer Flowers (Caltech)

Featuring Holman Research Group

The Holman Research Group, led by Professor Zachary Holman, is in the ASU School of Electrical, Computer and Energy Engineering.

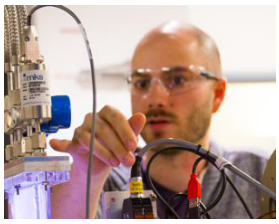
As a member of the Quantum Energy and Sustainable Solar Technology (QESST) Engineering Research Center, the group develops high-efficiency silicon solar cells.

Active research topics include silicon and metal oxide materials, silicon heterojunction solar cells, and silicon-based tandem solar cells.

Zhengshan (Jason) Yu, Ph.D. student, won the best poster award at the 2015 IEEE PVSC Conference in New Orleans in Topical Area III (High, Medium and Low Concentration, Cells to Systems) for his poster entitled "PV Mirror: A Tandem Solar Cell that Collects Diffuse Light."

Jianwei Shi, Ph.D. student, completed the week-long Hands-On PV Education (HOPE) workshop at NREL where he fabricated a working III-V tandem solar cell.

Privaranga Koswatta, master's student, completed a summer internship at Applied Materials in Santa Clara, CA.



Peter Firth, a Ph.D. student, is a recipient of a 2015 Ira A. Fulton Dean's Fellowship Award and completed a summer internship at On Semiconductor in Tempe, AZ.

Mathieu Boccard, post-doctoral researcher, just published a paper entitled "Amorphous silicon carbide passivating layers for crystalline-silicon-based heterojunction solar cells" in the Journal of Applied Physics. This paper is the result of the QESST-associated project FPACE-II.

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

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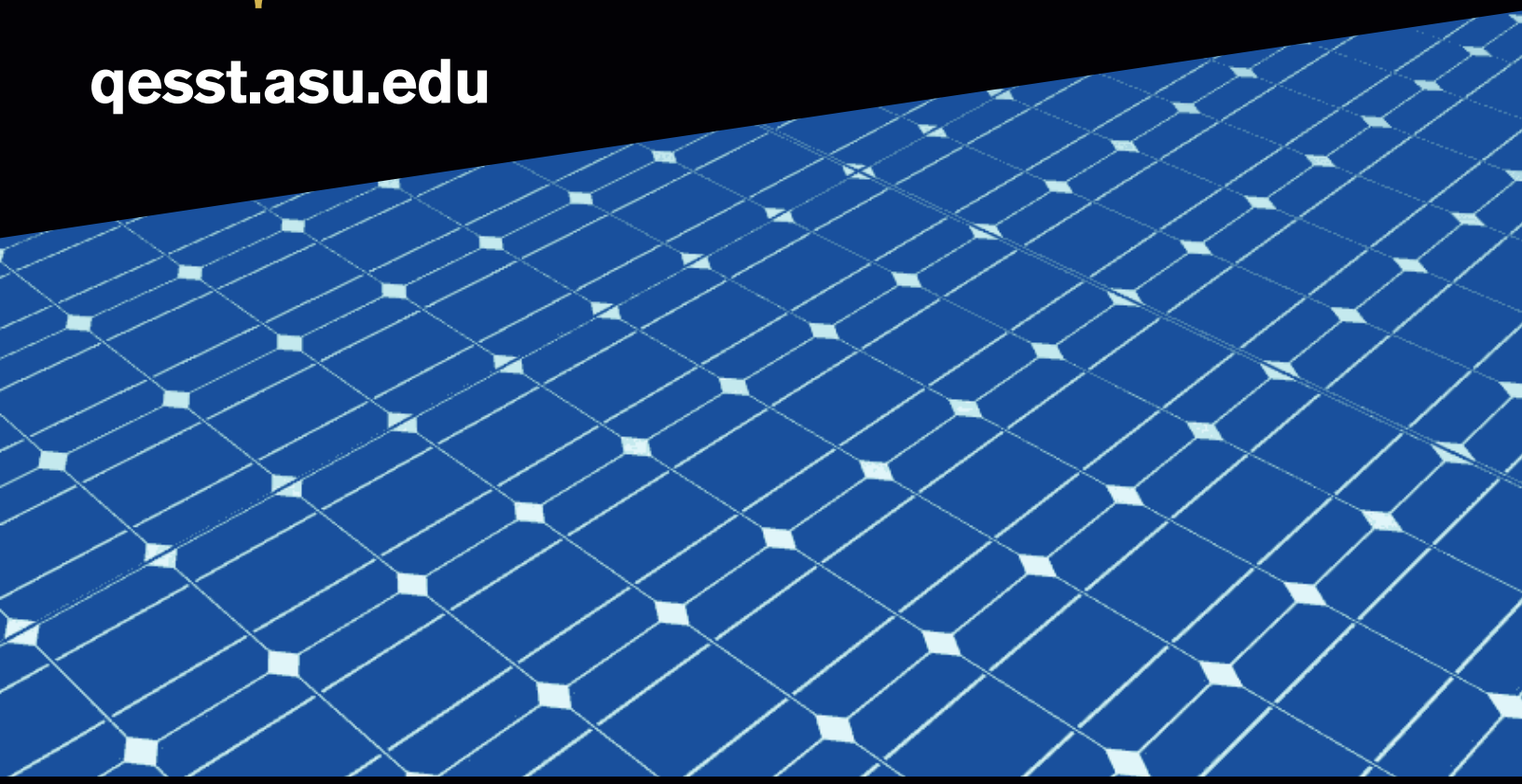

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