Performance and reliability characterization of conductive inks for solar cell front grids and busbars

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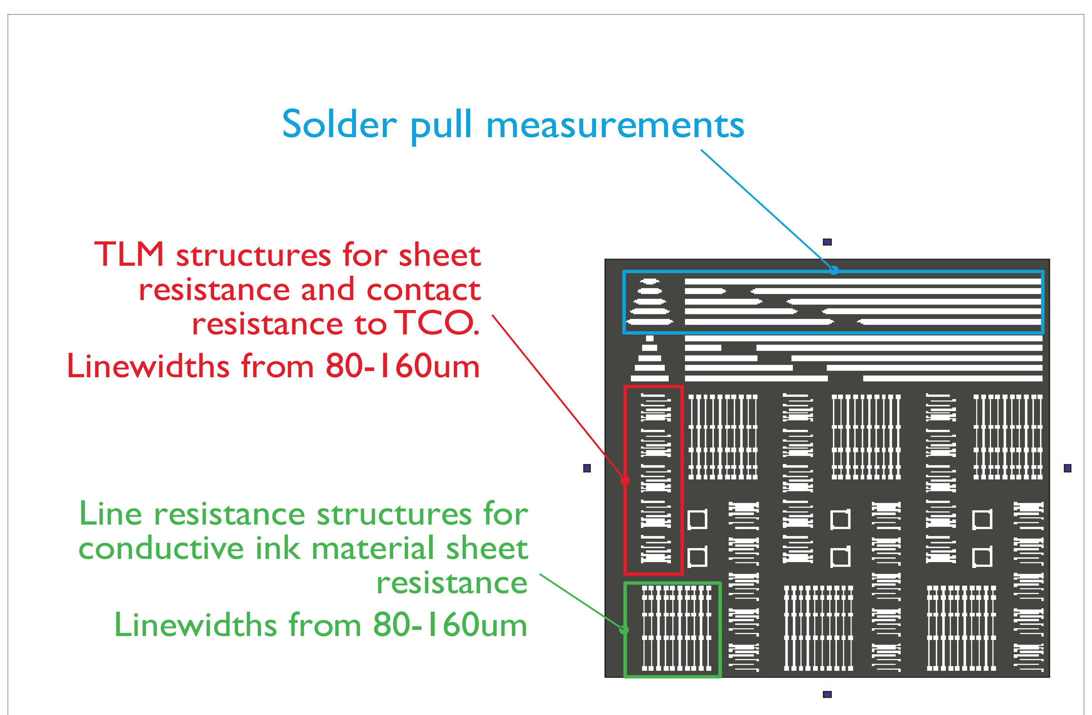
The temperature sensitivity of thin film CIGS cells and next generation crystalline silicon devices requires alternative metallization schemes for current collection and cell interconnection such as low temperature curable conductive inks. In addition to low contact and line resistance, ideally the conductive material should be solderable allowing serial connection of cells by tabbing and stringing of cells with solder coated copper ribbon. In comparison to traditional frit-fired silver pastes, silver filled conductive inks have both higher contact and line resistance due to the polymeric binder which can also reduce the metal surface available for soldering to the solder coated copper ribbon. In order to evaluate conductive inks for solar application, it is important to characterize both the electrical and mechanical characteristics pre- and post- reliability testing. In this study, a number of materials were characterized for their suitability as screen printed fingers and busbars both initially and as a function of reliability testing per IEC61646/61215 using non-encapsulated cells. Two materials were found as candidates for grid and busbar respectively that met the requirements for electrical and mechanical properties after reliability testing.

Electrical and mechanical characterization

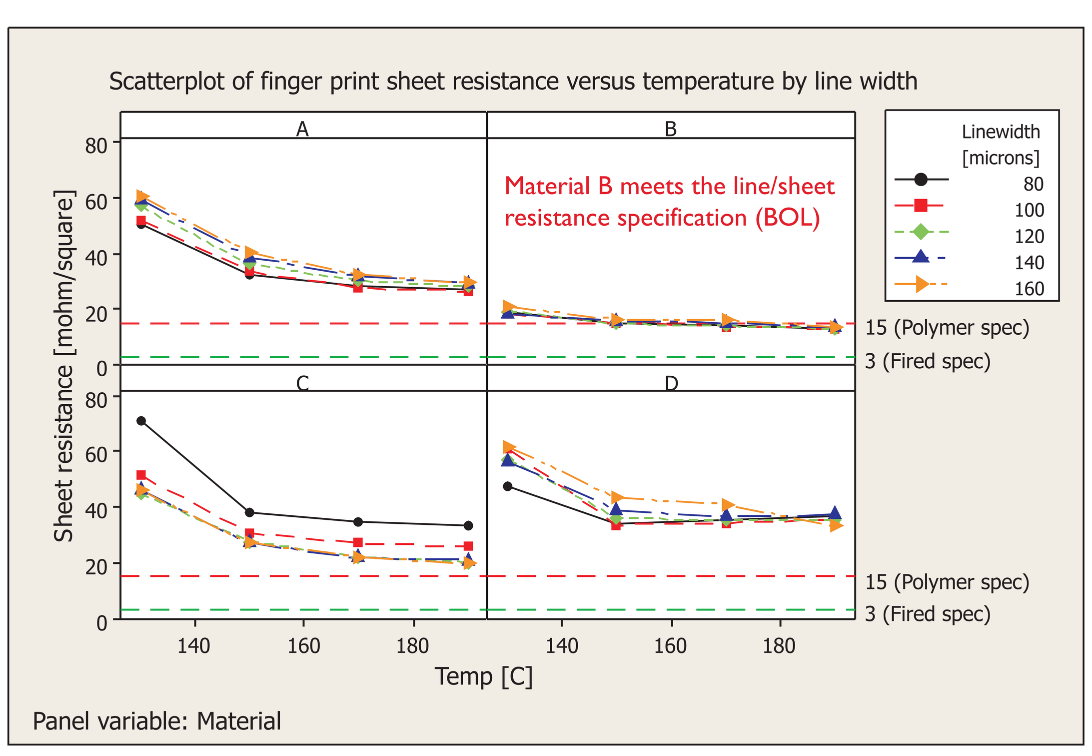
Conductive inks were evaluated for their suitability as both a conductor and interconnect surface using a screen printed test structure to evaluate the following parameters.

- Line resistance
- Contact resistance to surface e.g. TCO
- Print resolution - minimum line width
- Curing temperature
- Solderability - peel strength to cell surfaces



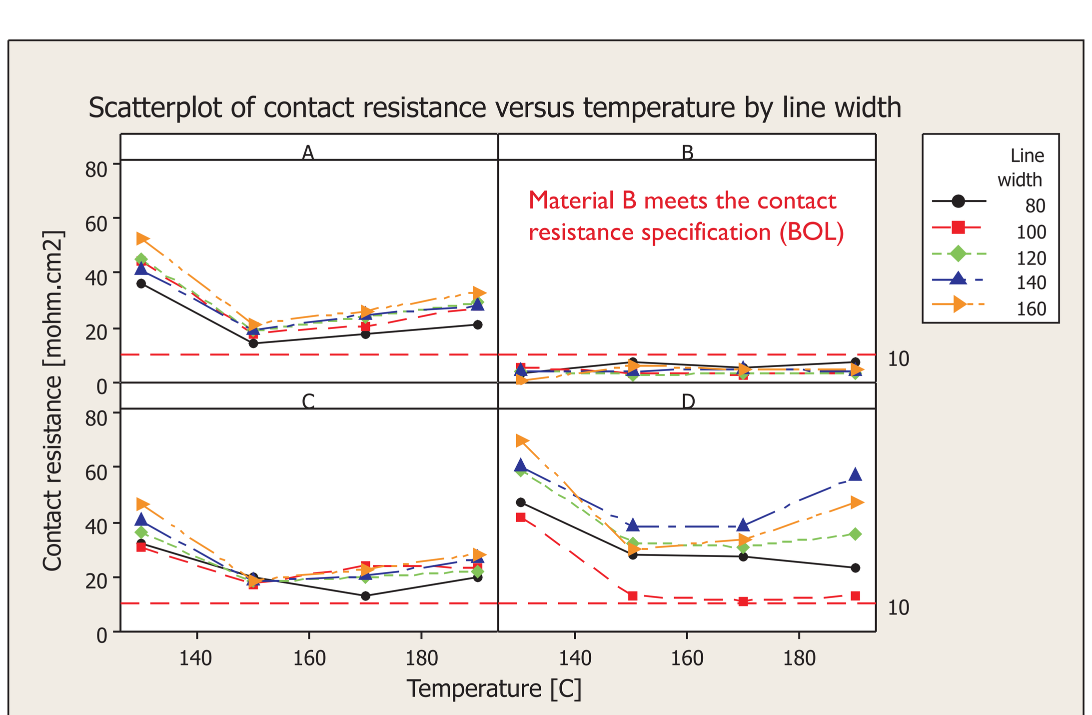
Line resistance versus curing temperature

As curing temperature increases, line resistance decreases. Print resolution issues at narrow line widths are revealed as higher sheet resistance when normalized to screen line width e.g. for material C 100um and 80um line show higher sheet resistance than expected.



Contact resistance vs curing temperature

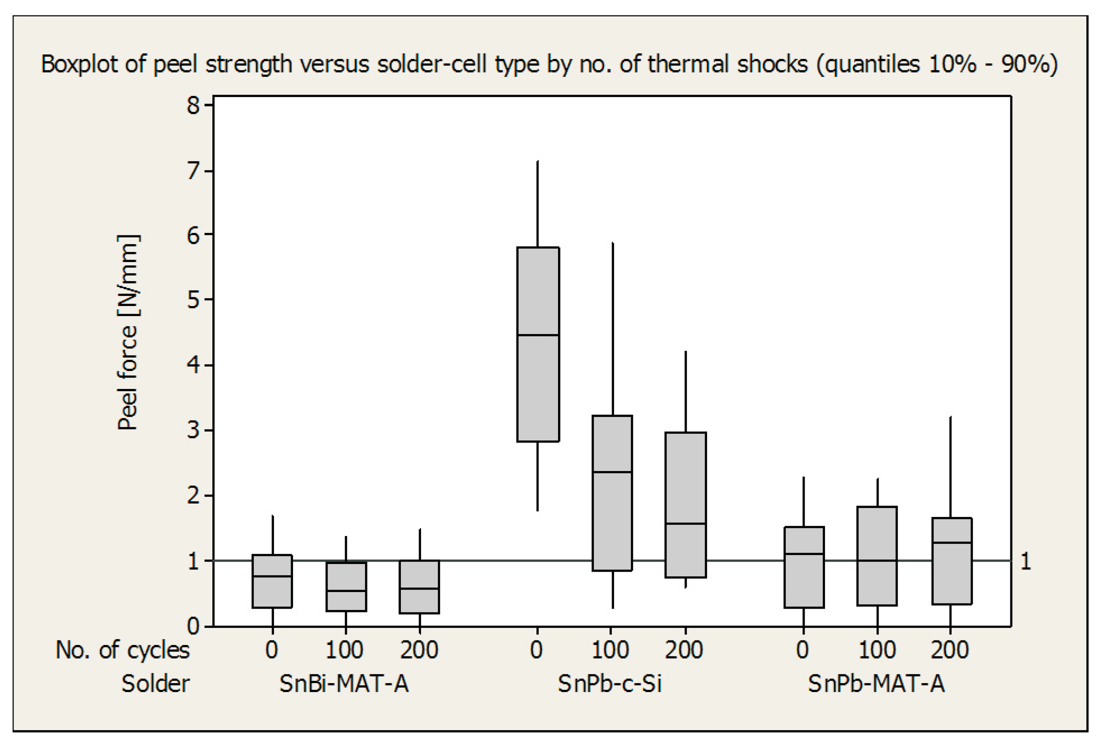
As curing temperature increases, contact resistance also decreases to a minimum but increases again as the conductive ink polymer binder begins to degrade. The maximum curing temperature is dictated by this minimum contact resistance value and the temperature sensitivity of the cell.



Based on the material and process evaluation for the conductive inks, material B was found to meet the requirements for sheet resistance of 15mohm/square and contact resistance of 10mohm.cm^2 at process temperatures below 200C.

Solder peel strength

Ideally, the material with the best electrical properties for grid (material B) would also be solderable allowing single step printing. However, this and many other materials were found to delaminate from the cell surface during soldering and only material A showed good solder peel values for both low temperature SnBi and conventional SnPb ribbon. Solder peel strength values are typically lower than a conventional fired contact but median values of 1N/mm were measured which remained stable over 200 thermal shocks in comparison to c-Si fired frits which start off higher but deteriorate with stress.



Reliability testing

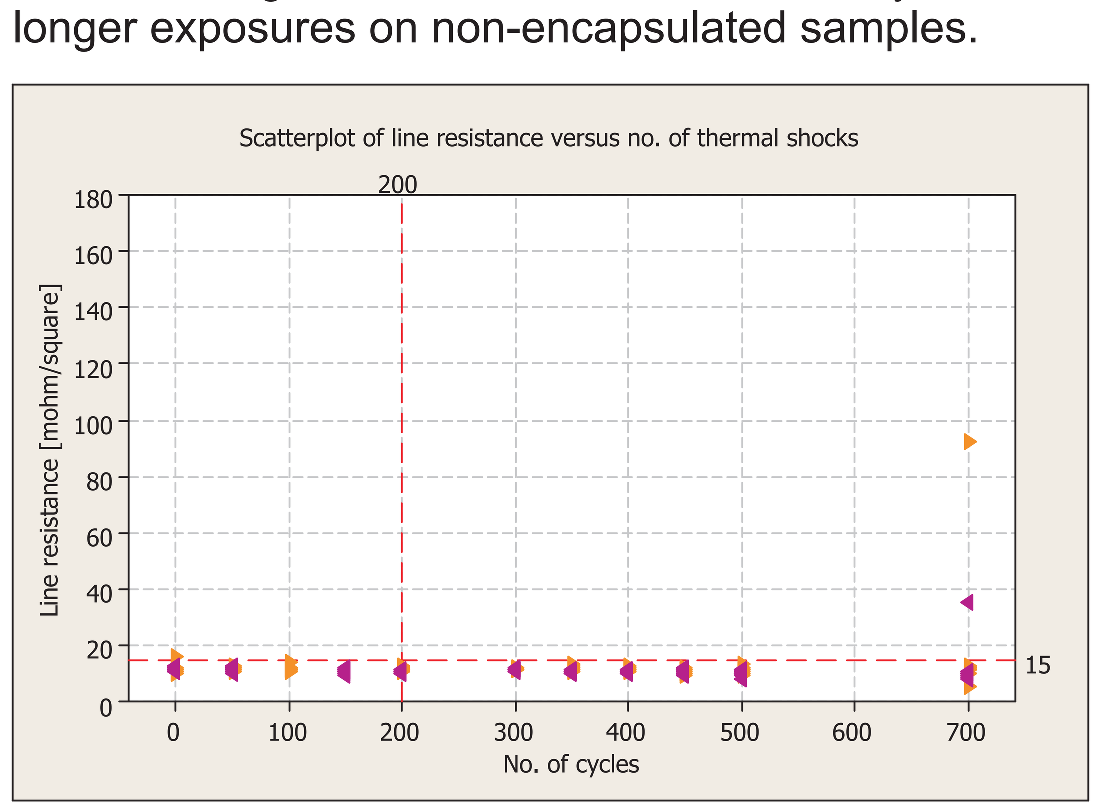
In addition to the solder peel strength of the busbars, the electrical characteristics of the grid materials were evaluated through reliability testing:

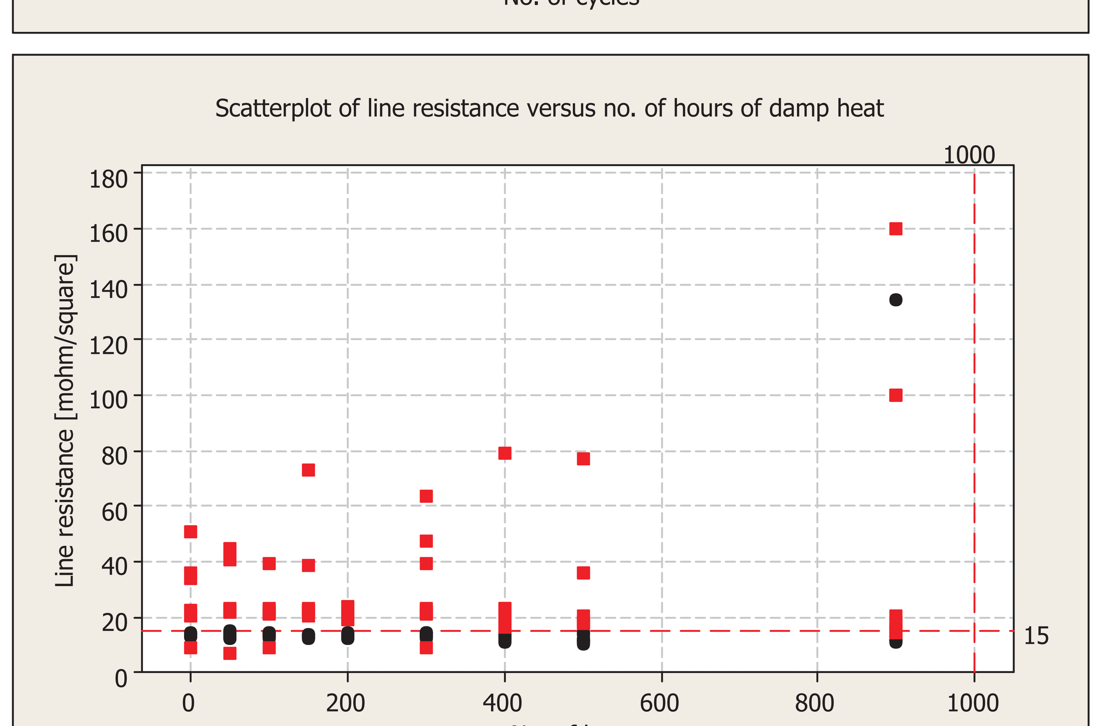
1. Thermal Shock (-40C to 90C)
2. Damp Heat (85C/85%RH)
3. Humidity Freeze (-40C to 85C/85%RH)

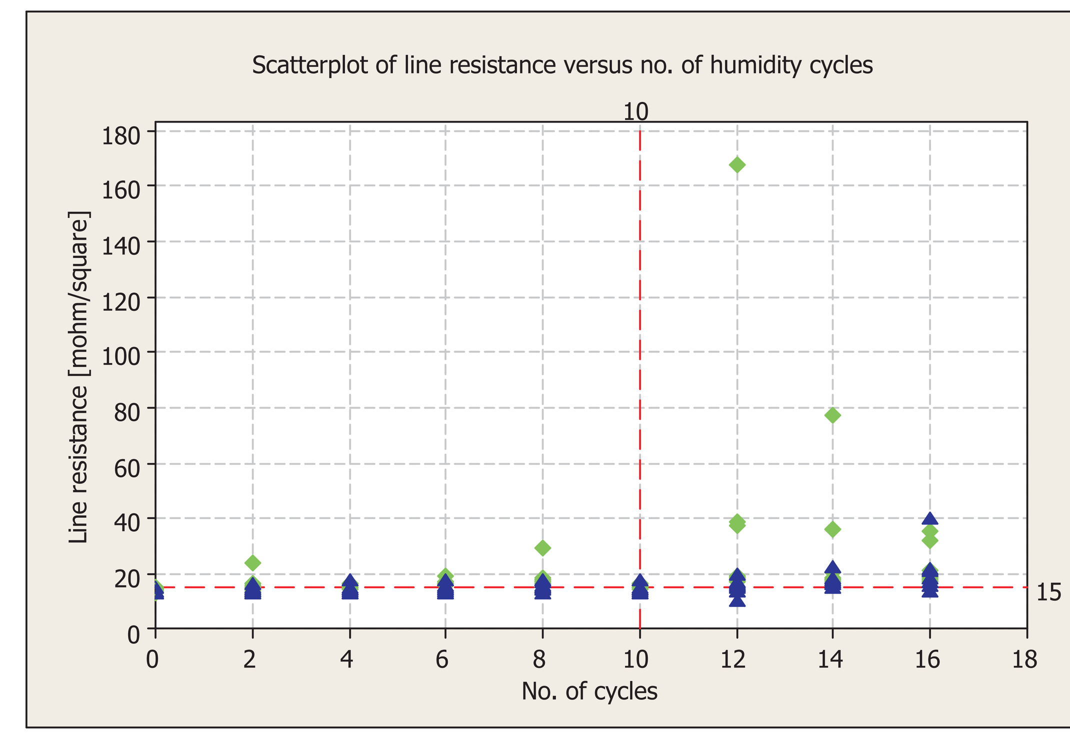
For worst case analysis, non-encapsulated test vehicles were used for these tests to determine the impact of both humidity and thermo-mechanical stresses on the materials. For edge sealed modules, moisture related failure modes e.g. damp heat, humidity freeze are eliminated but thermo-mechanical stresses are still present.

Line resistance versus reliability

Line resistance is seen to be very stable for thermal cycling stresses well in excess of IEC requirements but some degradation is observed in humidity tests for longer exposures on non-encapsulated samples.

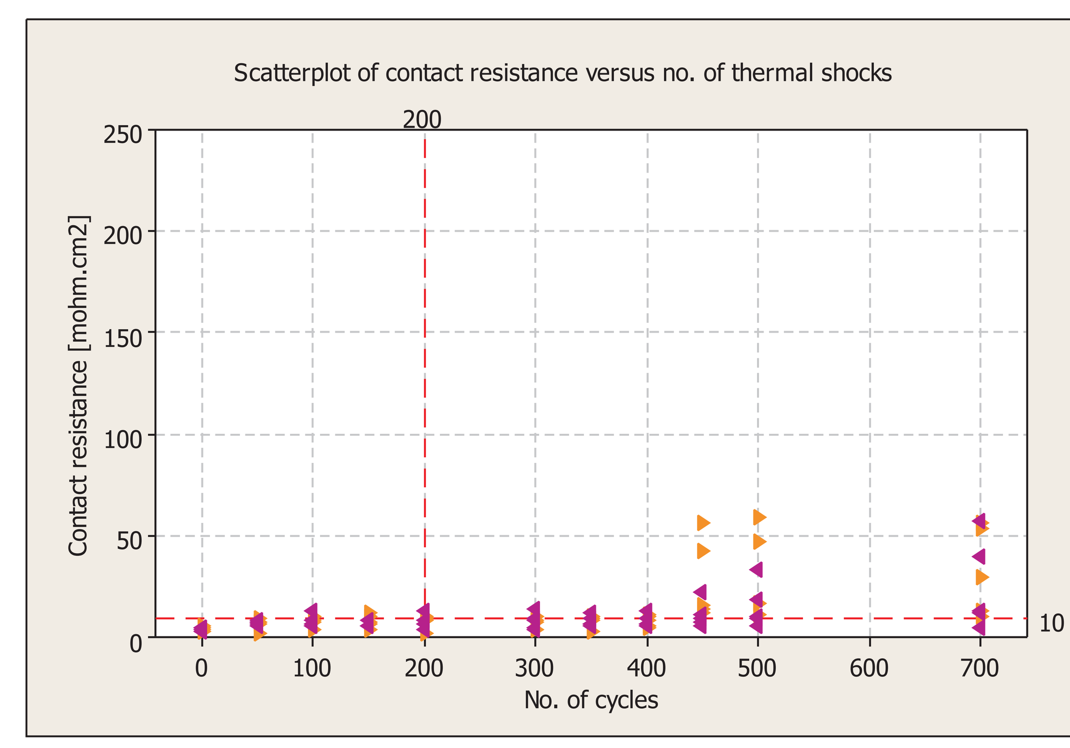


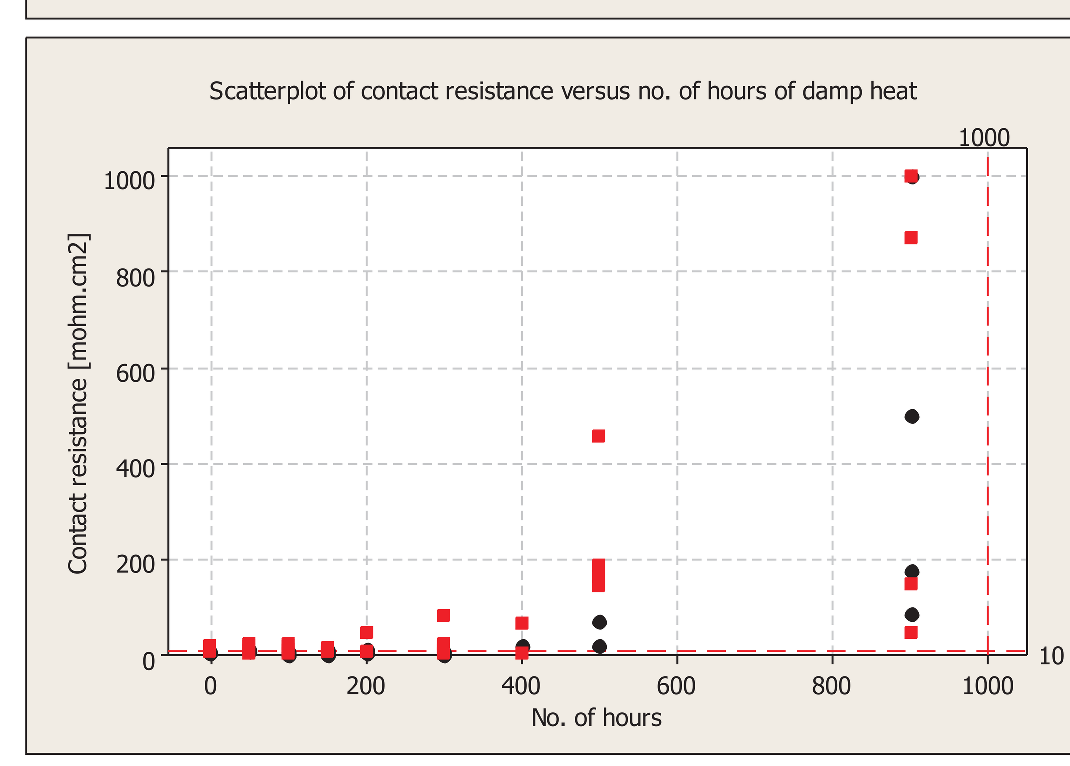


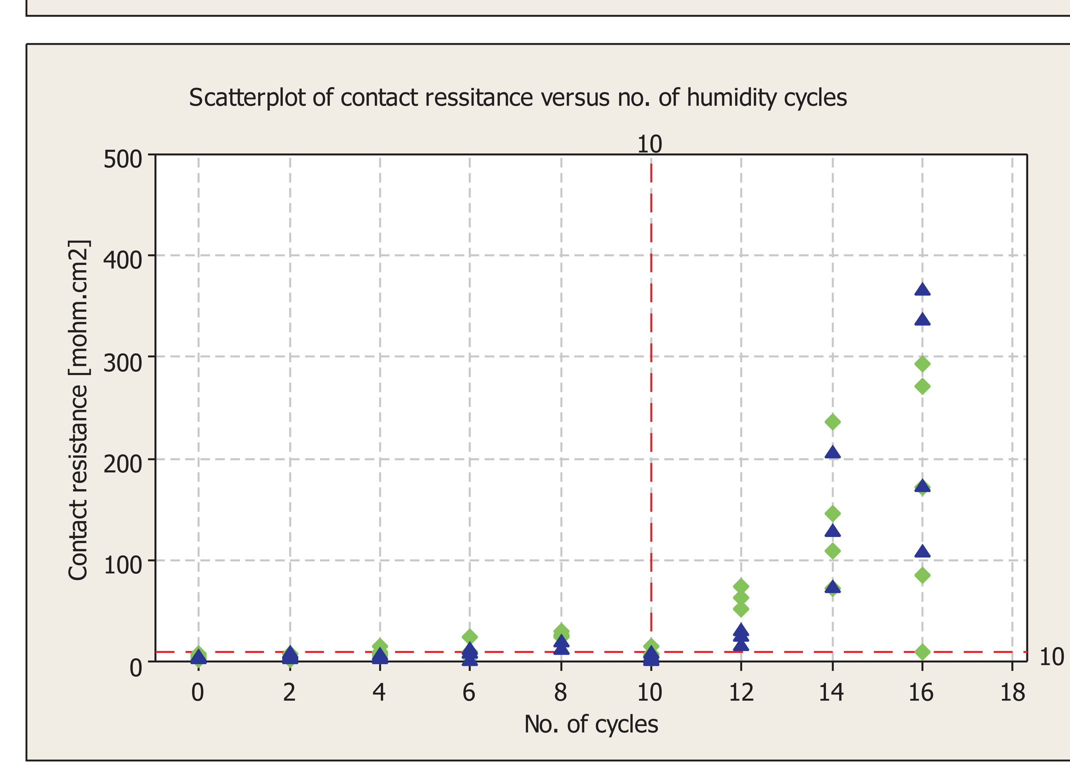


Contact resistance vs. reliability

Contact resistance on bare devices is more sensitive than line resistance to humidity exposure with similar increases seen in humidity cycle and damp heat testing.







Summary

Based on electrical, mechanical and reliability testing, two materials (A) and (B) were identified as promising candidates for application as busbar and grid materials.
A comparison of the performance of these materials and other candidates is summarized in the table below.

Property	Spec.	Material A	Material B	Material C	Material D	Material E
Line resistance [mohm/square]	<15	25	**15**	50	25	40
Minimum linewidth [microns]	<120	140	**100**	120	120	120
Contact resistance [mohm.cm2]	<10	30	**5**	100	25	35
Curing temperature [C]	<200	160	**130**	-	190	160
Median peel strength [N/mm]	>1	**1.1**	0.2	0.2	0	0.3
10th percentile peel strength [N/mm]	>0.2	**0.4**				