In-Line Quality and Process Control in Solar and Fuel Cell Manufacturing

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Ultrasonic Technologies, Inc.
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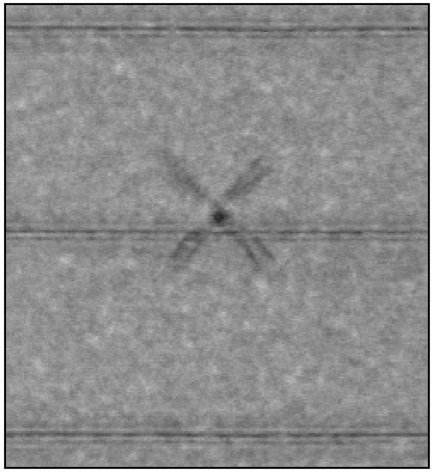
Project Objective

- **To prove concept of in-line Activation Station (AS) for sub-mm crack inspection in solar and fuel cells;**
- **To design AS prototype which meets technical requirements of the industry (throughput, sensitivity, accuracy),**
- **to test this prototype in production environment.**



Sub-mm crack in solar cell leading to cell breakage

<u>Challenges</u>: (a) real time inspection with 2 sec cycle time; (b) sensitive to sub-mm length hidden cracks, (c) applicable to bare wafers and finished cells, (d) compatible with up-stream production equipment

Technical Innovation

- To-day solution: optical imaging of full cell (luminescence and transmission). Sensitivity is limited: up to 50% false rejects due to interference with other features (e.g. scratches, grain boundaries). In fuel cells only camera inspection is used with poor success for hidden cracks under contacts.
- Ultrasonic developed and commercialized a proprietary crack inspection system using Resonance Ultrasonic Vibrations (RUV) technology (DOE/SBIR support). RUV method is simple, fast but is not sensitive to sub-mm cracks due to fundamental limitations.
- **Solution: In-line Activation Station**

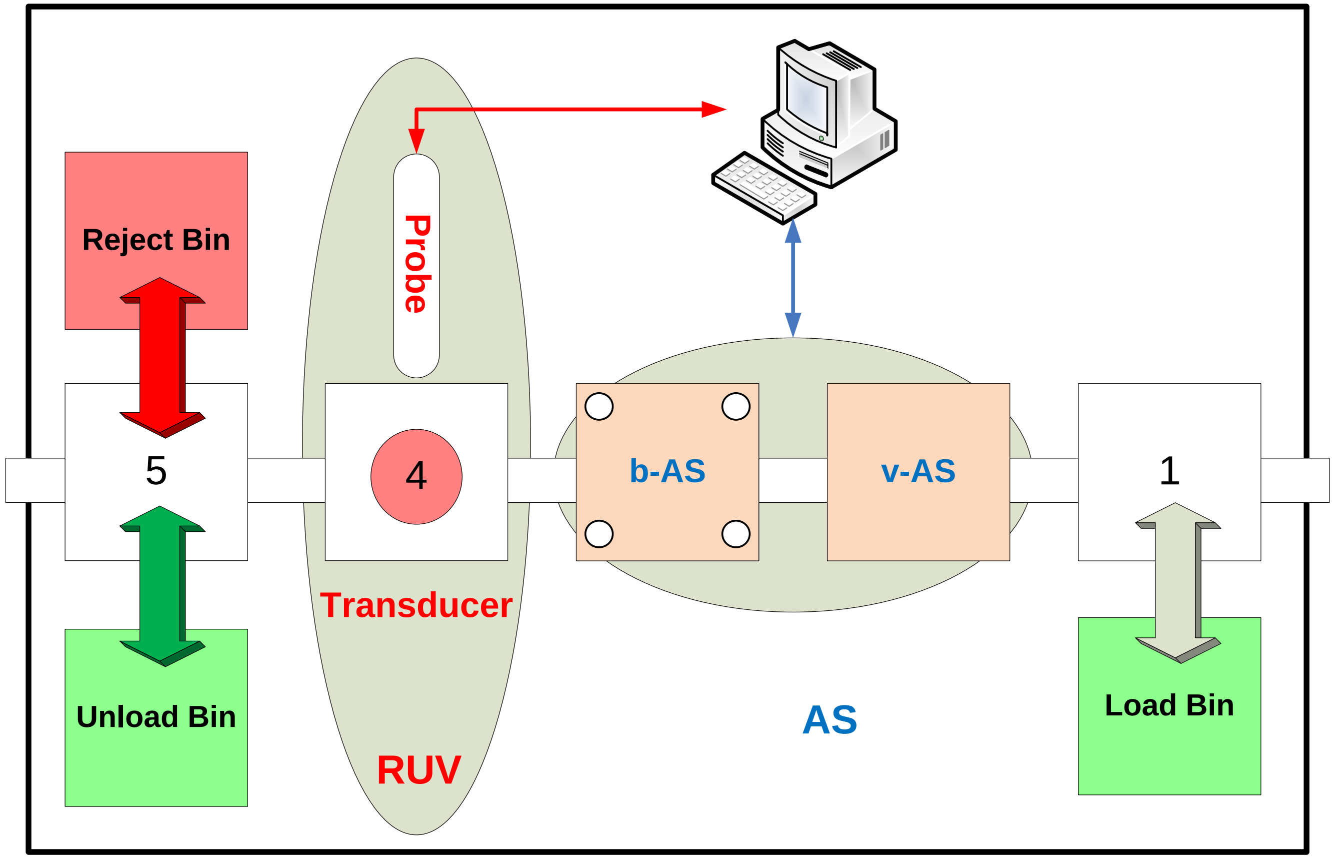
RUV system for in-line crack detection

Technical Innovation (continue)

- In-line Activation Station is able dramatically enhance RUV sensitivity toward short cracks without elongation of cycle time.
- AS-RUV concept: (a) load each cell with controllable strain profile to open hidden cracks, (b) fast measurement of elastic forces, and (c) use RUV to detect cells with enhanced flaw.
- Two AS configuration are under development: <u>bending and vacuum</u>.

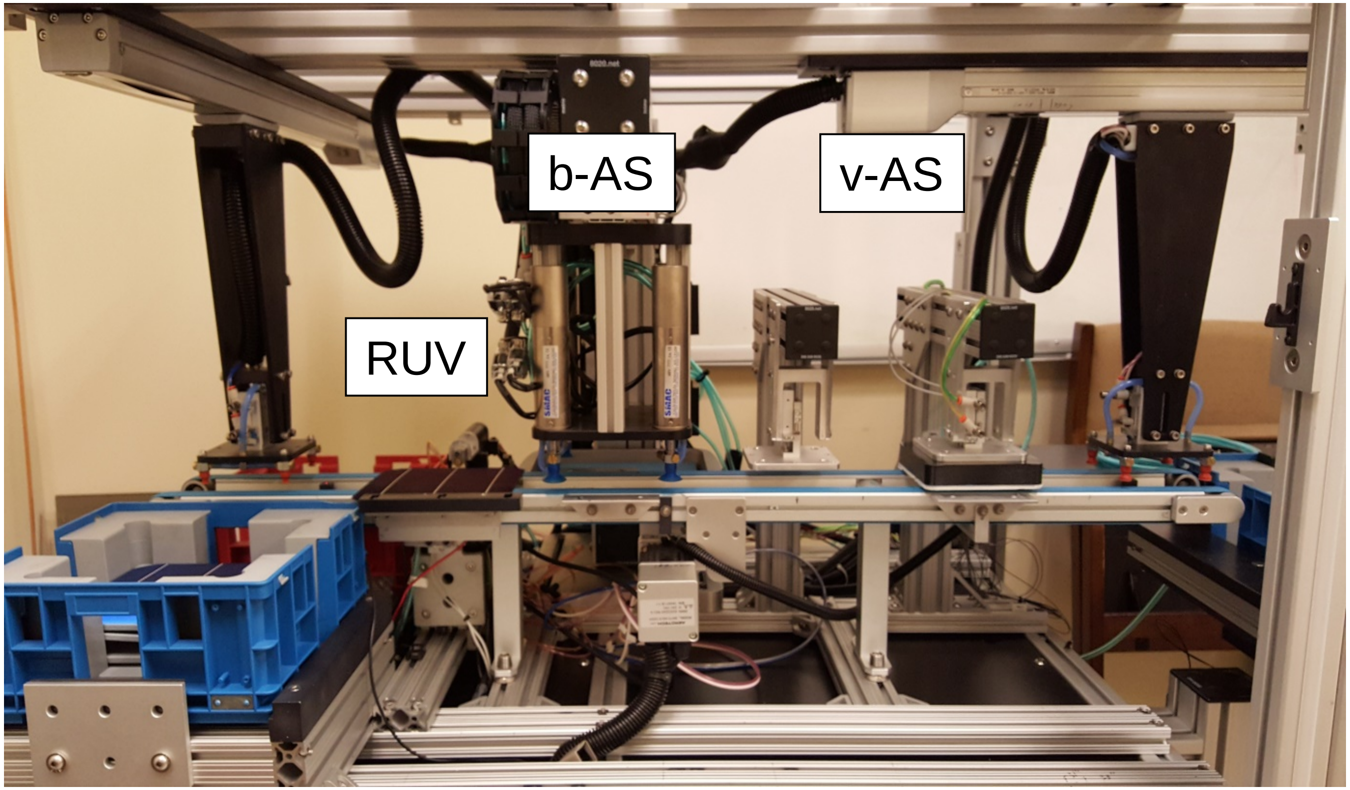
Laboratory prototype of the bend-type AS designed and tested in Phase II.

Technical Innovation (continue)



Crack inspection in the AS-RUV system: (1) cell is subjected to stress using bending or vacuum AS, (2) elastic force values show cells with cracks, which are rejected, (3) cells passed AS are inspected with RUV and sorted in “good’ and “bad” bins.

Technical Innovation (continue)



General view of automatic RUV system integrated with bending (b-AS) and vacuum (v-AS) Activation Stations.

Technical Approach: Bend-type AS

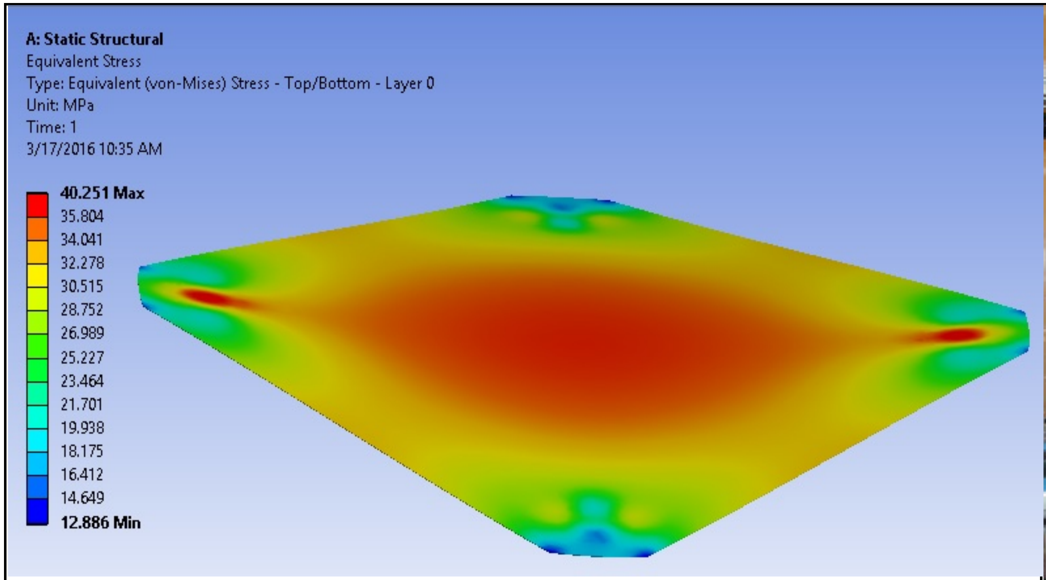


***Figure 1**: Finite Element Analysis calculation of stress distribution when Si wafer is twisted with four vacuum cups at 12mm deflection. Additional high stress is observed in areas of vacuum cups.*

***Figure 2**: Laboratory prototype of the bend-type AS designed and tested in Phase II.*

In b-AS the cell is picked from the belt with 4 vacuum cups and twisted along each diagonal. The load sensors integrated into the linear cylinders measure the bending force, which provides accurate data on the wafer integrity, as well as wafer elasticity.

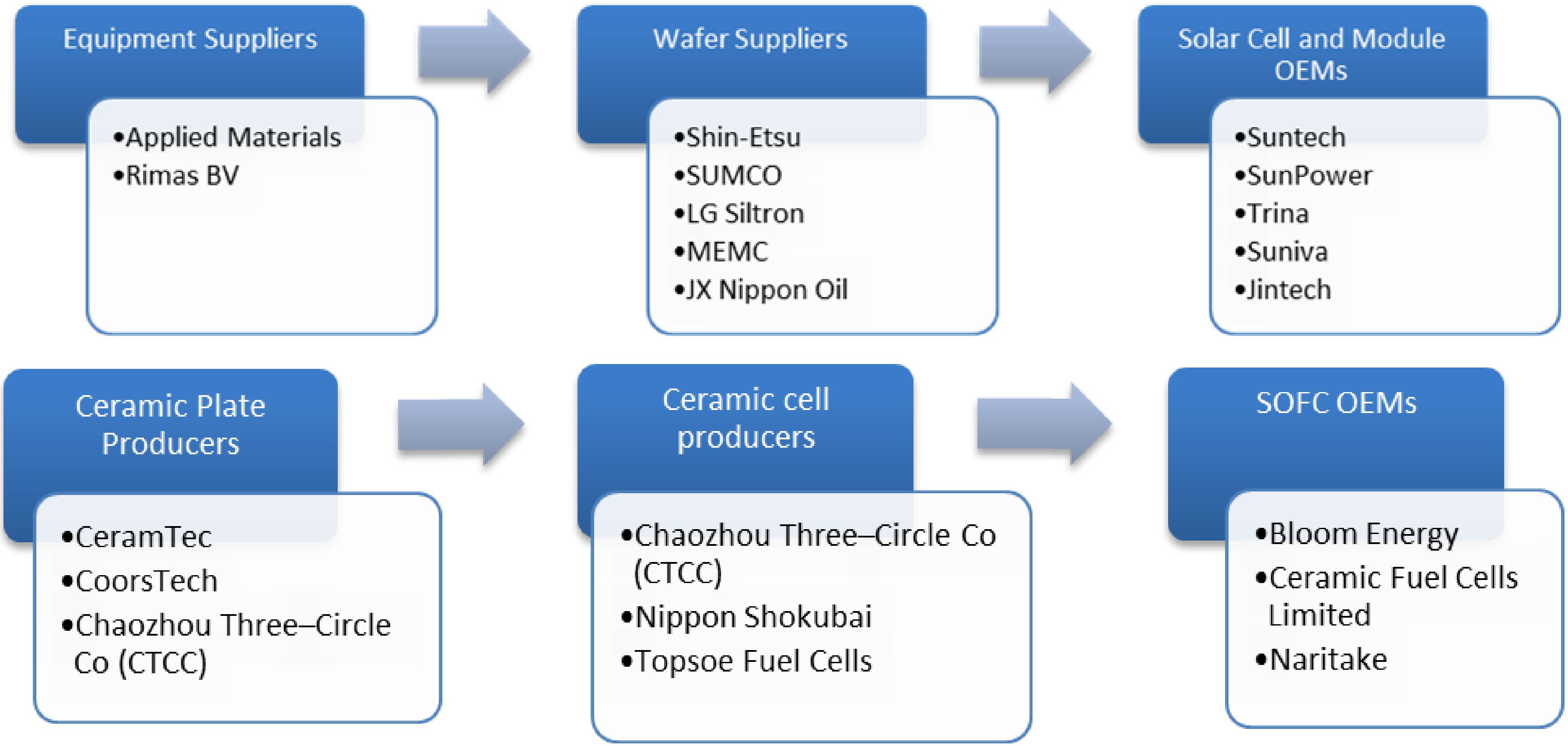
Technical Approach: vacuum AS

(a) (b)

In v-AS entire cell is subjected to vacuum deflection using customized vacuum chuck. Stress profile covers 97% of wafer surface.

Transition and Deployment

- Primary Markets: Si Solar Cells and Solid Oxide Fuel Cells



- 311 AS systems demand to retrofit 10% existed PV lines (2015)
- Commercialization Approach: initial stage – OEM, follow up with licensing when product mature and demand increase

Measure of Success

- RUV-AS systems targets increasing solar and fuel modules manufacturing yield and efficiency. This reduces production cost and consumer price.
- Value proposition: in-line RUV-AS crack inspection will reduce production cost up to 10% by eliminating cracked wafers and cells.
- In high volume RUV-AS test we documented 5.9% increase of yield (confirmed by the customer)
- Ultrasonic Technologies successfully commercialized proprietary RUV system for solar cells, fuel cells, body armor plates, and glass syringes.
- **RUV-AS systems are tested at Suniva (solar) and Bloom Energy (fuel)**

Project Management & Budget

- Project Duration: 24 months, Project Budget: $ 992,731

Project Task	Milestone Schedule
Task 1: Developed a computer-controlled AS system prototype that meets major specifications for in-line crack detection unit, such as (a) throughput rate, (b) high level of stability and repeatability, (c) sensitivity to crack length and crack location, and (d) low rate of false rejects.	January 2015
Task 2: Designed, manufactured, and tested the laboratory AS prototype with (a) bending (b-AS) and (b) vacuum (v-AS) modifications.	March 2015
Task 3: Performed Finite Element Analysis modeling of stress profiles, optimized the AS hardware.	July 2015

Project Management & Budget (continue)

Task 4: Designed a protocol and sub-system for controlled indentation of cracks in c-Si solar cell. Identified the length of indented cracks using scanning acoustic microscopy and determined probability of crack activation using AS.	November 2015
Task 5: Integrated b-AS and v-AS hardware and software with automatic RUV system.	January 2016
Task 6: Performed high volume crack detection in solar module production using RUV-AS prototype. Data of crack detection will be statistically evaluated using Analysis of Variance method.	June 2016

Results and Accomplishments

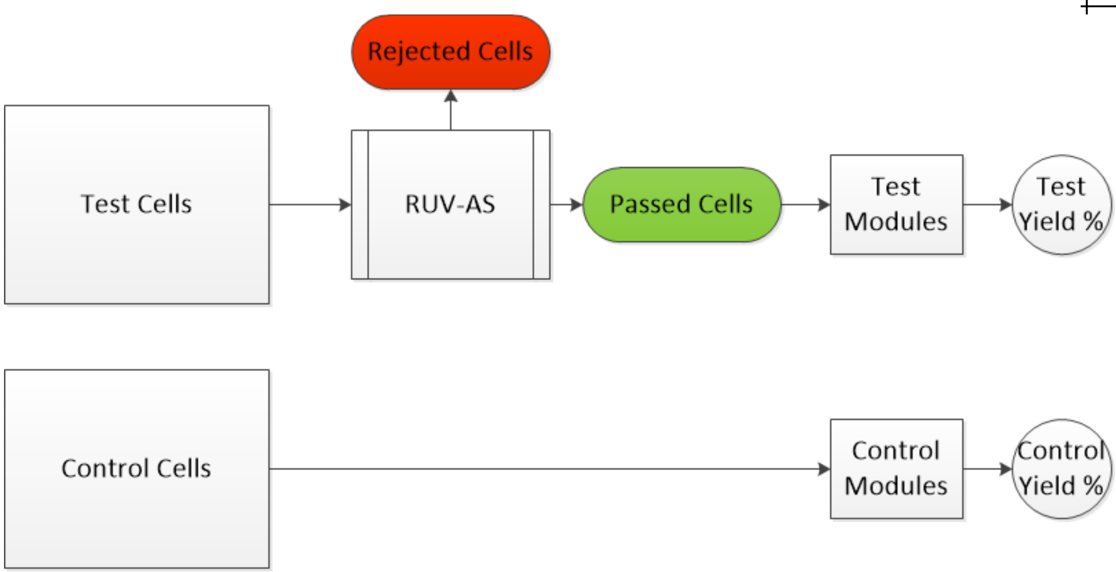
- Designed, manufactured, and tested a laboratory AS with two modifications: (a) bending activation with four vacuum cups (b-AS) and (b) vacuum activation (v-AS) using a quatrefoil vacuum chuck.
- Optimized the AS hardware using finite element analysis computer modeling.
- Designed a protocol and programming sub-system for controlled indentation of seed cracks in c-Si solar cell.

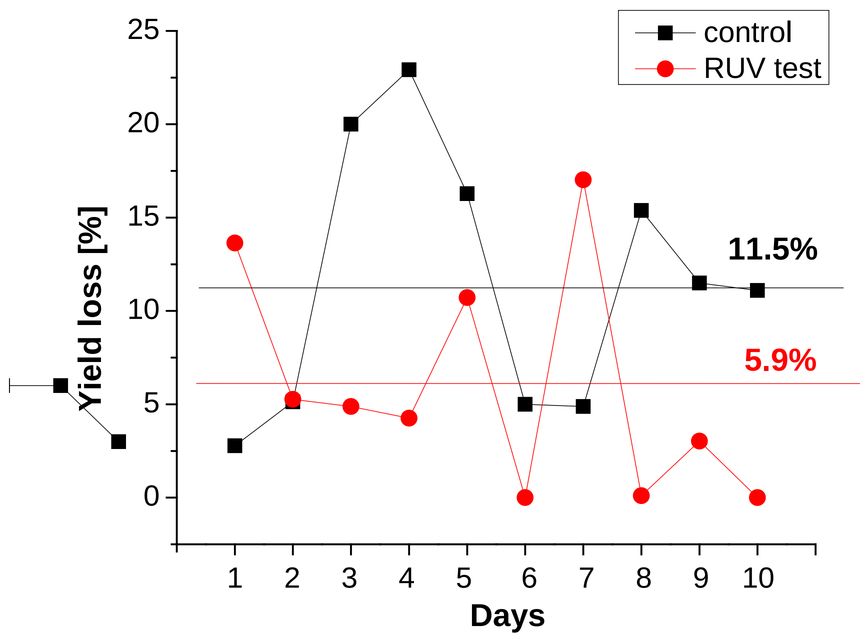
Results and Accomplishments (continue)

- Identified length of indented seed cracks and confirmed 100% wafer coverage of crack activation via combined AS tool. Confirmed findings using high-resolution Scanning Acoustic Microscopy.
- Integrated b-AS and v-AS hardware and software with automatic RUV system. Demonstrated 2seconds AS takt time.
- Performed high volume crack detection in solar module production using AS-RUV system. Documented 5.9% yield improvement in the front end module inspection.

Results and Accomplishments (continue)

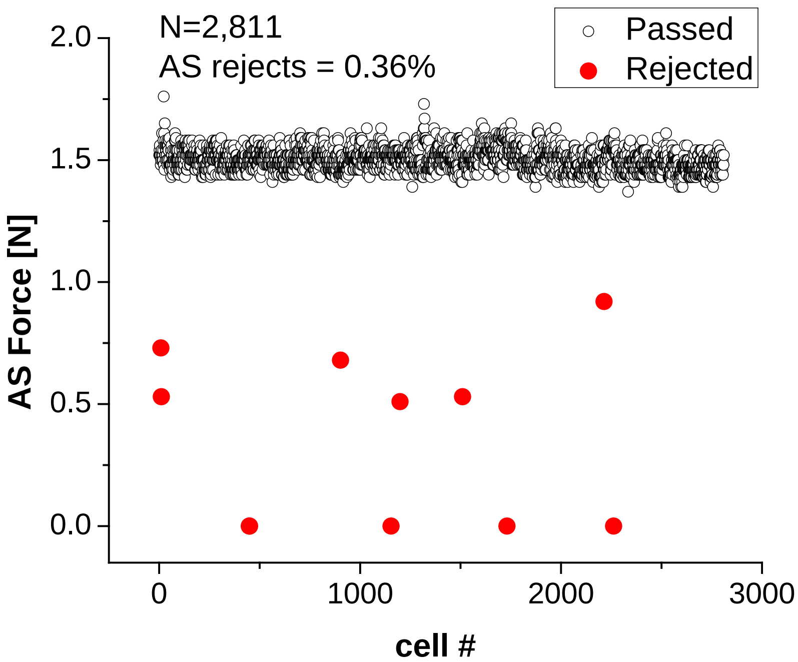
Following design of experiment was developed and implemented for RUV-AS system validation and verification in solar module production



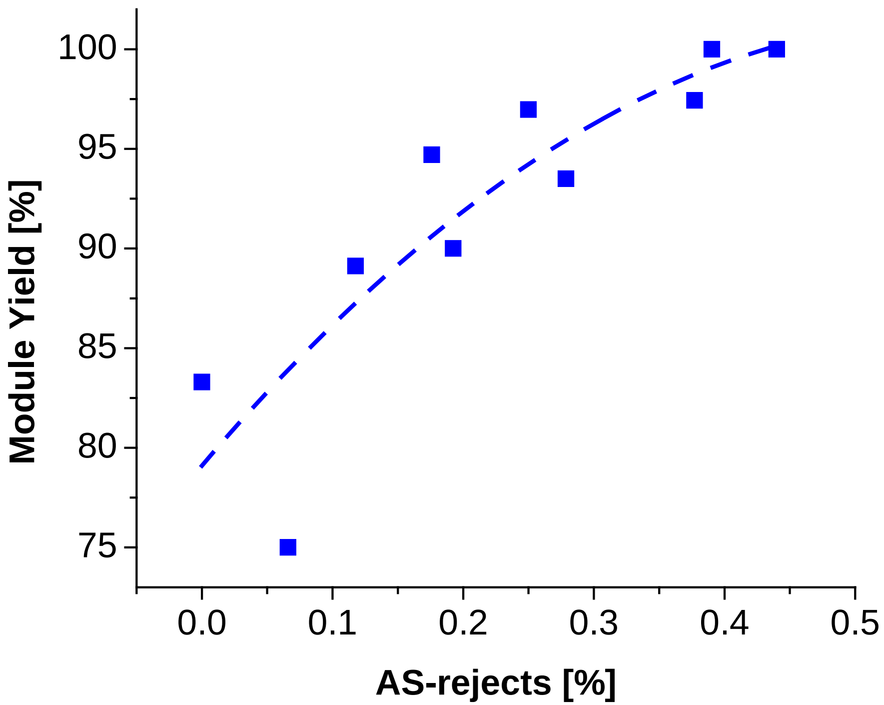


Improvement of average yield loss in RUV tested compared to control modules by 5.9% was statistically verified by Analyses of Variables (ANOVA) method.

Results and Accomplishments (continue)



Increase of solar module yield with percentage of AS rejects.



Daily crack test of RUV-AS prototype in solar module production.