Local deposition of Copper on Aluminum based MWT Back Contact Foil using Cold Spray Technology

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ABSTRACT

MWT cell and module technology has been shown to result in modules with up to 5% higher power output than H-pattern modules [1] and to be suitable for use with thin and fragile cells. In this study, the use of a low cost conductive back-sheet with aluminium as the current carrier in combination with locally applied copper (5 to 30 µm) using the cold spray method is benchmarked against a standard PVF-PET-copper foil in 2 x 2 cell modules. Cell to module losses and reliability during climate chamber tests according to IEC61215 ed. 2, are comparable to module made with the standard foil. Optimizing the cold spray process can result in a cost reduction of more than a factor 10 of the current carrying component, when compared to a full copper conductive back–sheet foil.

1. INTRODUCTION

ECN has developed an integrated module technology for MWT cells using a conductive back-sheet foil with up to 5% higher power output [1]. It has proven to be reliable in climate chamber testing and IEC certification has been achieved [2-5]. Manufacturing equipment is available with has a very high level of automation. The first industrial production has recently started [6].

The standard MWT module uses a copper based conductive back-sheet. Though the cost per Wp is already 0.05 € cheaper than for H-pattern technology, further reduction of the cost remains a priority. Exchanging copper for aluminium as the conductive path in the foil reduces the cost of that component by a factor of 10. The aluminium foil was locally covered with copper to reduce contact resistance issues, using a cheap and reliable cold spray technique [7]. In this work, aluminium based conductive back-sheet foils patterned by milling and conductive adhesives with a silver content of 10% were used to manufacture and test the output and reliability of mini-modules (2 x 2 cells) compared to reference modules using a full copper based conductive back-sheet.

2. EXPERIMENTS

2.1 Contact resistance to back-contact foil

Before module manufacturing the contact resistance of the foils, both aluminium and copper, using a standard conductive adhesive was measured. A standard test sample was developed for contact resistance measurements, see figure 2.

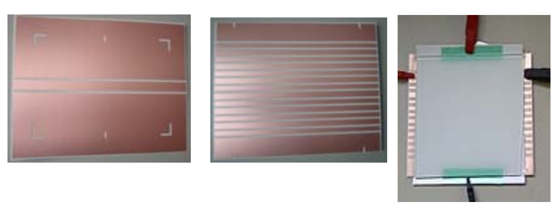

Fig 2. Construction of the foils and 4-point probe measurement for contact resistance. Base foil (left), tab foil (middle), connection of the wires for measurement (right)

For each sample, two foils were patterned by milling and placed at 90 degrees to each other. At the cross-points of the metals tracks, conductive adhesive was applied by stencil printing. The foils were then laminated on glass with 200 µm of sc-EVA between them, to simulate a contact in a MWT module. The contact resistance of the adhesive to the foil was measured using a 4-point probe method with a Keithly 2430 pulse source meter

2.2 Module manufacturing for climate chamber testing

In this test, we prepared 2 x 2 cell modules with different conductive layers in the conductive back-sheet foil as described in table 1. Group D is the reference, TPC3480.

Table 1. Foils use to produce 2 x 2 cell modules (Hard indicates heat threatened)

Group	*Conductive layer*	*Cold Spray Cu*
A	Soft aluminium	Yes
B	Hard aluminium	Yes
C	Copper	Yes
D	Copper	No

The back-contact foils were patterned by milling. Copper was locally applied with the cold spray technique. For a schematic drawing of this technique and the final result see figure 1.

For manufacturing the 2 x 2 cell modules, conductive adhesive, 200 µm thick sc-EVA and 3.9 mm thick solar grade glass were used. The modules were laminated using the lamination profile 4.5/1.5/18.5 at 155°C and 0/600 mbar min^{-1} /1 bar pressure.

The IV characteristics of the solar cells prior to module manufacturing were measured using a SUNSIM flash-tester and the IV characteristics of the modules were measured using a Pasan IIIA flash-tester.

Half of the modules were tested for 1000 hours in DH and half for 200 cycles in TC. Half way through the test period and at the end the IV characteristics were measured.

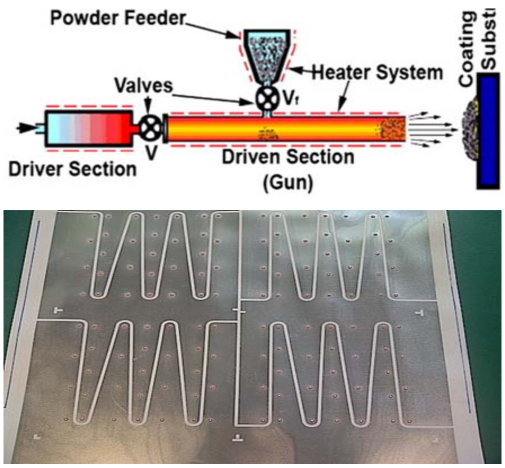

Fig. 1. Schematic drawing of cold spray principle and picture of the final result on patterned aluminium conductive back-sheet foil

3. RESULTS AND DISCUSSIONS

3.1 Contact resistances

The contact resistance shows that the contact resistance for the foils with deposited copper (group B and C) are lower than for foils without copper (group D). The reason for this is the state of the surface of the metal foils after cold spraying the copper layer.

Table 2. Contact resistance results

Group	*Contact resistance*	*Standard deviation*
B	0.16 mΩ	0.04 mΩ
C	0.25	0.06
D	1.4	0.5

The cold spray process is severe enough to remove the oxide layer on the aluminium surface, resulting in a lower contact resistance. The copper foil has a surface protection layer that prohibits oxidation of the copper during storage. During cold spraying this layer is also removed so resulting in a lower contact resistance. Without a cold sprayed copper layer the contact resistance between aluminium foil and conductive adhesive is more than 500 mΩ. A cross-section of an aluminium sample used for the contact resistance measurement is shown in figure 3.

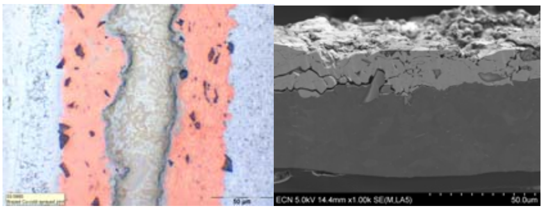

Fig. 3. Cross-section of aluminium foil, cold spray copper and conductive adhesive (left) and sprayed copper on aluminium (right)

The copper particles deposited by cold spraying are visible and are mechanically attached to the aluminium surface. In the copper powder, aluminium oxide particles are visible, showing the Al surface has been cleaned of the oxide layer.

3.2 Module results

The cell-to-module fill-factor (FF) loss was calculated from the initial solar cell and module data, see table 3.

Table 3. Average module IV characteristics and calculated cell-to-module fill-factor loss

Group	*power [W]*	*fill factor [%]*	*cell to module FF loss*
A	15.4	74.3	3.0%
B	15.6	75.6	2.1%
C	15.4	73.6	5.2%
D	15.5	75.5	2.0%

There is no significant difference in module output for the different foils. The fill-factor for soft aluminium and copper with cold spray copper is lower than for the reference and heat treated aluminium. Electroluminescence and infra-red imaging give also no clear reason for the observed differences in IV characteristics. The mechanical properties of the soft Al may make the cleaning effect of cold spraying less effective than for the heat treated Al.

3.3 Climate chamber tests modules

From each foil composition, three modules were tested in thermal cycling and three in damp-heat according to IEC61215. Half way through and at the end of the test period, the IV characteristics of the modules were measured. The change in fill-factor and power output during testing under TC conditions are shown in figure 4 and for testing under DH conditions in figure 5.

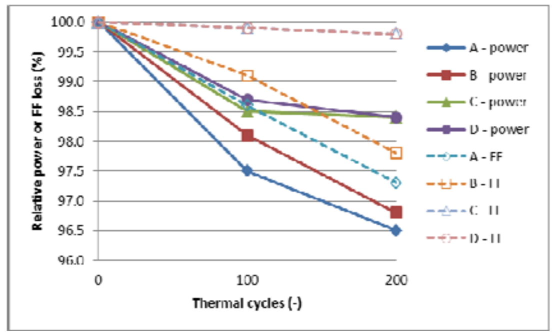

Fig. 4. Decrease in module power and fill-factor during thermal cycling

From these results it is obvious that the decrease in fill-factor and power during testing in TC for aluminium foil with cold spray copper is higher than for copper based foil. The degradation for copper based foils stabilises after 100 cycles. This is not visible for aluminium based foils up to 200 cycles. The degradation is within the limit of 5% as set in the standard.

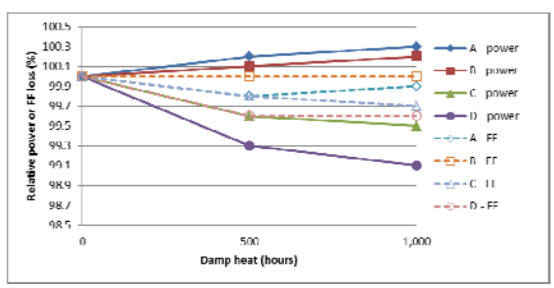

Fig. 5. Decrease in module power and fill-factor during damp heat

During DH testing the degradation for aluminium based foil is lower compared with copper based foils. Aluminium based back-sheet foil has an higher corrosion resistivity than copper based foil with OSP protection layer.

3.4 Preliminary cost price calculation conductive back-sheet foil

The weight of conductive material processed in a full size foil is 523 g for copper and 247 g for 55 micron aluminium. With a copper price of €5.42/kg the conductive part of the back-sheet has a cost of €2.83. The equivalent for aluminium with an aluminium price of €1.39/kg has a cost of €0.34 (metal prices from September 1th 2013).

The Cu cold spray layer for a 60 cells foio requires 375 g copper. The Cu pads on the foil (3 mm diameter and 30 micron thick) only require 3.8 g Cu. This indicates that the copper yield is 1%. Increasing the copper yield has a positive influence on the benefit of Cu cold spray on Al foil compared with standard copper foil, see table 4. With a copper yield of 50% the price of the metal incorporated in the foil is decreased by 50%.

Table 4. Effect of copper yield on the price of the aluminium foil with applied copper by cold spray technology

Copper yield	*copper used [g]*	*cost [€/foil]*	*Cost Al-foil [€]*
1%	365.3	1.98	2.32
5%	350.3	1.90	2.24
10%	331.9	1.80	2.14
25%	276.6	1.50	1.84
50%	184.4	1.00	1.34
75%	92.2	0.50	0.84
99%	3.7	0.02	0.36

4. CONCLUSIONS

Aluminium based back-contact foils with applied copper islands by the cold spray technology yields modules in which the degradation is within the limit of 5% after climate chamber tests according to IEC 61215, demonstrating suitability of the cold spray technology. Testing under thermal cycle conditions results in the main differences compared with copper based back-contact foil. Economic application of the cold spray technology requires further optimisation of the Cu yield.

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