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

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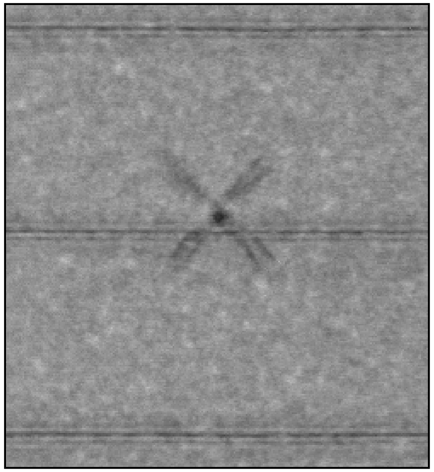
Project Objective

- **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

Challenges: (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

- Today solution: optical imaging of solar 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)

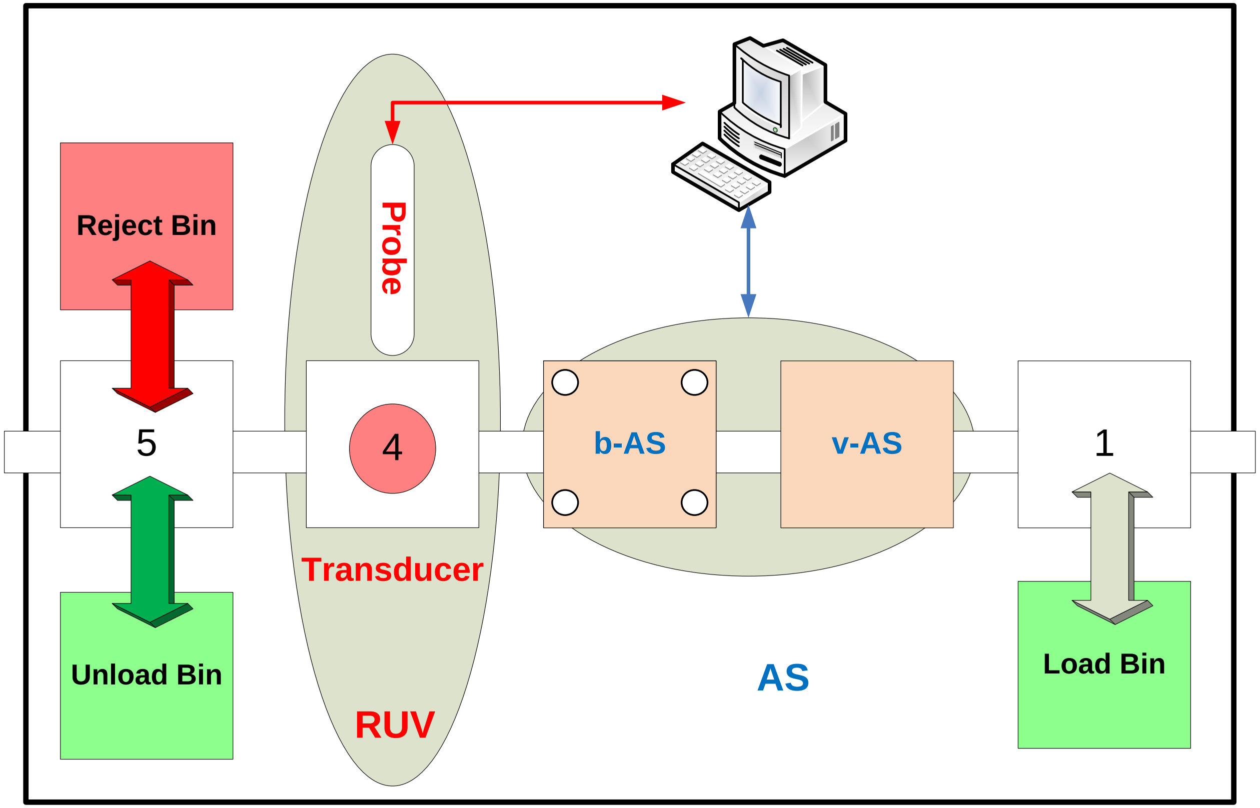
- In-line Activation Station is able to dramatically enhance RUV sensitivity toward short cracks without increasing cycle time.

- 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: bending and vacuum.

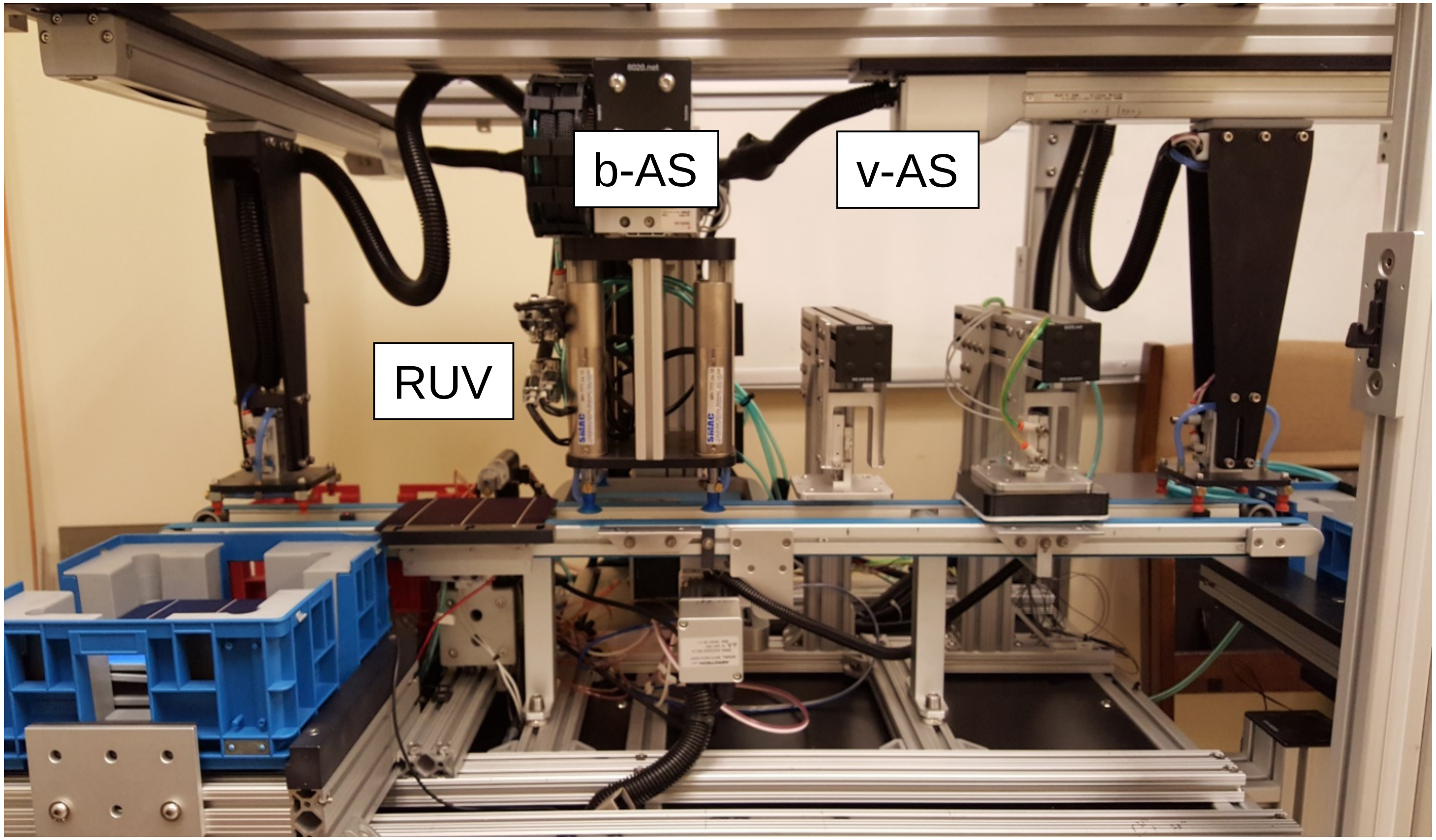
Laboratory prototype of the bend-type AS designed and tested in Phase II.

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

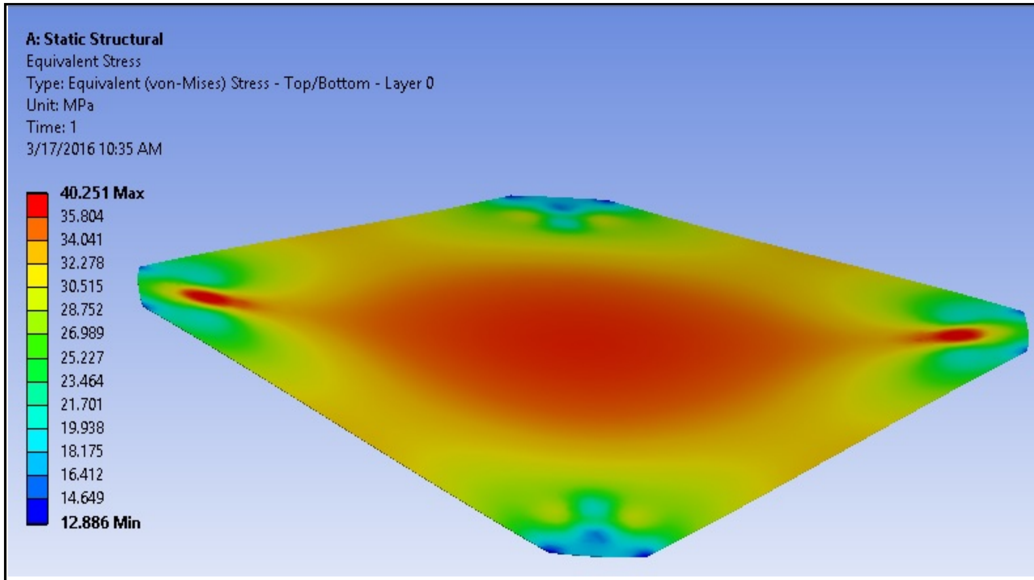


Figure 1*: Finite Element Analysis calculation of stress distribution when Si wafer is twisted with four vacuum cups at 12mm deflection. Additional high stress is observed in areas of vacuum cups.*

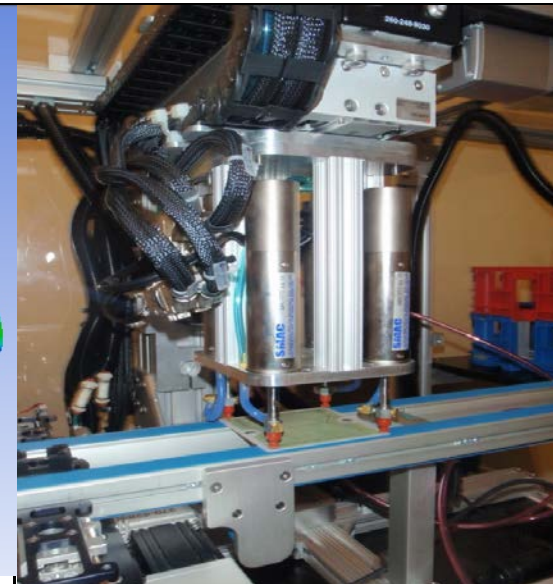


Figure 2*: Laboratory prototype of the bend-type AS designed and tested in Phase II.*

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.

Results and Accomplishments

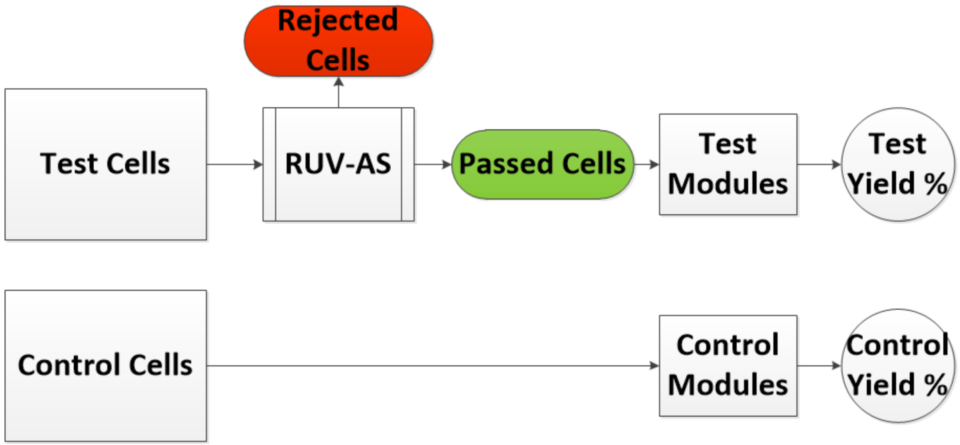
- Designed, manufactured, and tested a laboratory AS with two modifications: (a) bending activation with four vacuum cups (b-AS) and (b) vacuum activation (v-AS) using a quatrefoil vacuum chuck.
- Optimized the AS hardware using finite element analysis modeling.
- Designed a programming sub-system for controlled indentation of seed cracks in c-Si solar cell.
- Confirmed 100% wafer coverage of crack activation via combined AS tool. Confirmed findings using high-resolution Scanning Acoustic Microscopy.

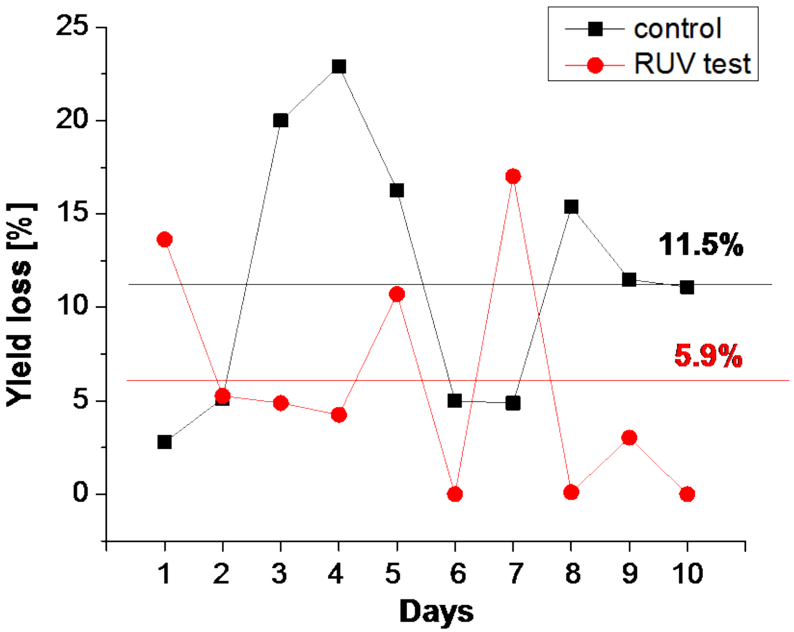
Results and Accomplishments (continue)

- Integrated b-AS and v-AS hardware and software with automatic RUV system. Demonstrated 2 seconds 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.
- Proved yield improvement correlated with efficiency of AS system.
- **AS-RUV system is tested at Solar Cells (Suniva) and Fuel Cells (Bloom Energy)**

Results and Accomplishments (continue)

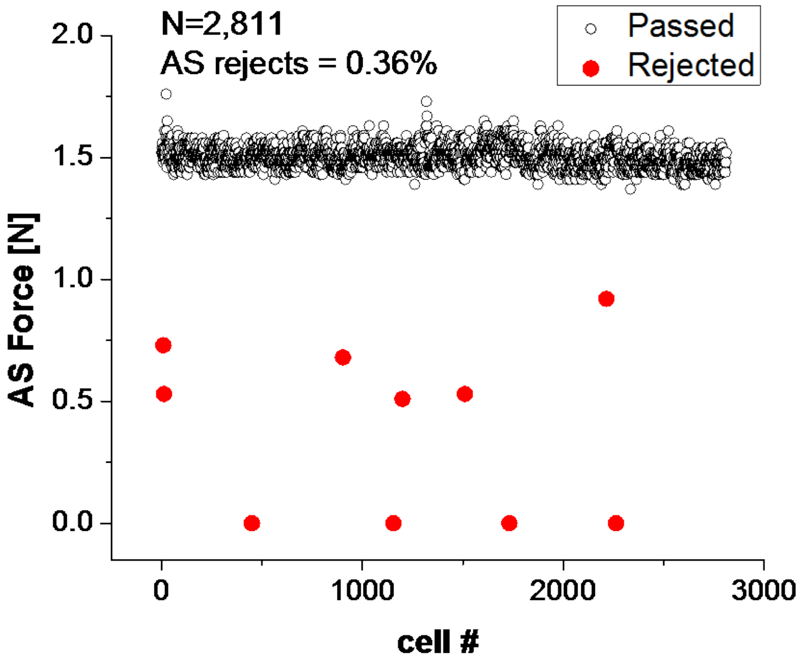
Following design of experiment was developed and implemented for AS-RUV system validation and in solar module production



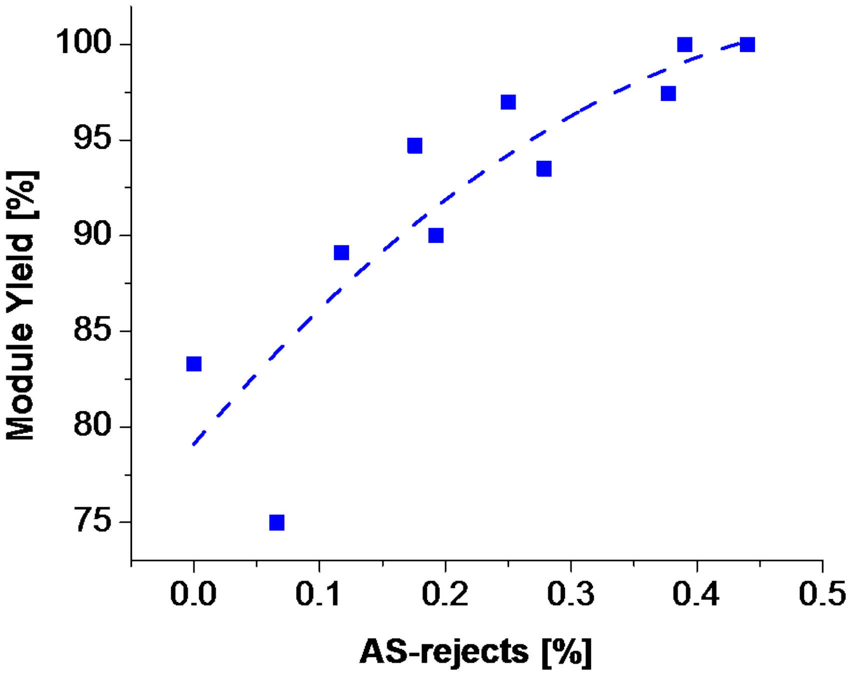


Improvement of average yield loss in RUV tested compared to control modules by 5.9% was statistically verified by Analyses of Variables (ANOVA) method.

Results and Accomplishments (continue)

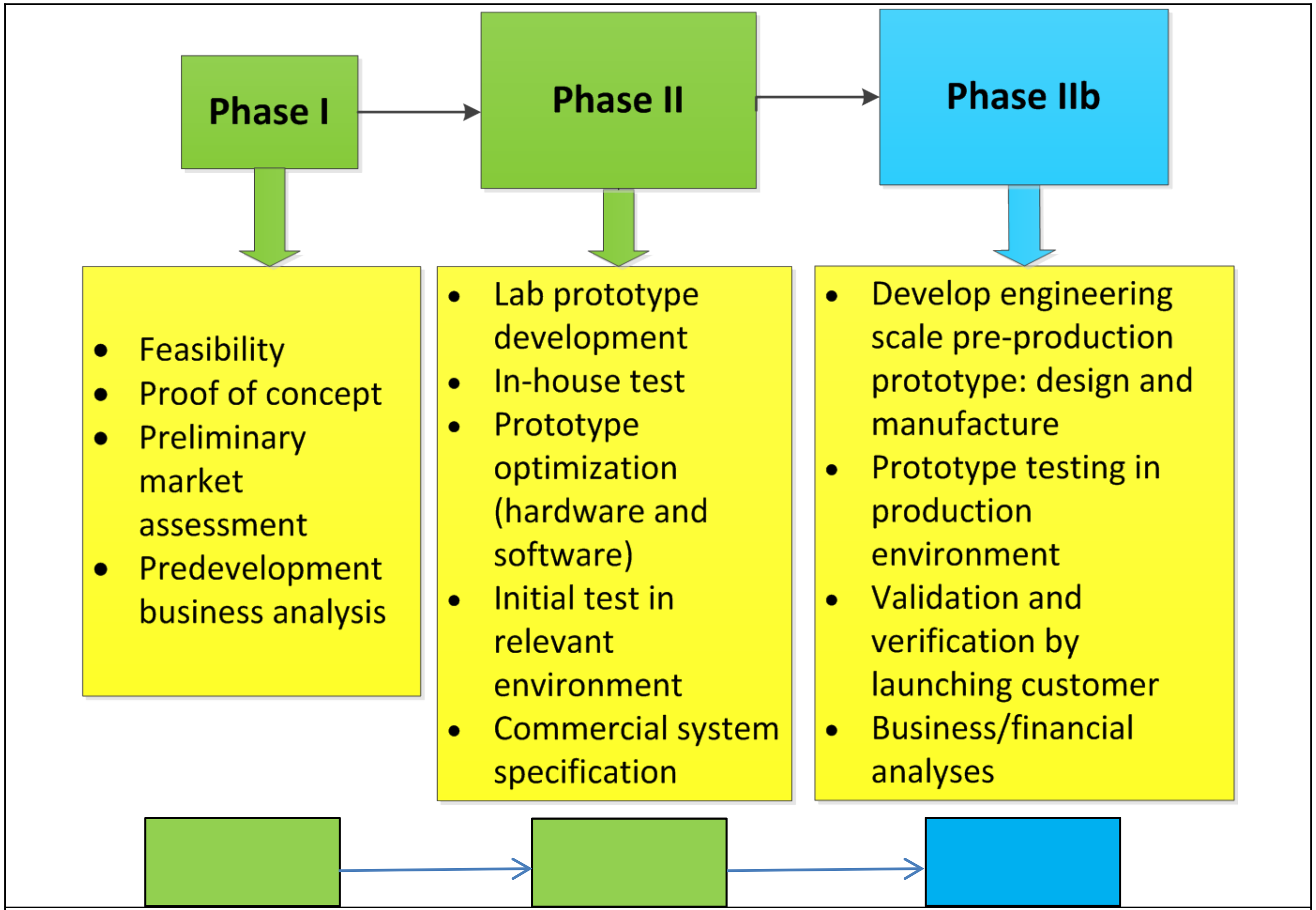


Increase of solar module yield with percentage of AS rejects.



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

Product Commercialization



Flow chart of the SBIR project leading AS system to commercial product.

Follow-up

- By the end of Phase II AS system will be at TRL5
- R&D steps will advance AS technology to TRL 7:
  1. Upgrade AS tool hardware using Programmable Logic Controller technology to improve AS reliability, accuracy, and maintainability.
  2. Upgrade AS tool operational software to allow handshaking with in-line commercial equipment.
  3. Improve throughput and ensure AS applicability to different shapes and types of substrates.
  4. Integrate AS tool in solar and fuel cell module production lines.
- **Commitment from partners: Solar (Suniva), Fuel Cells (Bloom Energy), PV equipment producer (Rimas Systems)**