DuraMAT
Durable Module Materials Consortium

FY 2018

Annual Report

A year of capability development and new collaborations

Energy Materials Network
U.S. Department of Energy

NREL

Sandia National Laboratories

BERKELEY LAB

SLAC NATIONAL ACCELERATOR LABORATORY

Table of Contents

Director's Letter 3

DuraMAT's Capabilities & Projects 4

Data Analytics. 5

Data Hub 6

Predictive Simulation. 7

Materials Characterization and Forensics 8

Module Prototyping and Accelerated Stress Testing. 9

Field Deployment 10

Technoeconomic Analysis 11

Other DuraMAT Projects 12

DuraMAT Workforce Development 13

Outcomes of August 2018 Workshop 14

Publications, Presentations, and Research Output 15

Contacts 16

DuraMAT Director's Letter

The Durable Module Materials Consortium (DuraMAT) launched in November 2016 with five years of funding as part of the U.S. Department of Energy's Energy Materials Network. DuraMAT is a multi-lab consortium, led by the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL) with SLAC National Accelerator Laboratory (SLAC) and Lawrence Berkeley National Laboratory (LBNL) as participating research labs. The overarching goal of DuraMAT is to discover, develop, de-risk, and enable the rapid commercialization of improved materials, designs, and predictive tests and models for photovoltaic (PV) modules that increase performance, extend lifetimes, and enable new applications. We do this work to ensure that quality PV systems are installed in the U.S., producing low-cost, reliable, resilient electricity. DuraMAT works in partnership with our 15-member industry advisory board (IAB) and the technical management team in the U.S. Department of Energy Solar Energy Technologies Office.

DuraMAT kicked-off seven capability development or demonstration projects in early 2017 to develop critical foundational expertise at the national labs. In 2018, these projects were quickly followed by 11 projects led by our university research partners at the Quantum Energy and Sustainable Solar Technologies (QESST) research center, the Bay Area Photovoltaic Consortium (BAPVC), and the Next Generation PV Center (NGPV) in 2018. We also initiated three one-year, industry-led projects and began a "Spark" program for new ideas in 2018. The Spark program awards up to $50,000 to national laboratory researchers through a rolling quarterly solicitation, focusing on industry-identified focus areas or blue-sky research topics. We have awarded eight Spark awards to-date in 2018 and look forward to continuing this innovative program as another mechanism for collaboration with industry.

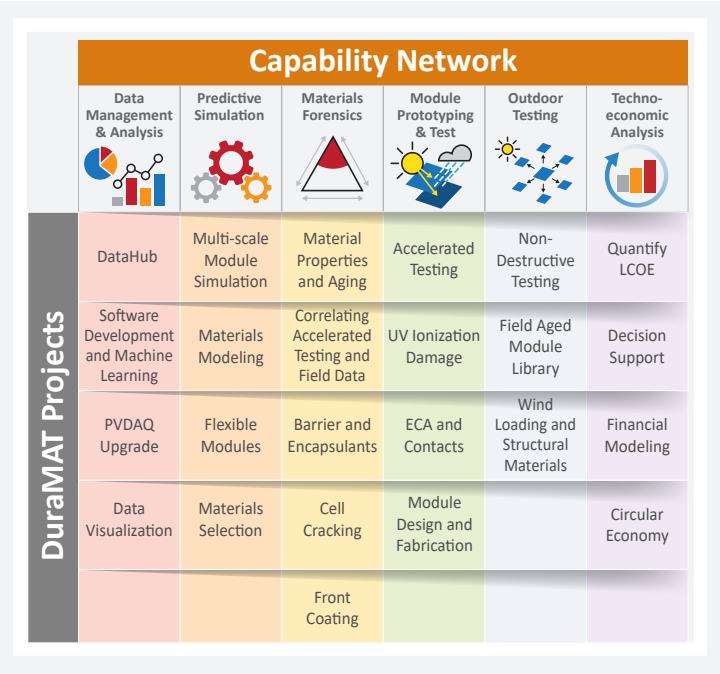
DuraMAT leverages the national laboratories' decades of experience, expertise, and world-class facilities to create a "one-stop-shop" for timely solutions to critical problems limiting module reliability. We have become a trusted partner that the U.S. solar industry relies on for high-quality, relevant, timely, and impactful research. DuraMAT uses its capability network to study and validate improved materials, methods, modeling approaches, and big data management and analytics to reduce risk—and levelized cost of electricity—and increase the value of PV systems. Please reach out to us at duramat@nrel.gov or www.duramat.org if you are interested in learning more about our work.

Sincerely,
Teresa Barnes

DuraMAT's Capabilities & Projects

The foundation of DuraMAT is our capability network, which has the facilities, expertise, tools, and resources required for high-impact research to improve the reliability and increase the value of PV modules.

Each capability's leader is based at one of DuraMAT's core national laboratories and is poised to tap into expertise across the national laboratory system to solve problems in their capability area. Researchers and industry members can access multiple capability areas as needed.



DuraMAT's six core capability areas provide the research foundation for all DuraMAT projects.

DuraMAT functions as a matrix organization, where projects can either build on our foundational capability network or leverage the capabilities to solve a specific problem. Projects are led by national laboratory researchers, universities, and companies. Most rely on several capabilities. The DuraMAT project portfolio includes progressive research on electrically conductive adhesives, flexible packaging materials, metallization, mechanical stress, interconnects that mitigate cell cracking, optical coatings, and module design. This portfolio evolves each year with industry needs.

The DuraMAT 2018 Annual Report focuses on the capability network. We have been working to build and demonstrate our capabilities since March 2017 and these capabilities will also shape the future of DuraMAT. Here, we feature information on each capability, including a very short highlight on how the projects use these capabilities. Please join us at our fall or spring workshops, check our website, and or reach out to us directly to learn more about our projects and other capability development efforts.

Data Analytics

PI: Anubhav Jain, LBNL

CAPABILITY SUMMARY

The Data Analytics Area Capability uses statistical and machine learning techniques to assist domain scientists with their research. The capability also develops reusable software tools. As a demonstration, initial work has focused on robust methods for data filtering for degradation estimation, as well as high-throughput image analysis for testing of anti-soiling coatings.

Capability Highlight

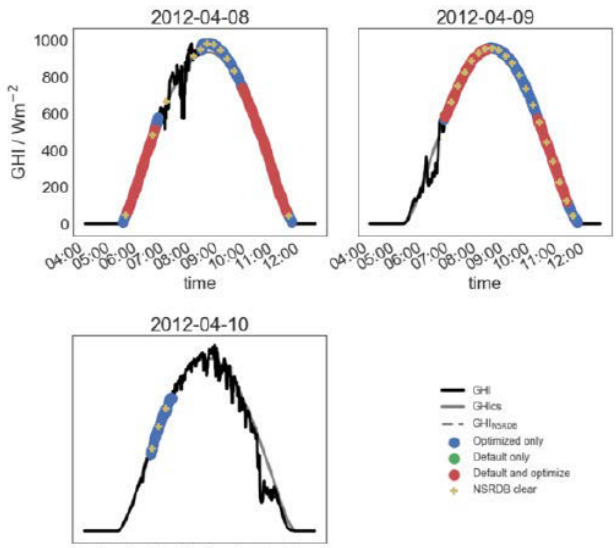
Automatic Detection of Clear-Sky Periods From Irradiance Data

Benjamin H. Ellis, Michael Deceglie, and Anubhav Jain

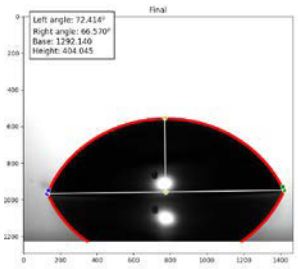
Recent studies have highlighted the importance of considering cloud cover when calculating degradation rates. In this work, we developed a classifier for clear-sky conditions from descriptors based on modeled and measured irradiance values. This method is tested on global horizontal irradiance data from ground collectors at six sites across the United States and trained against clear sky classifications determined from satellite data. The final, optimized classifier works across multiple locations and several data collection frequencies with an F0.5 score of 0.943, providing an algorithm for clear-sky data filtering that does not require tuning by the end user.

Next Steps

The DuraMAT data analytics team will be tackling several new projects in the future, include analysis of combined accelerated stress testing data and developing web-based photovoltaic degradation analytics tools for researchers.



Example performance of clear sky detection algorithm (blue/red) versus default implementation in pvlib (green/red). (Joint work with NREL.)



Example of an image analysis algorithm developed for the automated assessment of contact angles, used for high-throughput characterizations of anti-soiling coating. (Joint work with SNL and SLAC)

FEATURED COLLABORATIONS

- Collaboration with NREL to develop an optimized clear-sky detection algorithm
- Collaboration with SNL and SLAC to develop automated image analysis routines for contact angle determination for anti-soiling coatings

EXPECTED OUTCOMES

Apply advancements in statistical learning and machine learning to tackle the significant data analysis problems facing the solar industry—whether to automate experiments, better connect lab data with field data, or analyze large data sets.

Data Hub

PI: Robert R. White, NREL

CAPABILITY SUMMARY

The DuraMAT Data Hub provides a means for the collaborators and partners to securely and efficiently archive and share the data produced by DuraMAT projects. The Time-Series PV Field Database provides a detailed view of PV systems that have been in operation for up to twenty years across the United States.

Capability Highlight

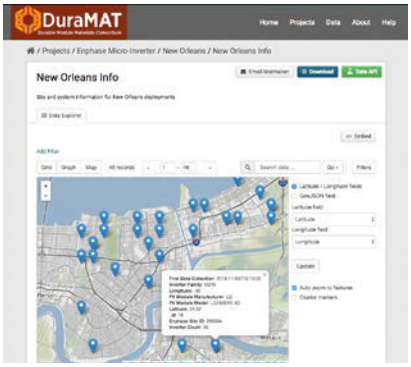
DuraMAT Data Hub: First Year of Operation

Benjamin H. Ellis, Michael Deceglie, and Anubhav Jain

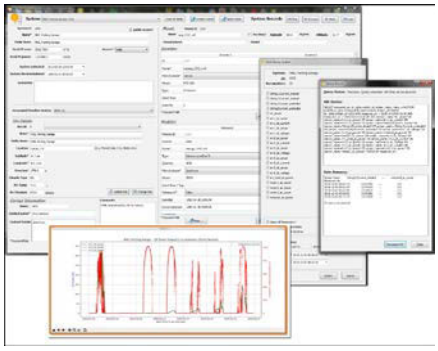
The Data Hub became an operational prototype in October 2017 and was then opened to all DuraMAT researchers in November 2017. All currently funded projects are now installed on the hub and datasets are being uploaded by researchers to their projects. The Data Hub has 50 registered users, 28 projects, and 775 resources and files uploaded. Development of the time-series database is also entering the operational phase while still undergoing importing and search testing.

Next Steps

We plan to continue expanding and improving user experinece on the Data Hub and to further integrating and providing access to the PV time-series field data. As users identify additional needs we will coninue to expand DuraMAT's data archiving and sharing capabilities.



The Data Hub enables users to search and plot datasets. Data with GIS information can be displayed and mapped.



The PV Durability and Reliability Time-Series Database Data Explorer Tool allows users to examine details of various PV systems and query field data.

FEATURED COLLABORATIONS

- Developing metadata standards for all DuraMAT data allowed us to customize the Data Hub interface, capturing information that is often difficult to get.
- The inclusion of public datasets for micro-inverters has verified previously published work through full datasets from US-wide PV installations.

EXPECTED OUTCOMES

The Data Hub framework creates a "virtual lab" forum to facilitate and enable the distribution of work across the consortium. It provides a platform to communicate research and leverage data beyond its original intent, enabling new understandings.

Predictive Simulation

PI: James Hartley, SNL

CAPABILITY SUMMARY

The Predictive Simulation Capability Area utilizes computational simulations to examine the effects of deployment environments on packaging integrity at the module scale. Modeling goals include prediction of degradation mechanisms driven by thermal, mechanical, electrical, and combined stressors. Our models enable efficient design and accelerated test specifications and provides insight into difficult-to-measure damage mechanisms.

Capability Highlight

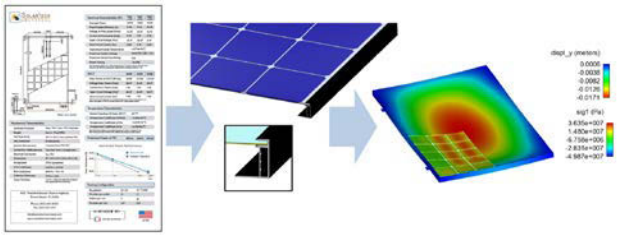
Multi-Scale, Multi-Physics Finite Element Models for PV Module Reliability

James Hartley, Ashley Maes, Scott Roberts, Christine Roberts, Nick Bosco, and Laura Schelhas

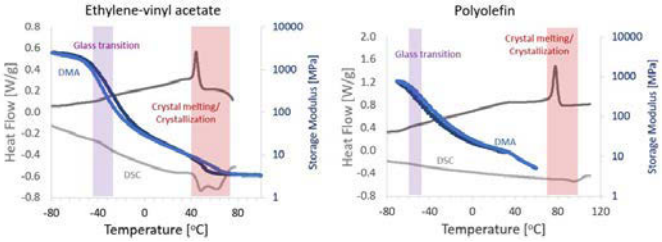
A predictive finite element model at the full-module scale provides the ability to analyze stress states anywhere within a PV module under arbitrary external loads- whether thermal, electrical, or mechanical (including snow, wind, transport, or installation). The model provides information useful for designing modules to adequately endure expected environments and for designing accelerated test protocols to best match worst-case stressors. In this work, models of two commercial modules with typical design architectures were constructed and validated against loaded deflection data: a framed, glass-backsheet silicon cell module and a glass-glass thin film module.

Next Steps

Sensitivity analyses are planned to explore the influence of module materials and design on stress states, along with experimental characterization and model implementation of PV-specific, viscoelastic polymer materials. These studies will inform best practices on module modeling and design for durability.



A simulation of module lifecycle drawn from module design information through finite element models and predicted stress state under load.



Characterized material behavior is a key input for simulation models. For example, heat flow and storage modulus vs. temperature shows key thermal transitions in ethylene-vinyl acetate (EVA) and polyolefin (POE) enctapsulants.

FEATURED COLLABORATIONS

- Simulation models are being exercised to evaluate and maximize the representativeness of the combined-accelerated stress test introduced at NREL.
- First Solar provided module designs to act as a real-life model development testbed, resulting in useful insights.

EXPECTED OUTCOMES

A simulation workflow capable of predicting expected lifetime of a PV module in different deployments and valuable for informing module design, materials selection, and interpretation of field and accelerated testing observations.

Material Characterization and Forensics

PI: Laura Schelhas, SLAC

CAPABILITY SUMMARY

Materials characterization and forensics provide high-quality, in-depth characterization of PV module materials to our industrial and academic partners. These methods provide empirical data for understanding PV module failures and degradation mechanisms. Over the long-term, these data improve PV module materials development and design, ultimately leading to the discovery of new materials and the adoption of materials from other industries.

Capability Highlight

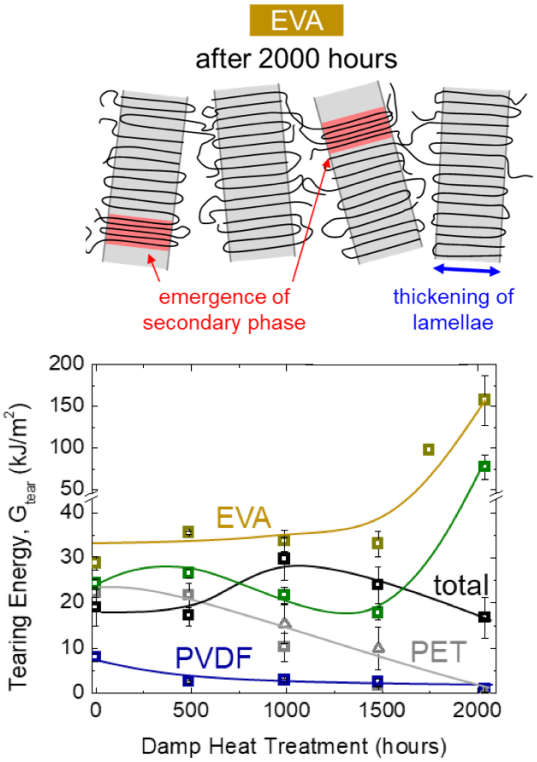
Tearing and reliability of photovoltaic module backsheet structures

Pak Yan Yuen, Stephanie L. Moffitt, Fernando D. Novoa, Laura T. Schelhas, and Reinhold H. Dauskardt

Here, we developed an understanding of the mechanical property changes occurring in multiple tri-layer polymer backsheet materials after accelerated aging by damp heat exposure. Evolution of mechanical properties are correlated with changes in polymer microstructure and chemistry, observed through small and wide angle X-ray scattering and modulated differential scanning calorimetry. This work highlights the importance of using more advanced characterization methods to fully understand failure mechanisms in PV module materials.

Next Steps

The completed work demonstrates a methodology for studying backsheet failure. This method of coupling synchrotron X-ray scattering to convential laboratory-scale methods provides a complete picture of the mechanical, chemical, and microstructural properties of PV materials. This approach will be used to study backsheets aged in the combined-accelerated stress test system.



The tearing energy of each polymer in the backsheet evolves independently. Focusing on the EVA/PET/PVDF backsheet we see the tearing energy of the EVA layer drastically increases after 1500 hours. This behavior can be explained by the emergence of secondary crystalline phases.

FEATURED COLLABORATIONS

- This work is direct collaboration with the Dauskardt Group at Stanford University and supports their DuraMAT/BAPVC award.
- The described methods are also being used to determine backsheet degredation mechanisms for capability 4.

EXPECTED OUTCOMES

Using advanced characterization methods coupled to convential laboratory-scale techniques, we are providing a complete picture of the mechanical, chemical, and microstructural properties of PV materials.

Module Prototyping and Accelerated Stress Testing

PI: Peter Hacke, NREL

CAPABILITY SUMMARY

The Module Prototyping and Accelerated Stress Testing Capability Area is developing a toolset and protocol for combined-accelerated stress testing (C-AST) that combines the stress factors into a single test that requires fewer modules, fewer tests, and makes it possible to discover weaknesses in new module designs that are not known a-priori. This will help to reduce risk, accelerate time to market and bankability, reduce costly overdesign, and estimate service life for PV modules.

Capability Highlight

Combined-Accelerated Stress Testing System for Photovoltaic Modules and Application for Evaluation of Backsheets and Encapsulants

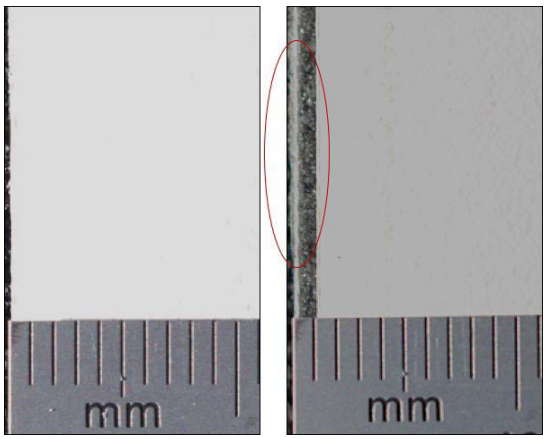
Peter Hacke, Sergiu Spataru, David C. Miller, Michael Owen-Bellini, Michael Kempe, Bill Gambogi, and T. Tanahashi

We instrumented a C-AST chamber for six mini modules to apply five stress factors of the natural environment: temperature, full spectrum light, system voltage bias, mechanical pressure, and humidity (non-condensing and spray). Based on the ASTM D7869 weathering standard that is designed for acceleration of the hot/humid climate of Miami, we tested three backsheets and two encapsulants. The testing revealed the vulnerability of one backsheet by cracking and delamination, UV degradation of cells occurring with UV-pass EVA, corrosion, potential-induced degradation, interconnect failure, and crack growth.

Next Steps

We will extend the stress protocol to include seasonality. We will also apply in-situ IV measurements, electroluminescence, and the stress factor of reverse electrical bias to the modules. We will continue discussions with various stakeholders for facilitating adoption of C-AST.

Interior view of the combined-accelerated stress testing chamber



Shrinkage of polyamide backsheet leading to delamination, cracking, and offset from the glass on the right (encircled) compared to the initial state shown to the left.

FEATURED COLLABORATIONS

- S. Spataru (Aalborg University, Denmark) collaborated on the queued state machine architecture for control of the multiple stress factors and for data acquisition in the toolset.
- B. Gambogi (DuPont) assited with design of the backsheet demonstration experiment.
- T. Tanahashi (AIST, Japan) tested the same module designs through differing test sequences for comparison.

EXPECTED OUTCOMES

Combined-accelerated stress testing is anticipated to be implemented over the entire PV value chain, including by materials manufactures, module manufacturers, insurers, investors, customers, test equipment makers, and testing laboratories to de-risk and lower the levelized cost of electricity.

Field Deployment

PI: Bruce King, SNL PI: Bruce King, SNL

CAPABILITY SUMMARY

The Field Deployment Area Capability provides infrastructure and instrumentation to support outdoor durability and performance assessements of PV modules, packaging materials, balance of systems components, and module concepts. As a demonstration project, a publicly available library of naturally aged, commercially relevant modules is under development.

Capability Highlight

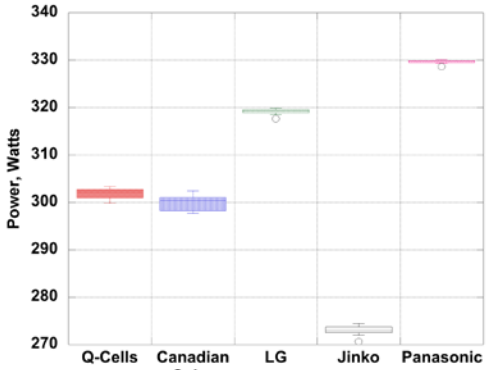
Field-Aged Module Library

Bruce King, Josh Stein, and Ashley Maes

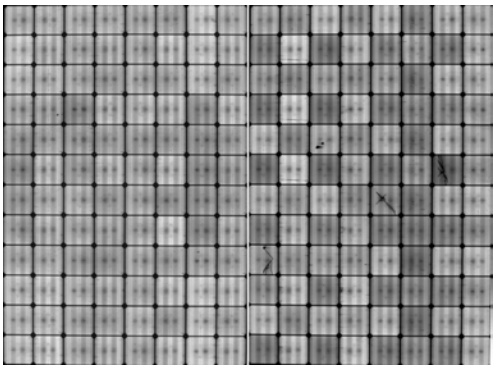
Most fielded, PV degradation studies focus on measuring changes in electrical output over time. However, material degradation may begin before electrical impacts are seen. The Field-Aged Module Library addresses this gap by characterizing and fielding commercially relevant modules. As the library evolves, it will include a set of module material samples from a range of manufacturers as well as a range of field exposure times. The library is coordinated with the separate PV Lifetime project, which is focused on accurately determining power degradation. The two projects represent a globally unique combination of publicly available data.

Next Steps

For the first phase, 60 modules have been procured and electrically characterized to capture initial performance. Next steps include destructive baseline characterization of packaging materials, installation of modules in the field, and selection of scond phase modules.



A chart of initial flash test results of as-received modules



Electroluminescence imaging of modules showing a typical, undamaged module (left) compared to a module damaged during shipping (right). Despite evidence of cell cracking, flash testing does not indicate damage.

FEATURED COLLABORATIONS

- Aligning with Solar Energy Technologies Office core capability PV Proving Grounds for module selection and data sharing
- DuraMAT's Materials Forensics Capability is performing compositional analyses and degradation assessments of module materials samples

EXPECTED OUTCOMES

A globally unique, publicly available data set that includes a library of module material samples representing a snapshot of each material's state, along with time series materials condition, time series PV system performance data, and modules' bill of materials.

Technoeconomic Analysis

PI: Michael Woodhouse, NREL

CAPABILITY SUMMARY

NREL's Strategic Energy Analysis Center (SEAC) has established itself as a global competency leader of objective, credible, and rigorous technoeconomic analysis, and serves DuraMAT researchers, the industry advisory board, and the leadership team, by developing customized lifecycle financial models for PV products and systems. This analysis is used to evaluate the market impact and overall value proposition of DuraMAT research projects.

Capability Highlight

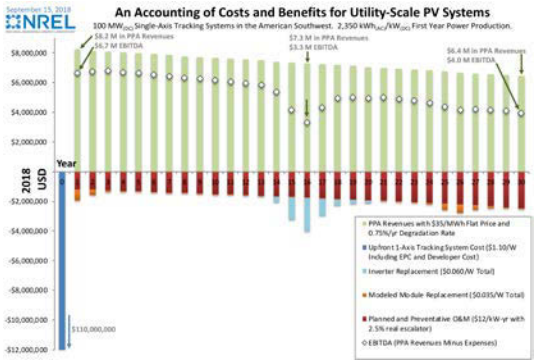
Development of pro forma PV project economics models

Michael Woodhouse

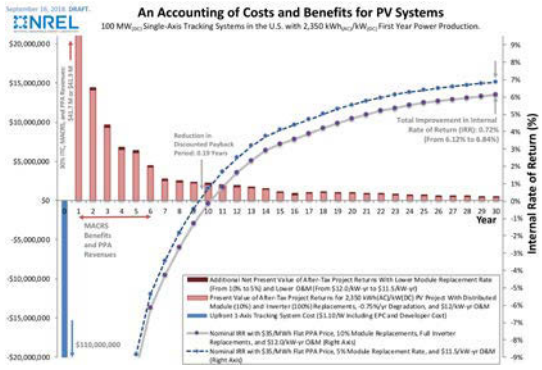
The technoeconomic analysis team has developed pro forma PV project financial models to quantify the influence of technology improvements achieved by DuraMAT. The applications include reduced operations and maintenance (O&M) expenses, improved energy yield, lower degradation rates, and more favorable project risk assesments. The models that we use—and training to use the models—is available to all DuraMAT researchers, the leadership team, and the industry advisory board.

Next Steps

The next major focus area will be to assemble module-related O&M field data in order to quantify the impact that DuraMAT research could have on project levelized cost of electricity and internal rate of return. The SEAC team will also quantify the overall value proposition of new glass coatings and new module packaging technologies.



Typical revenues and expenses for utility-scale PV power plants in the American Southwest



Discounted after-tax project returns for a baseline utility-scale power plant and one with lower module replacement rates and lower O&M expenses demonstrate the economic value of improved module reliability.

FEATURED COLLABORATIONS

- Working with SNL and the DuraMAT Data Hub to develop models and analyses to detail module-related O&M issues and expenses
- Detailing energy yield benefits and bottom-up manufacturing costs for new glass coatings being researched within DuraMAT

EXPECTED OUTCOMES

Elucidate the most effective pathways for technologies to improve PV project economics by reviewing cost model results and informing researchers and external stakeholders about our technoeconomic analysis methodology and input data.

Other DuraMAT Projects

Capability Development Projects

- A Unified Constitutive Model for ECA Degradation
- Correlation of Advanced Accelerated Stress Testing Procedures with Field Data through Advanced Characterization and Data Analytics
- DuraMAT Fielded Module Study
- Module-Level Solutions for Degradation by Ionization Damage
- Advanced Lab and Field Testing for PV Systems

Industry-Led Projects

- Osazda Energy — Low-Cost, Crack Tolerant Metallization
- Wattglass — Advanced Multifuntional Coatings for PV Glass to Reduce Soiling and PID Losses
- SunPower — 25-Year, Low-Cost, Flexible Frontsheet

University-Led Projects

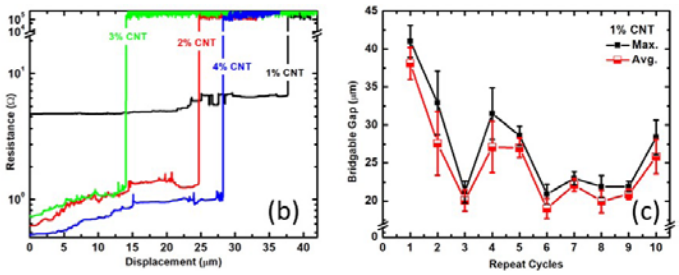
- Scalable Packaging Materials for R2R Thin Film Solar Cells
- A Hybrid Hydrophobic-Hydrophillic Coating with Combined AR/AS Properties
- Highly-Conductive, Low-Cost Polymer Adhesive Composites with Complex Dimensional Fillers
- New Concepts for Reliable Low-Cost Module Encapsulation and Barrier Technologies
- Direct Imaging of Stress in Crystalline Silicon Modules
- Failure Mechanisms in Electrically Conductive Adhesive Interconnects
- Reliability of Modules with High-Efficiency Solar Cells with Copper Contacts
- Discovering New Materials for PV Encapsulation

Spark Projects

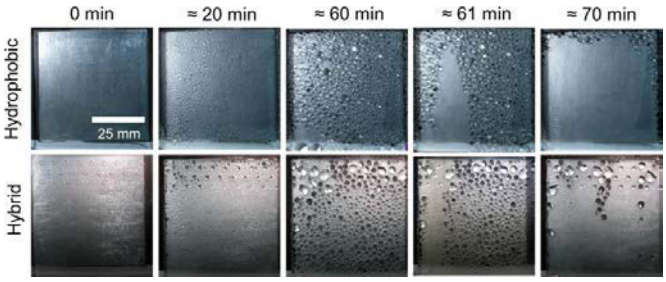
- Establishing Structural Changes with Backsheet Degradation and Cracking
- Development of a Spray Deposition Method for a Polysilsequioxane Coating for PV Modules
- Cohesive Zone Model to Simulate PV Encapsulant Delamination
- A Novel Method to Evaluate the Crack Propensity of PV Backsheets

FY18 Awards

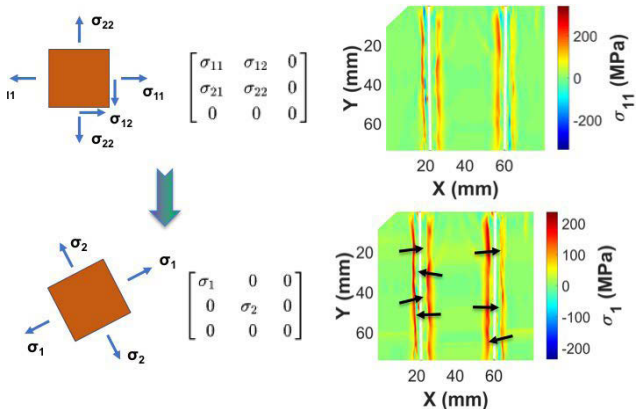
At PVSC, Osazda and NREL won the Best Poster Award in Area 9 for" Development of Low-Cost, Crack-Tolerant Metallization for Solar Cells"



At PVSC, DuraMAT-funded students from City University of New York won the Best Student Paper Award for "Hydrophobic-Hydrophilic Surfaces Exhibiting Dropwise Condensation for Anti-Soiling Applications"



At PVSC, DuraMAT-funded students from Arizona State University were a finalist for Best Student Paper Award for "Stress Analysis of Encapsulated Silicon Solar Cells on Soldering, Lamination, Cell Thickness and Electrical Performance"



DuraMAT Workforce Development

Workforce development is central to DuraMAT's mission through our "DuraMAT Early Career Scientists" (DECS) program. The DECS program consists of early career scientists and postdoctoral researchers at the national laboratories that are primarily funded (>50%) to work on DuraMAT projects. We train these researchers in the skills that they will need to work in the PV industry or national laboratories. They also serve as the "glue" that holds the consortium together. Each lab has one or two DECS participants each year who participate in both research and leadership roles throughout their three-year appointments.

The DECS have a weekly teleconference to discuss research progress and they are often able to plan and perform collaborative research. Frequent conversations often lead to joint experiments and higher impact science since someone usually has access to the right instrument or the required sample. The DECS also plan a professional development and social event at each workshop that is tailored to their needs. They organize and attend an annual industry visit to one of the IAB sites as well.

DECS are often the daily mentors or points of contacts for students working on various DuraMAT efforts. They know how to get things done in the laboratories. DECS assist capability area leaders and one DECS works directly with the leadership team as a "concierge" between the capability network and interested potential partners. DECS help organize the bi-annual workshops. They work directly with industry partners on research and serve as the vital link between all of the DuraMAT institutions. This program exposes them to research in multiple labs, universities, and in industry.

DuraMAT Early Career Scientists at DuraMAT's August 2018 workshop.

Outcomes of August 2018 Workshop

Data Will Be Crucial to DuraMAT's Success

DuraMAT held a consortium workshop at SLAC in August 2018 to evaluate our capability network and project portfolio in order to strategically plan our remaining three years of work. This workshop convened our core DuraMAT research team from the labs, the industry advisory board, academic researchers, industry, and other members of the PV community. We asked each participant to provide input on the capabilities and projects and we discussed that work and feedback with our industry board.

This workshop confirmed the value of the technical work in our capabilities as well as the high value of the collaborative DuraMAT research community. The IAB recommended that we maintain our technical and community building efforts, while we start improving our communications and outreach beyond DuraMAT. They recommended that we focus on increasing collaboration across the capability network as it is very easy to "build silos" at this research stage. A brief analysis of the relative "strengths" and "weaknesses" (shown in word clouds) of DuraMAT's capabilities revealed that data is our biggest opportunity for impact, but that access to it may also be the greatest risk to our success. We are committed to working with our lab and industry partners to build a consortium for field-data driven materials research, where we can use the world-class national lab capabilities to solve real-world reliability problems. Field data also includes new products quickly taking over the PV market. One of our biggest challenges is adapting our knowledge of older, fielded products to higher efficiency technologies. DuraMAT is ideally suited to address materials challenges for high efficiency modules, bifacial modules, 1500V systems, and trackers.

The IAB encouraged us to take this opportunity to define the critical outcomes that DuraMAT will achieve after five years of work. DuraMAT will define its success by becoming the central resource in these four areas:

- Solar Material, Module, and System Data
- Multi-Scale, Multi-Physics Module Models
- Acceleration Science
- Module Forensics

Strengths of DuraMAT's capabilities, as described by participants at the August 2018 workshop.

Weaknesses of DuraMAT's capabilities, as described by workshop participants.

Outcomes of August 2018 Workshop

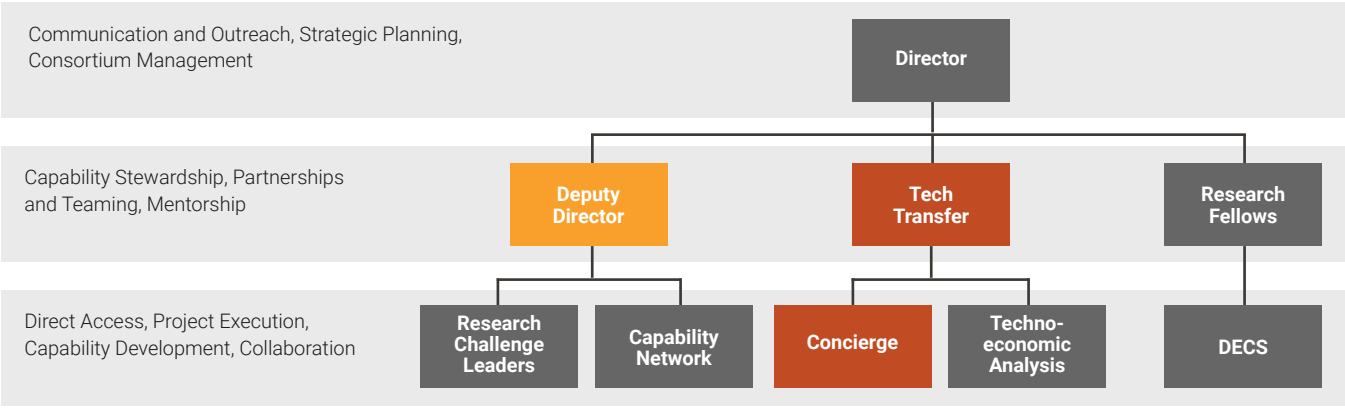
Looking Ahead to Fiscal Years 2019-2021

Our August 2018 workshop provided clear direction to increase collaboration within DuraMAT, make it easier for companies outside of DuraMAT to use the capability network, and to focus our efforts on clear goals for the end of the five-year project. The IAB also encouraged DuraMAT to make techno-economic analysis more central to our decision making and planning processes. DuraMAT is fully committed to using field failure and degradation data to drive our priorities for developing materials solutions.

DuraMAT's FY19 Critical Outcome: Access PV plant performance data through the Data Hub from three system/data owners for use in anonymized degradation and performance analysis. Quantify the number of systems (greater than 250 megawatts) and develop anonymization procedures. Begin using this data to develop a module degradation Pareto analysis for systems as a function of module technology.

As we move from consortium start-up to regular operations, DuraMAT is making minor adjustments to its leadership team and organizational structure to increase efficiency and responsiveness. The first change is the formal addition of the EMN "technical concierge"—currently Laura Schelhas of SLAC, a member of the DECS program—as a single point of contact for anyone wishing to use the capabilities to solve a research problem. The technical concierge will work with potential collaborators to refine their question and define their technical needs, then identify the correct institution and researcher to perform the work. We will also add a technoeconomic advisor to the leadership team to help identify research problems and topic areas that have big impacts on either cost or market applications. The technoeconomic advisor will also support DuraMAT with technology sensing and market changes, which is critical in a fast-moving industry. DuraMAT needs to be able to respond to an industry that has moved from multi-Si to PERC, HIT, and n-type, and towards bifacial modules in just a few years.

We will also combine outdoor data and detailed materials characterization in an effort to understand what drives premature module degradation in the field. DuraMAT will maintain its focus on data management and analytics, while more explicitly linking each work effort to the Data Hub. We will also place a very high priority on modeling as a tool to accelerate new designs and new testing protocols.



DuraMAT Leadership Team

Central Data Resource	Multi-Scale, Multi-Physics Model	Acceleration Science	Module Forensics
• Accessibility • Centrality • Security • Adaptability	• Publicly Accessible • Experimentally Validated • Models Bulk, Interfaces, Interconnects, and Stressors	• Data-Driven • Indoor Testing • Outdoor Testing and Validation • Materials and Modules	• "Field Performance to Failure Mode" • Multi-Scale • Multi-Modal • Practical

The Capability Network is the Foundation of DuraMAT's Success

DuraMAT's Research Challenges

Publications, Presentations, Research Output

Journal Articles

- Nayshevsky, I.; Xu, Q.F.; Lyons, A.M. "Hydrophobic-Hydrophilic Surfaces Exhibiting Dropwise Condensation for Anti-Soiling Applications." *IEEE Journal of Photovoltaics*. Under review.
- Nicholas Rolston, Adam D. Printz, Florian Hilt, Michael Q. Hovish, Karsten Brüning, Christopher J. Tassone, Reinhold H. Dauskardt. "Improved stability and efficiency of perovskite solar cells with submicron flexible barrier films deposited in air." *Journal of Materials Chemistry A*. 2017.
- Pak Yan (Daisy) Yuen, Stephanie Moffitt, Fernando Novoa, Laura Schelhas, Reinhold Dauskardt. "Tearing and reliability of photovoltaic module backsheets." *Progress in Photovoltaics*. Under review.

Book Chapters

- S. L. Moffitt, L. T. Schelhas, S. Melkote, and M. F. Toney. *Multifunctional Optical Coatings and Light Management for Photovoltaics*. In press.

Conference Publications

- Benjamin H. Ellis, Michael Deceglie, Anubhav Jain. "Automatic Detection of Clear-sky Periods Using Ground and Satellite Based Solar Resource Data." 7th World Conference on Photovoltaic Energy Conversion (WCPEC-7). Waikoloa, HI. June 10–15, 2018.
- S. L. Moffitt, R. A. Fleming, C. S. Thompson, M. F. Toney, and L. T. Schelhas. "Fundamental Characterization of Anti-Soiling Coatings for PV Glass : Application of Small-Angle X-ray Scattering." Photovoltaic Specialist Conference (PVSC) 2018 IEEE 45th. Waikaloa, HI. June 10, 2015.
- Peter Hacke. "Testing and analysis for multiple PID mechanisms and stresses." 4th Atlas/NIST Workshop on Photovoltaic Materials Durability. Gaithersburg, MD. December 5–6, 2017. *https://www.nist.gov/sites/default/files/documents/2017/12/04/4thatlasworkshop_agendanew.pdf*.
- O.K. Abudayyeh, C. Nelson, A. Chavez, J. Chavez, Y-L Shen, F. Zimbardi, B. Rounsaville, V. Upadhyaya, A. Rohatgi, B. McDanold, T. Silverman, and S.M. Han. "Development of Low-Cost, Crack-Tolerant Metallization for Solar Cells." WCPEC-7/IEEE PVSC 45. Waikoloa, HI. June 10–15, 2018. In print.
- Nayshevsky, I.; Xu, Q.F.; Lyons, A.M. "Hydrophobic-Hydrophilic Surfaces Exhibiting Dropwise Condensation for Anti-Soiling Applications." WCPEC-7/45th IEEE-PVSCAREA 9: SOILING 1. Waikoloa, HI. June 10–15, 2018.
- J. Karas, L. Michaelson, K. Munoz, J. Rand, S. Bowden. "Degradation Studies Including Light-Induced Degradation of c-Si Solar Cells with Nickel-Copper Plated Contacts." 7th World Conference on Photovoltaic Energy Conversion. Waikoloa, HI. June 10–15, 2018.
- James Y. Hartley; Scott Roberts. "Effects of Solar Cell Materials and Geometries on Thermally Induced Interfacial Stresses." 45th IEEE PVSC Conference. Waikoloa, HI. June 10–15, 2018.
- Stephanie L. Moffitt, Robert A. Fleming, Corey S. Thompson, Michael F. Toney, Laura T. Schelhas. "X-ray Scattering Characterization of Anti-Soiling Coatings for PV Glass." WCPEC 2018. Waikaloa, HI. June 10–15, 2018.
- Sergiu V. Spataru, Peter Hacke, Michael Owen-Bellini. "Combined-Accelerated Stress Testing System for Photovoltaic Modules." AREA 9/RELIABILITY TOPICS/7th World Conference on Photovoltaic Energy Conversion. Waikoloa, HI. June 10–15, 2018. *http://www.wcpec7.org/WCPEC-7/program-technical.php?page=program&displayday=6&pads=&start_range=&start_interval=&changing_days=yes&hide_details=*.
- Xiaodong Meng, Rico Meier, Michael Stuckelberger, April Jeffries, Simone Bernardini, Mariana Bertoni. "Stress Analysis of Encapsulated Silicon Solar Cells." Area 5. Hawaii. June 10–15, 2018.

Conference Presentations

- Ashley M. Maes; James Y. Hartley; Christine C. Roberts. "Thermal and Viscoelastic Behavior of Polymer Films used as Photovoltaic Module Encapsulants." 90th Annual Meeting of The Society of Rheology. Houston, TX. October 14–18, 2018.
- Pak Yan (Daisy) Yuen, Stephanie L. Moffitt, Michael F. Toney, Laura T. Schelhas, and Reinhold H. Dauskardt. "Understanding the mechanical degradation of polymer backsheet structures in solar modules." Stanford Polymer Collective. Stanford, CA. April 26.
- Laura Schelhas, Stephanie Moffitt, Mike Toney, Drew Fleming, Cory Thompson. "Materials forensics for understanding PV module material durability." 2018 Photovoltaic Reliability Workshop. Lakewood, CO. Feb. 17–March 1, 2018.
- Michael F. Toney, Laura T. Schelhas, Stephanie L. Moffitt, Margaret Gordon, Bruce King, Patrick Burton, Andriy Zakutayev, Peter Hacke, Nick Bosco. "Advanced Characterization & Forensics." 2018 Photovoltaic Reliability Workshop. Lakewood, CO. Feb. 17–March 1, 2018.
- Stephanie L. Moffitt, Sunjay Melkote, Robert A. Fleming, Corey S. Thompson, Michael F. Toney, Laura T. Schelhas. "Anti-Soiling Coatings for PV Glass Understanding Functionality and Degradation Pathways." BAPVC 2018. Berkeley, CA. Nov. 13, 2017.
- Stephanie L. Moffitt, Sunjay Melkote, Robert A. Fleming, Corey S. Thompson, Michael F. Toney, Laura T. Schelhas. "Anti-Soiling Coatings for PV Glass Understanding Functionality and Degradation Pathways." DuraMAT Fall Workshop 2017. Albuquerque, NM. Nov. 7–8, 2017.
- Stephanie L. Moffitt, Sunjay Melkote, Michael F. Toney, and Laura T. Schelhas. "Anti-Soiling Coatings for PV Glass Understanding Functionality and Degradation Pathways." SSRL/LCLS Annual User's meeting 2017. Menlo Park, CA. Sept. 27–29, 2017.
- Robert A. Fleming, Stephanie L. Moffitt, Patrick Burton, and Laura T. Schelhas. "Advanced Multifunctional Coatings for PV Glass to Reduce Soiling Losses." DuraMAT Fall Workshop 2018. Menlo Park, CA. Aug. 28–30, 2018.
- Laura Schelhas, Michael Toney, Stephanie Moffitt, Margaret Gordon, Patrick Burton, Andriy Zakutayev, Conor Riley, Peter Hacke, Nick Bosco, Robert Fleming, Corey Thompson, Pak Yan Yuen, Reinhold Dauskardt. "Material Forensics for Understanding PV Module Materials Durability." DuraMAT Fall Workshop 2018. Menolo Park, CA. Aug. 28–30, 2018.
- Robert A. Fleming, Sergiu C. Pop, Stephanie L. Moffitt, Laura T. Schelhas, and Corey S. Thompson. "Advanced Multifunctional Coatings for PV Glass to Reduce Soiling and PID Losses." Photovoltaic Reliability Workshop 2018. Denver, CO. Feb. 27–March 1, 2018.
- Robert A. Fleming, Corey S. Thompson, Sergiu C. Pop, Stephanie L. Moffitt, Laura T. Schelhas, Michael F. Toney, and Bruce King. "Advanced Multifunctional Coatings for PV Glass to Reduce Soiling and PID Losses." DuraMAT Fall Workshop 2017. Albuquerque, NM. Nov. 7–8, 2017.
- Stephanie L. Moffitt, Sunjay Melkote, Robert A. Fleming, Corey S. Thompson, Michael F. Toney, Laura T. Schelhas. "Anti-Soiling Coatings for PV Glass: Understanding Functionality and Degradation Pathways." DuraMAT Fall Workshop 2017. Albuquerque, NM. Nov. 7–8, 2017.
- D. Okawa, H. Ng, A. Taussig, M. Kempe, P. Hacke. "25 Year Low Cost Flexible Frontsheet." DuraMAT Symposium. SLAC, Palo Alto, CA. Aug. 28–30, 2018.
- Yu Zhu, Bryan D. Vogt, Hongyou Fan. "Highly-conductive, Low-cost Polymer Adhesive Composites with Complex Dimensional Fillers." DuraMAT workshop. Albuquerque, NM. Nov. 17.
- Yu Zhu, Bryan D. Vogt, Hongyou Fan. "Highly-conductive, Low-cost Polymer Adhesive Composites with Complex Dimensional Fillers." BAPVC workshop. Berkeley, CA. Nov. 13.

- Clinton Taubert, Kun Chen, Fang Peng, Chao Wang, Kewei Liu, Yu Zhu, Bryan D. Vogt, Hongyou Fan. "Highly-Conductive, Low-Cost Polymer Adhesive Composites with Complex Dimensional Fillers." DuraMAT workshop. Denver, CO. Feb. 18.
- Yu Zhu, Bryan D. Vogt, Hongyou Fan. "Novel Electrically Conductive Adhesive Materials with Multiple Fillers." DuraMAT workshop. SLAC. Aug. 28, 2018.
- Pak Yan (Daisy) Yuen, Michael Q. Hovish, Florian Hilt, Mike Toney, Laura T. Schelhas, Reinhold H. Dauskardt. "New Concepts in Encapsulation and Barrier Technologies." DuraMAT Kickoff Meeting. Berkeley, CA. Nov. 1.
- Pak Yan (Daisy) Yuen, Michael Q. Hovish, Florian Hilt, Stephanie L. Moffitt, Michael F. Toney, Matthew Reese, Laura T. Schelhas, Reinhold H. Dauskardt. "New Concepts in Encapsulation and Barrier Technologies." 2018 Photovoltaic Reliability Workshop. Lakewood, CO. Feb. 27–March 1, 2018.
- Nicholas Rolston, Adam D. Printz, Florian Hilt, Michael Q. Hovish, Karsten Brüning, Christopher J. Tassone, Reinhold H. Dauskardt. "Spray Plasma Processing of Barrier Films Deposited in Air for Improved Stability of Flexible Electronic Devices." Materials Research Society Spring Meeting. Phoenix, AZ. April 18.
- Nicholas Rolston, Adam D. Printz, Florian Hilt, Michael Q. Hovish, Karsten Brüning, Christopher J. Tassone, Reinhold H. Dauskardt. "Spray Plasma Processing of Barrier Films Deposited in Air for Improved Stability of Flexible Electronic Devices." International Interconnect Technology Conference. Santa Clara, CA.
- Pak Yan (Daisy) Yuen, Nicholas Rolston, Stephanie Moffitt, Laura Schelhas, Reinhold H. Dauskardt. "Demonstrating New Concepts for Reliable Low-Cost Module Encapsulation and Barrier Technologies." 2018 DuraMAT Fall Workshop. Stanford, CA. Aug. 18.
- J. Karas, L. Michaelson, K. Munoz, J. Rand, A. Augusto, A. Sinha, G. Tamizhmani, S. Bowden. "Degradation Studies of c-Si Solar Cells with Nickel-Copper Plated Contacts." 2018 Photovoltaic Reliability Workshop. Denver, CO. Feb. 27–March 1, 2018.
- K. Fisher, J. Huxel, M. Branch Kelly, N. Chawla, M. Bertoni, Z. Holman. "Failure Mechanisms in ECA Interconnects." DuraMAT Fall Workshop. SLAC. Aug. 28–30.
- J. Hartley, S. Roberts, N. Bosco, L. Schelhas. "Thermal-mechanical modeling of PV modules and components." 2018 Photovoltaic Reliability Workshop. Lakewood, CO. Feb. 27- March 1, 2018.

Patent Applications and Patents Awarded

- S.M. Han, O.K. Abudayyeh, D.M. Wilt, and A. Chavez. "Materials Engineering to Increase Crack-Tolerance of Screen-Printable Metal Paste." July 5, 2018. Provisional patent application.

Contacts

www.duramat.org • duramat@nrel.gov

DuraMAT
Durable Module Materials Consortium

The DuraMAT—or Durable Module Materials—Consortium brings together the national lab and university research infrastructure with the photovoltaic (PV) and supply-chain industries for a grand goal: to discover, develop, de-risk, and enable the commercialization of new materials and designs for PV modules—with the potential for a levelized cost of electricity of less than 3 cents per kilowatt-hour.

FY 2018

Annual Report

duramat.org

NREL/BR-5K00-72934
December 2018

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the report do not necessarily represent the views of the DOE or the U.S. Government.