Investigating performance variations and electrical resistance of Electrically Conductive Adhesives (ECAs) for Solar Cells.

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Introduction

This study evaluates the **electrical performance and reliability of Electrically Conductive Adhesives (ECAs) as interconnection alternatives to soldering** for solar cells, focusing on their compatibility with low-temperature curing and UV-assisted processes. These processes could be easily implemented in industrial tabber-stringer equipment, reducing production time and energy consumption in a high-temperature-free method. Three ECAs (ECA UV, thermal ECA and bicomponent ECA) were printed onto mini solar cells using customized printing methods to optimize line resolution and adhesion. Key parameters, such as series resistance (Rs), fill factor (FF), and point-to-point resistance, were evaluated. The most promising electrically conductive adhesive (ECA) (UV-curable) was dispensed from a syringe using a method compatible with automated equipment for industrial production. Its performance was evaluated to assess differences in electrical characteristics, and the method was applied to interconnect IBC solar cells, fabricate a mini-module, and investigate resistance behavior.

Experimental procedure

Application of Electrically Conductive Adhesives (ECAs) to Solar Cells

ECAs were applied to both standard and back-contact (interdigitated back contact, IBC) solar cells **using printing methods and semi-automated dispensing techniques**

- **Printing methods**: Manual and semi-automated processes were employed to deposit ECA lines onto designated contact regions of the solar cells.
- **UV curing**: A top-mounted UV lamp was used for curing, with uniform pressure applied manually to ensure optimal adhesion. Different volumes of ECA were tested.
- **Interconnection**: For back-contact architectures, semi-automated dispensing of UV-curable ECA was utilized to interconnect IBC cells. ECA drops were precisely dispensed to bond dogbone connectors to the cell surface, enabling targeted electrical connections.

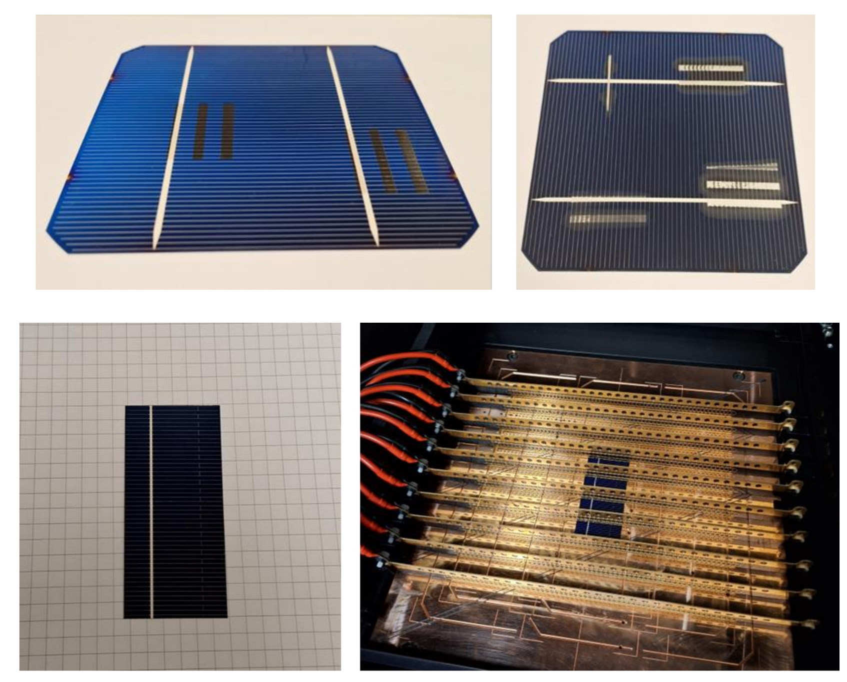

Figure 1: (top) First tests of printing ECA lines onto solar cells. (bottom) mini-cells employed for the study and their unconnected characterization using strips in the solar simulator.

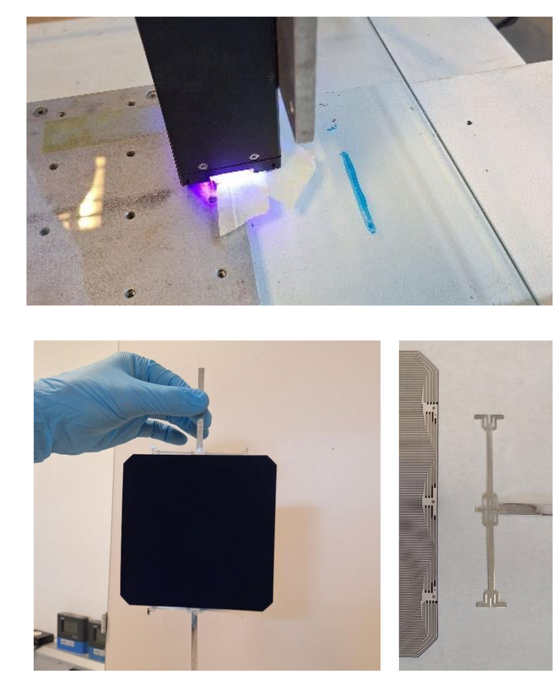

Figure 2: (top) UV-lamp used for curing the ECA from the top. (bottom) IBC cells with dogbones joined with ECA-UV.

Results

Standard solar cells (ribbon)

Material compatibility: The thermally curable ECA showed poor surface adhesion, while the bicomponent ECA was incompatible with the printing method. In contrast, the UV-curable ECA exhibited strong adhesion and compatibility.

Printing challenges: Automated printing required precise parameter tuning to avoid cell cracking.

Electrical performance variability: Some cells showed minimal resistance loss, but results were highly inconsistent, with many cells displaying a significant resistance increase due to uneven ECA application.

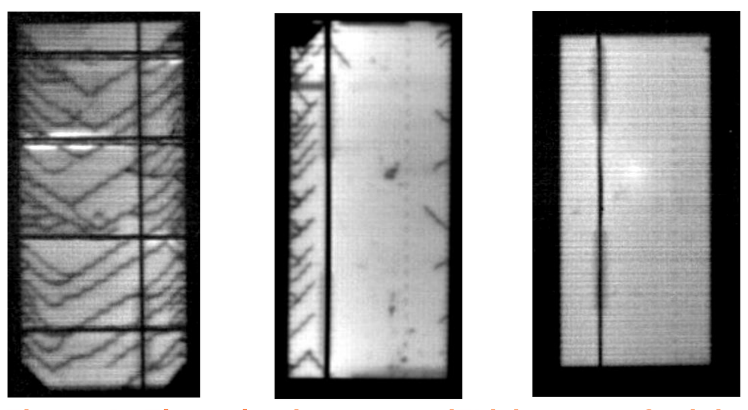

Figure 3: Electroluminescence (EL) images of mini-cells after applying ECA with different printing parameters. Samples 1–3 were printed under the same conditions as the rightmost reference sample.

Sample	FF (%) w/strips	FF (%) w/ECA	R_s (%) w/strips	R_S (%) w/ECA
MINI-CELL-1	77.0	72.0	35.7	70.5
MINI-CELL-2	75.8	75.9	35.8	27,3
MINI-CELL-3	76.2	74.6	31.8	46,8

Table 1: Fill factor (FF) and series resistance (R_s) of three samples, measured via strip-based testing and ribbon-based connection using ECA-UV.

IBC solar cells (interconnection)

Interconnection: Two IBC cells were interconnected using a UV-curable ECA droplet dispensed from the top onto the backside of an upside-down cell.

Post-lamination: The interconnection resistance decreased, suggesting that thermal exposure during lamination enhances the curing process.

Performance comparison: Compared to a reference module using traditional welding.

PCE (abs) = -1.7%

FF (abs) = -5.3%

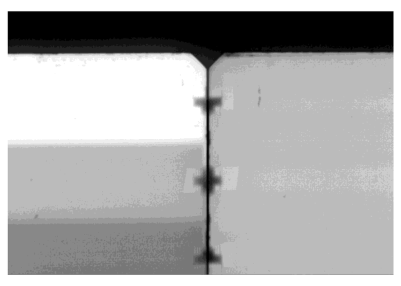

Figure 6: EL with intensity changes per connected area, associated to different connection resistances.

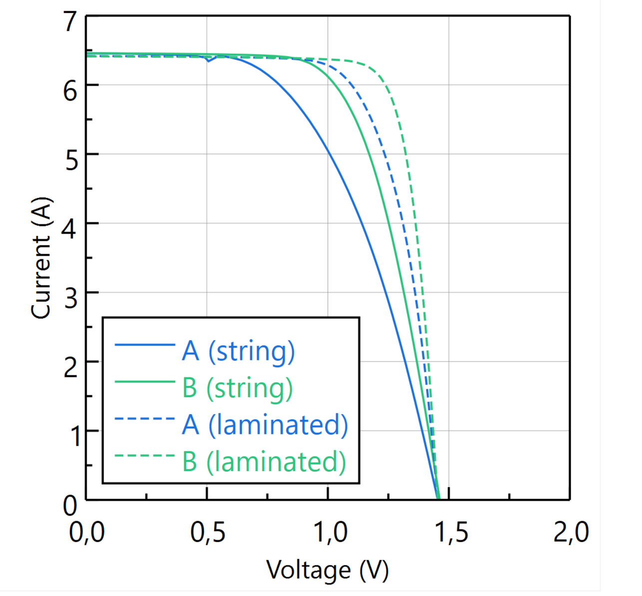

Figure 4: I-V curves of ECA-connected IBC cells mini-modules before and after lamination.

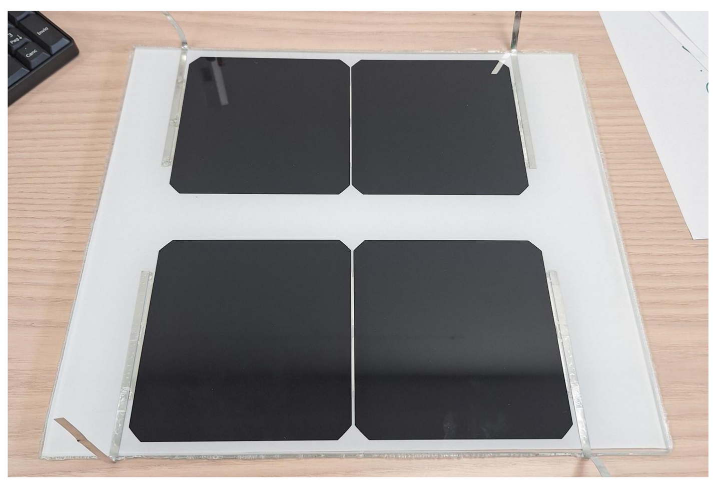

Figure 5: Mini-modules of 2 cells interconnected with ECA-UV, after lamination.

Conclusions

- **Cost and Process Advantages**: Electrically conductive adhesives (ECAs) eliminate the need for high-temperature welding, offering potential cost and complexity reductions in photovoltaic manufacturing. We demonstrated the feasibility of curing UV-ECA with a top-mounted UV lamp.
- **Validation of UV-Curable ECA for Standard Cells**: The UV-curable ECA was validated as a viable alternative to traditional soldering for the top-contact of standard solar cells. However, inconsistent results highlighted the sensitivity of printing parameters to performance. Further optimization is required to ensure reproducibility and long-term reliability.
- **Successful IBC Cell Interconnection**: UV-curable ECA enabled the fabrication of strings and mini-modules by interconnecting IBC cells. Despite semi-manual, non-optimized processes and FF losses, post-lamination mini-modules achieved efficiencies exceeding 22%, demonstrating ECA's potential as a scalable alternative. To prevent disconnections during lamination, it is critical to secure interconnections with a non-conductive adhesive (e.g., tape or glue) prior to final lamination.

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