SAND2019-9971C

Discover, Develop, and De-Risk module materials, architectures, accelerated testing protocols, data analytics, and financial models to reduce the LCOE of solar energy

SPARK Project: Highly Instrumented Modules for Environmental Characterization and Simulation Model Validation

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DuraMAT Capabilities

1. **Data Management & Analytics, DuraMAT Data Hub**
2. **Predictive Simulation**
3. **Advanced Characterization & Forensics**
4. **Module Testing**
5. **Field Deployment**
6. **Techno-Economic Analysis**

Project Goals

- Design, build, and test full-sized modules with embedded instrumentation to better characterize the internal states of modules in deployment environments
- This project provides model validation data to support the **Predictive Simulation** capability area. If highly successful, instrumentation concepts could be applied in **Field Deployment** and **Module Testing** capability areas.

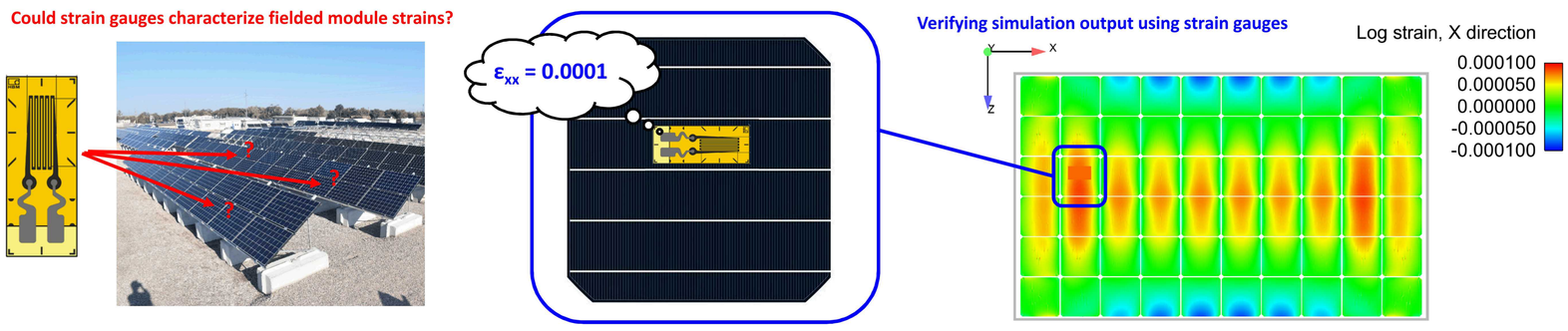
Accomplishments

- Scoped strain gauge hardware and data acquisition needs, and post-processed existing simulation results to identify module locations of greatest interest for measurements.
- Produced design drawings for 4 instrumented modules to capture specific data objectives. Currently in queue with D2 Solar to be manufactured.

Outcomes and Impact

- This project provides module scale mechanical test data to support computational model validation
- If successful, instrumentation concepts may be applied to field deployed modules to quantify the stresses imposed by outdoor exposures, or to supplement data acquired in modules undergoing accelerated testing

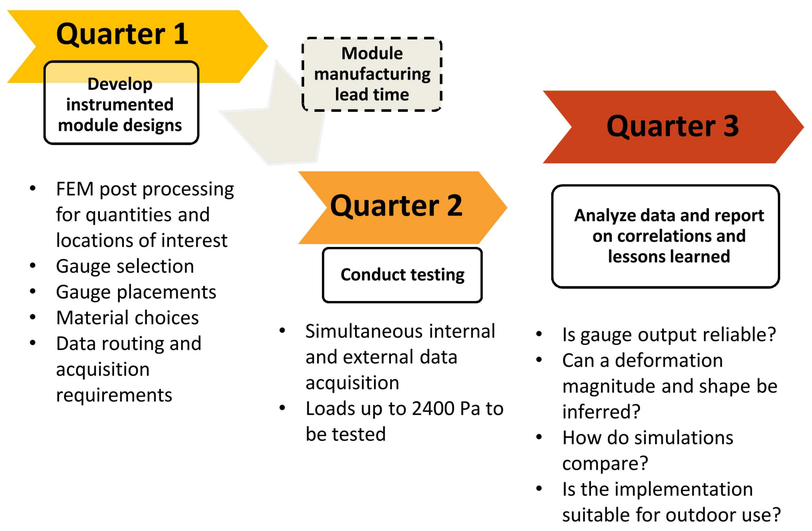
Project Summary and Motivation



Can we verify that simulations predict the correct internal strain in a full PV module? Can gauges report fielded module strain?

Computational Finite Element Models (FEM) are a useful tool enabling assessment and optimization of PV module designs. However, to be applied with full confidence, models must be validated against experimental data in controlled test cases. Currently, validation for full module mechanical FEM consists of comparing external deflection vs. load measurements, which is qualitatively adequate but could be improved upon, particularly when attempting to validate more complex quantities of interest. This project seeks to design, build, and test a set of custom modules containing internal strain gauge instrumentation, to collect internal measurements for detailed model validation. If the embedded instrumentation concept is successful, instrumented models could be deployed in the field to collect mechanical exposure histories, or subjected to accelerated testing to improve confidence in test representativeness.

Timeline



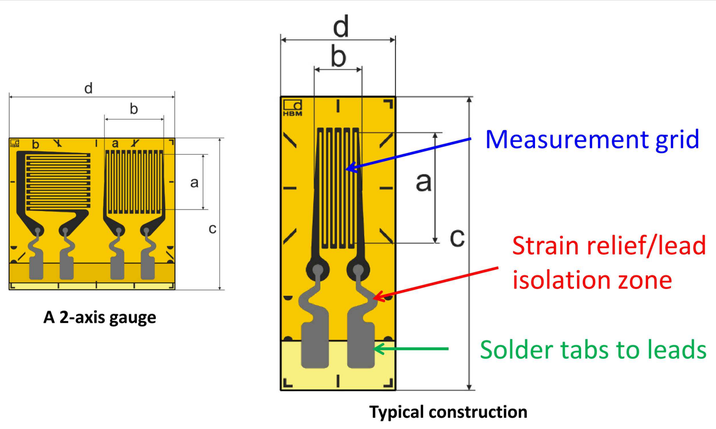
- FEM post processing for quantities and locations of interest
- Gauge selection
- Gauge placements
- Material choices
- Data routing and acquisition requirements

- Simultaneous internal and external data acquisition
- Loads up to 2400 Pa to be tested

- Is gauge output reliable?
- Can a deformation magnitude and shape be inferred?
- How do simulations compare?
- Is the implementation suitable for outdoor use?

Project will design, build, test, and report on lessons learned

Strain Gauge Background



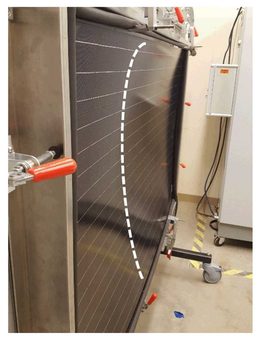
A 2-axis gauge

Typical construction

Thin foil pattern encapsulated in polyimide film reports strain as changes in electrical resistance

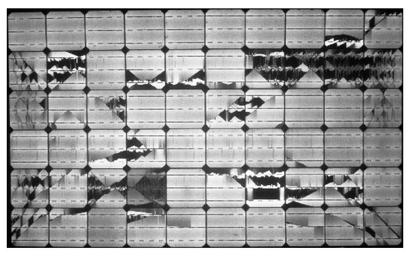
- Typically consist of a foil pattern contained within a thin (~50µm), fully insulated polyimide package
- Adhered to cell back sides prior to module lamination could provide a robust, non-invasive internal measurement
- Module electrical functionality could be retained

Load Spot Module Mechanical Tester



Module under test, -5400 Pa

BrightSpot Automation

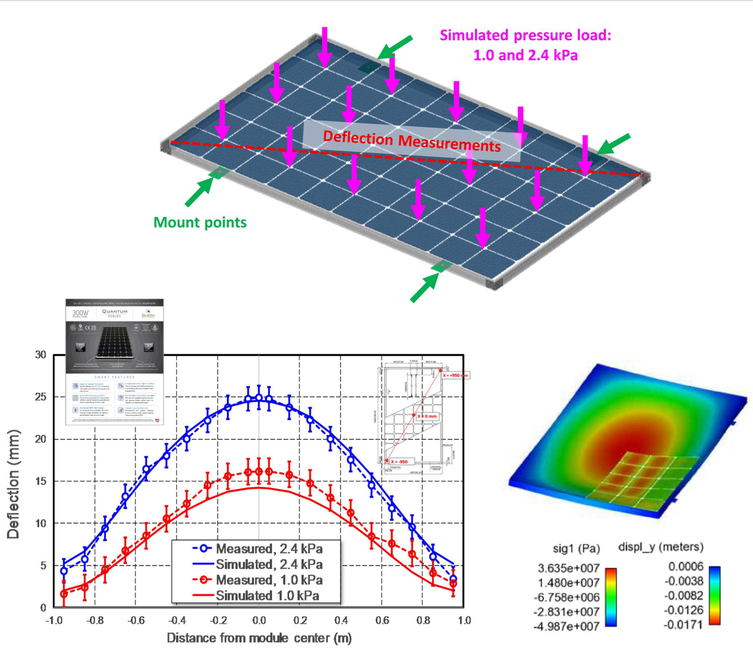


Simultaneous EL @ -5400 Pa loading

Load Spot mechanical tester enables controlled module loading with simultaneous internal & external measurements

- Air pressure based mechanical tester enables repeatable, controlled loads with simultaneous internal and external data collection
- Experimental Load Spot test scenario can be simulated and compared against strain gauge output as well as electroluminescence images and external deflection measurements to validate outputs

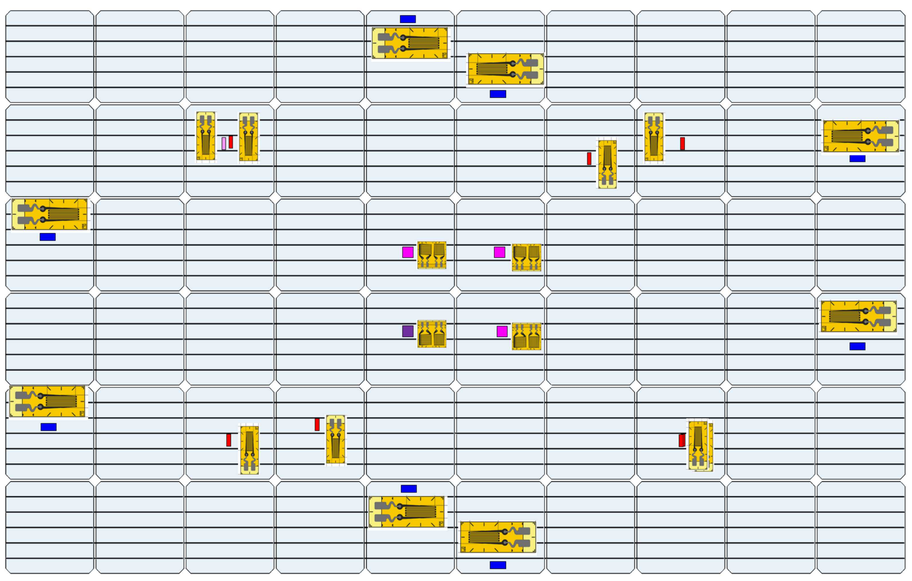
Module-Scale Finite Element Model



Existing module FEM have only been validated against external deflection vs. load tests: No internal strain data available

- Predicted deflection vs. load comparisons for an existing c-Si module model provided evidence of model validity
- Additional quantities to be obtained with internal measurements could include cell strains for different cell positions, and strain at cell vs. glass vs. backsheet layers.

Instrumented Module Design and Data Objectives



60-cell, commercially representative mono-Si module design with desirable strain gauge placement locations

Approximately 4 modules to be built, including one control module with no instrumentation. Data objectives to be gathered include:

- Confirm symmetry across module quadrants
- Assess J-box effect on nearby cell strain
- Probe cell with max ZZ strain
- Probe cell with min ZZ strain
- Probe cell with max XX strain
- Probe cell with min XX strain
- Assess effect of gauge layer placement
- Assess module-to-module variability

Module fabrication and design considerations accomplished in collaboration with D2 Solar.

D2 solar

Project Status and Next Steps

- Instrumented module designs submitted to D2 Solar for evaluation; discussions of implementation (i.e. wire routing, processing steps, material choices) ongoing prior to fabrication in September/October 2019
- Strain gauges selected and ordered

- Full module finite element model updates in progress to exactly match frame designs, dimensions, materials to be used by D2 Solar
- Preliminary check-out tests of data acquisition systems and Load Spot operation ongoing to prepare for instrumented module delivery

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