The New Age of Silicon Photovoltaic Modules: Optimisation with Half cells, Ribbons, Films, Wires …


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Metallised Encapsulant for Silicon PV Modules: A Path to Reduced LCOE for PV

Project Duration: 06/12/2017 to 30/06/2021

Partners

- LONGi Solar (Module Group)
- Sizhuo PV Tech
- DSM Advanced Solar (Netherlands)
- ANU
- ECN part of TNO
Cell Interconnection

- Historically modules have been interconnected with flat ribbons soldered to the cell BBs.
- $2\text{BB} \rightarrow 3\text{BB} \rightarrow 5/6 \text{ BBs} \rightarrow \text{MBB (} \downarrow \text{Ag,} \downarrow R_s \text{)}$.
- Ribbons have become thinner and narrower (1.5 mm for 3BB, 0.7-0.9 mm for 5/6 BB)
Wafer and Cell Sizes – For more power!

- Half cells → ↓ Ag, ↑ Power
- No cell gaps, bigger wafers (M2 → M6, M12)

Shingling …

- Lots of initial excitement with SunPower’s shingled module
- Many companies can now produce shingled modules
- But is interest waning?
- Complex patent situation
- Technical issues?

Dickson’s shingling patent in 1960, just 6 years after Chapin’s first silicon cell.
Proposed mainly for powering satellites at early stage.
Obvious way of interconnecting cells?

Fig. 1 of US 2,938,938 to Dickson

Problems in ‘Shingle-town’

- Ag consumption in today’s edge-glued shingled modules is greater than for 5BB
- 5% of cell area is lost with overlap
- High failure rates in manufacturing
- High ECA cost


(Honda Dream, 1996 “World Solar Challenge” Solar Car Race winner, used UNSW shingled PERC cell modules.)
But everyone seems keen on MBB!

- Screen-print Ag tabs on the cell and then IR solder wires to the Ag tabs.
- Easily adapted to half-cell modules.

- The wires both ‘scatter’ (indirect) and ‘redirect’ incident light on the ribbon into the solar cell.
- The big attraction of MBB over Smartwire Connection Technology (SWCT) is that MBB can use similar tabbing equipment.

Tiled Ribbon/Paving/Seamless Soldering

But how does a manufacturer decide what module technology to use?
It’s not just about Module Power!

- In the past, it was all about module power under standard test conditions (STC).
- But yield (electricity generation) and LCOE are becoming more critical.

Higher power modules do not always result in more electricity!

$/kWh and kWh_{(AC)}/kW_{(DC)}$ are the new metrics

Nominal power → Electricity Yield → Temperature coefficients & NMOT

Climatic Conditions
E.g., Irradiation intensity (angle, spectral), temperature, wind
How to Reduce $/kWh?

- Increase Module Power (more W)
- Reduce Module Cost (less $)
- Increase Module Durability (more kWh)
Reducing $/kWh: (i) Increase Module Power

- Reduce $I^2R_s$ losses → half (or smaller) cells (i.e., keep I low, reduce Rs)
- Improve optics – many options 😊
  - Round wires
  - LRF
  - Structured ribbon

Reducing $/kWh: (i) Increase Module Power

$J_{SC}$ (power) enhancements (compared with flat ribbon) from LSF and LSR depend on the film/ribbon geometry.

Y. Li et al. (2019) Comparison of Ribbon Light Management Designs for Photovoltaic Modules, IEEE PVSC, Chicago, IL, US.
Reducing $/kWh: (ii) Increase Module Durability

- Improved durability (lower degradation rate)
  - Directly reduces LCOE (Sunshot 2030 goals)
  - Improves profitability of investments (internal rate of return; IRR)
  - Important differentiator for ‘brand’ marketing

Reducing $/kWh: (ii) Increase Module Durability

Finite element modelling can be used to predict how and where stress can be induced in silicon wafers and metal by cell interconnection methods.

Learning so far ...
- Cross-sectional shape of interconnectors affects stress induced in Si by soldering
- Cell metallisation can be adapted to minimise this stress

P.-C. Hsiao et al. (2019) Comparative Models of Induced Thermomechanical Stress in Silicon Solar Cells Interconnected with Conventional Tabbing and Wire Based Interconnection Methods, IEEE PVSC, Chicago, IL, US

J. Ma, M. O’Neill, Q. Nie, R. Wan, M. Strommen, A. Lennon, Y. Li, P.-C. Hsiao, Optimizing Silicon PV Module Power and Reliability Using Light Management Solutions, PVSEC 2019, Xi’an, China
Increasing $\text{kWh}_{(\text{AC})} / \text{kW}_{(\text{DC})}$

Difficult to quantify

Yield measurements take a long time, need to have accurate simulations
Optimising for kWh\(_{(AC)}\)/kW\(_{(DC)}\)

Yield depends on many factors
- Location
- Orientation/tilt
- +/- tracking

Optimising for power does not necessarily result in greater yield! Developers want a return (kWh) on their investment (kW)

Yield depends on many factors
- Location
- Lat: 31.2
- Tilt: 26.0
- Orientation: South
- Temperature: 25 °C
- Both direct/diffuse components considered
- Insolation: clear-sky

Yield simulations performed using Angular Matrix Framework (AMF)

and the Conclusion is?

- How you make modules right now is a really hot topic!
- It is costly (in time and $$) to develop multiple interconnection technologies in parallel to cover your bets.
- There is scope for modelling (stress and optical) to identify technological paths that are not viable and to more accurately predict yield.
Thank you!