Effect of carbon nanotubes in conductive adhesives for photovoltaics

ISC research for a sunny future

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Motivation

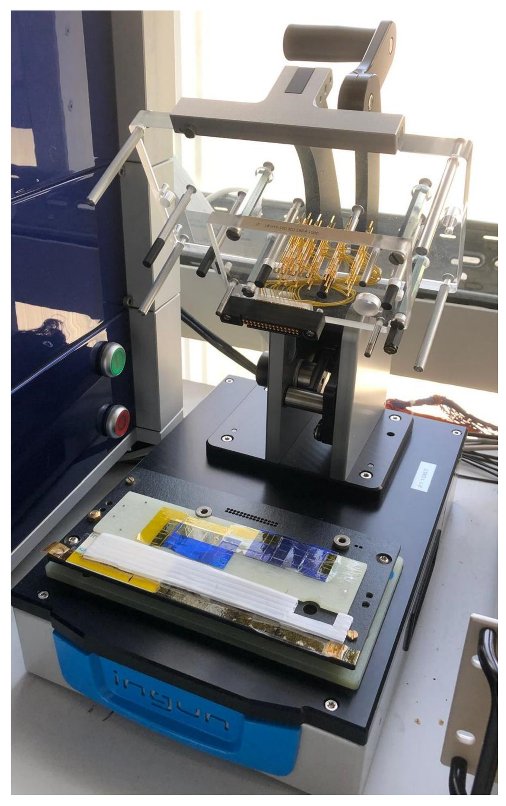
Relevance: Shift to Pb-free, low-temperature and low-silver PV with reduced costs drives need for better conductive adhesives (ECAs)

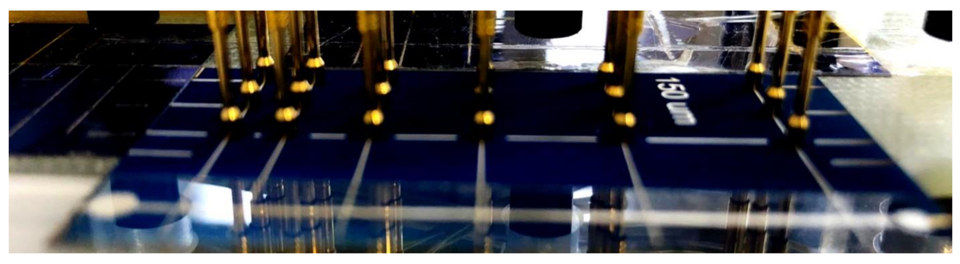
Potential: Carbon nanotubes (CNTs) could enhance conductivity, stability, and strength in ECAs, improving PV module performance.[1-4] CNTs are more expensive than silver on a per-weight basis, but tiny amounts of these nanomaterials usually have a big effect

Challenges: Obtaining homogeneous CNT dispersion in ECAs; unknown effects on PV module degradation; lack of knowledge regarding how much should be used; huge variety of CNTs and their properties

How do we test?

- Measuring contact resistivity with high accuracy is challenging for ECA-paste interfaces, unlike metals-semiconductors[5]
- ISC in-house developed hardware, software, test structures and methodology is used[6]





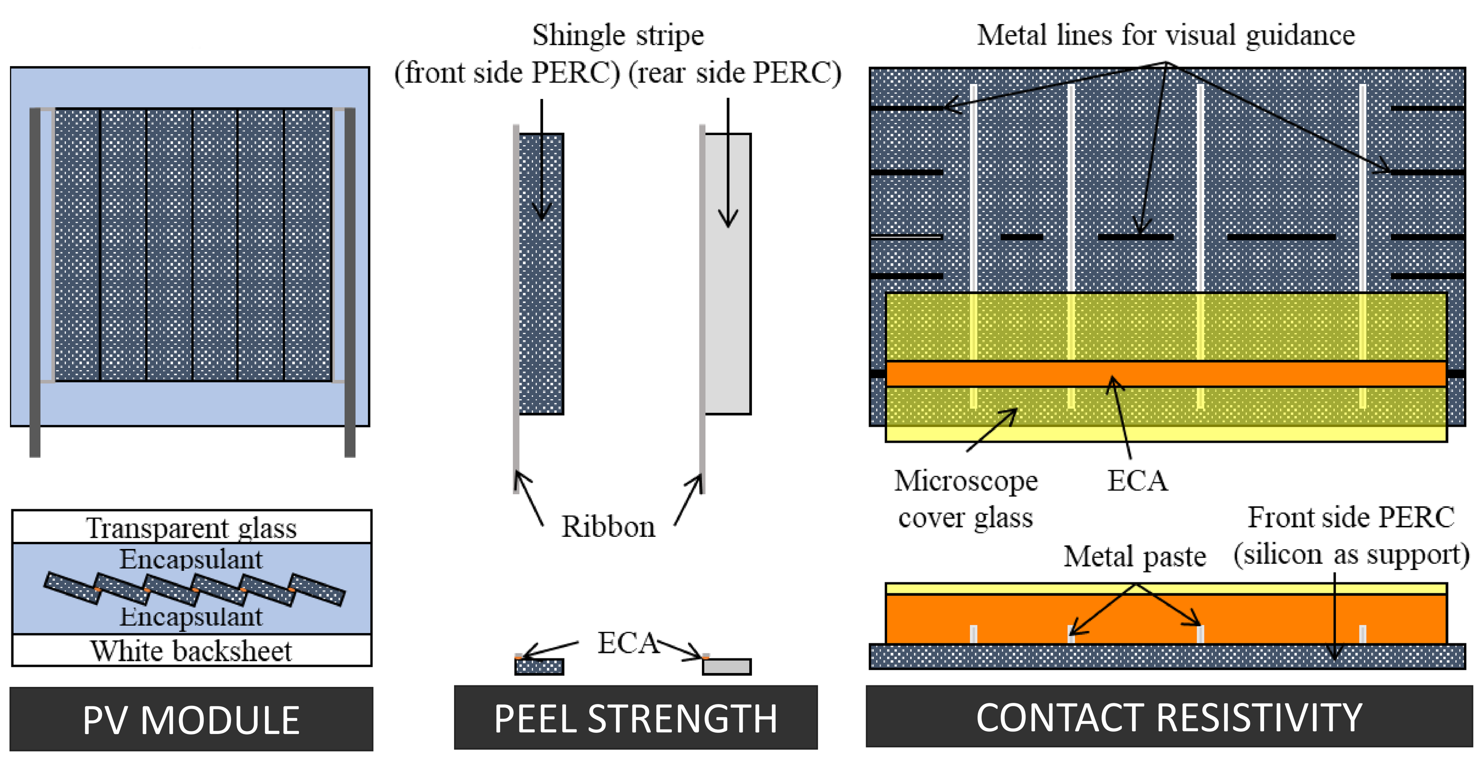
Experimental design

- Commercially available CNT-Epoxy (already mixed in epoxy resin) was added to silver-based epoxy ECAs in various weight%

CNT-free reference (G00); Increasing CNTs (G01 → G04)

Group	Ag filler	Epoxy-1	CNT	Epoxy-2	Fillers	Polymer
G00	70.00	30.00	0.00	0.00	70.00	30.00
G01	69.30	29.70	0.05	0.95	69.35	30.65
G02	70.15	25.97	0.19	3.69	70.34	29.66
G03	69.01	24.25	0.34	6.41	69.35	30.65
G04	68.22	19.24	0.63	11.91	68.85	31.15

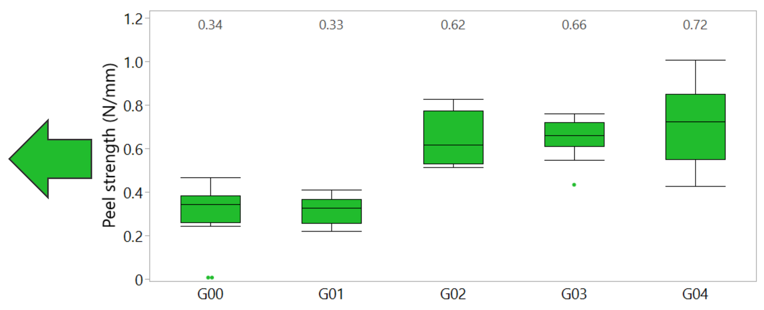
- To isolate the effect of the CNT-Epoxy, the source ECAs were chemically identical (resin, filler and additives) but had different loadings of silver filler particles such that the silver filler content was comparable after addition of CNT-Epoxy
- Minimodules and test structures were produced as shown below



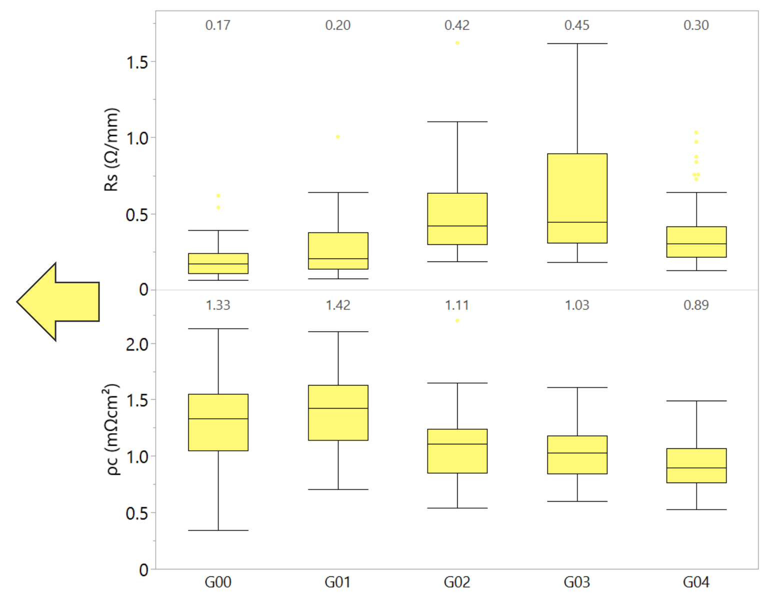
- **Shingled minimodules** (only G00 & G04) using PERC cells in a glass-backsheet configuration with POE encapsulant
- **Peel strength** of cell metallization-ECA-ribbon (Ag-coated copper)
- **Contact resistivity** between cell metallization and ECA was tested using a dedicated test structure
- The ECA lines/bonds (in all sample types) were cured in an industrial laminator for 10 min at 180°C under 1 bar and modules were subsequently laminated using standard POE conditions

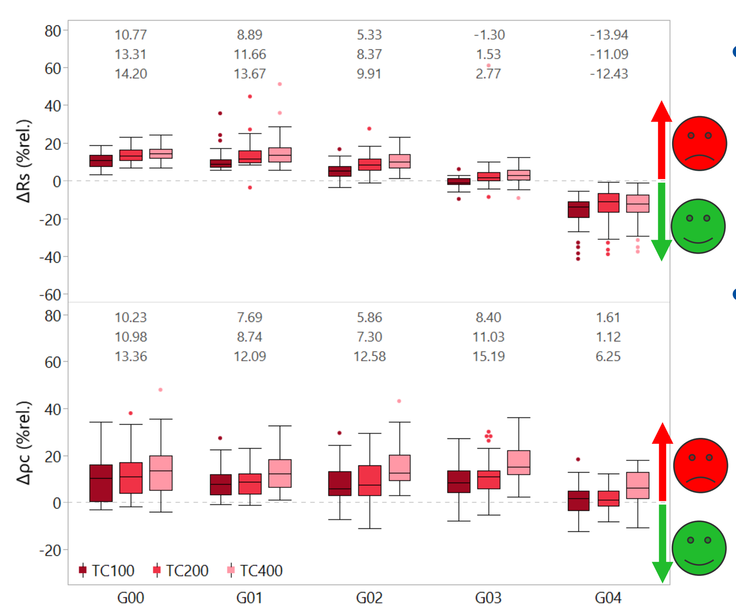
Results

- Adding 0.05 wt% of CNT-Epoxy does not impact peel strength
- More than 0.19 wt% does not further improve mechanical properties

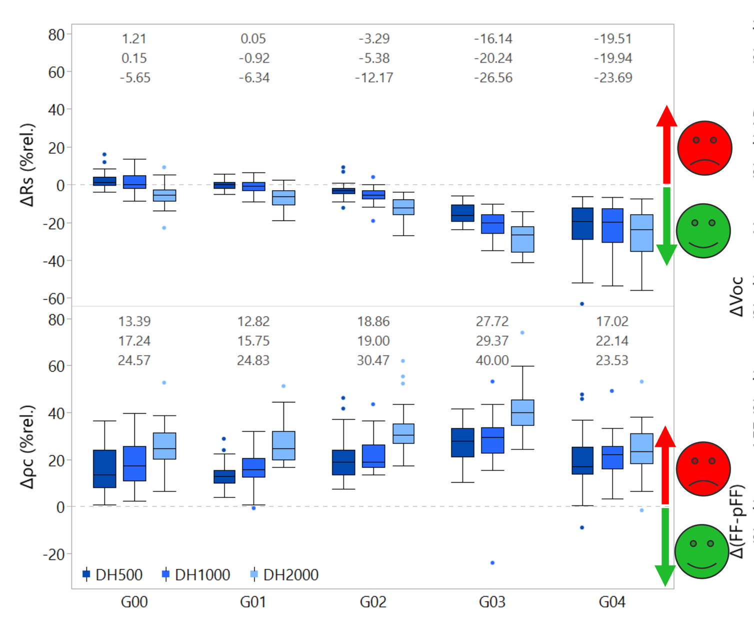


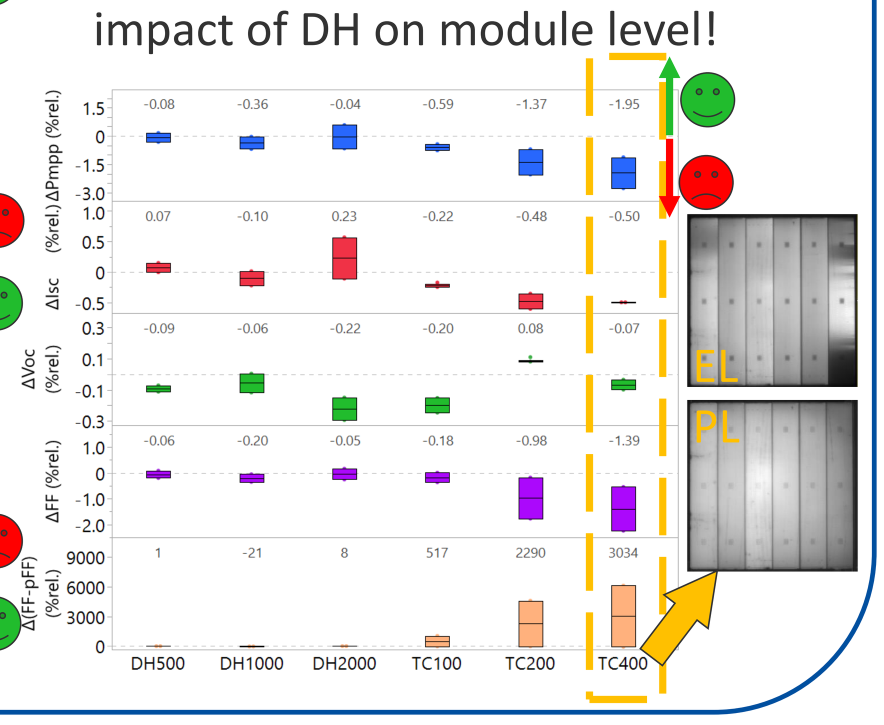
- Specific sheet (R_s) and contact (ρ_c) resistivities are affected differently by CNT-Epoxy
- CNT-Epoxy > 0.19 wt% gives improved ρ_c
- R_s increases with CNT-Epoxy up to 0.34 wt% then decreases when adding 0.63 wt%





- **TC test**: increasing CNT-Epoxy reduces degradation of both R_s and ρ_c with best performance from the highest CNT-Epoxy (0.63 wt%)
- **DH test**: R_s improves during test. More CNT-Epoxy gives a bigger improvement. ρ_c degrades but for the highest CNT-Epoxy dose the impact is less than without CNT. No impact of DH on module level!





Conclusions

- Adding CNT-Epoxy to silver-based ECAs increases peel strength. However, there is a minimum amount at which the mechanical adhesion is increased and up to a certain degree there is no further increase
- Contact and bulk resistivities are affected differently by the addition of CNT-Epoxy: bulk conductivity tends to improve while the contact resistivity is degraded
- As well as adding CNTs, the base polymer of the ECA was also diluted to varying degrees by the added epoxy resin and the effect of this could not be de-coupled from the effect of adding just CNTs. Future investigations should mitigate this so as to better isolate the effect of the CNTs on their own

References

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