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Aluminium foil and cold spray copper technology as cost reduction process step in back-contact module design

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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]. Back-contact modules allow automated processing and are 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 (TPC3480 from Isovoltaic AG) in 2 x 2 cell modules. Cell to module losses and reliability during climate chamber tests according to two times 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.

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Keywords: MWT-Modules; Cost Reduction; Aluminium Foils; Cold Spray Technology

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] compared to conventional modules. It has proven to be reliable in climate chamber testing and IEC certification has been achieved [2-5]. Manufacturing equipment is available which 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], see figure 1. With this technique the copper powder is deposit with high velocities (between 300 to 500 m/s) and low temperatures on the aluminium surface. The maximum temperature increase at the aluminium

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surface is approximately 60-70°C above room temperature. Due to the kinetic energy the copper particle will attached the surface and remain sticked to the surface. During this process the native oxide layer on top of the aluminium foil is destroyed, resulting in a metal-metal contact with low contact resistance. 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). These were compared to reference modules using a full copper based conductive back-sheet.

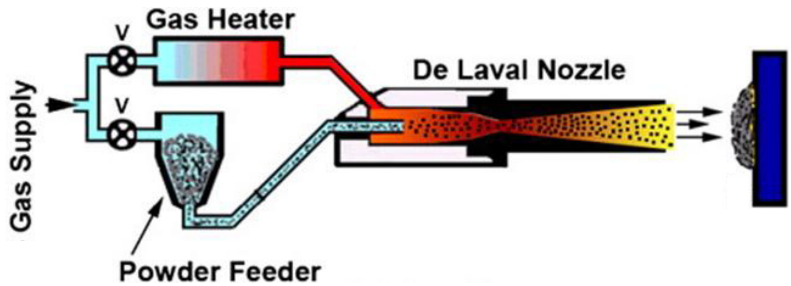

Fig.1. Schematic view of the cold spray equipment used for locally applying copper on the surface of an aluminium based conductive back-sheet

2. Experiments

2.1. Contact resistance to conductive back-sheet foil

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

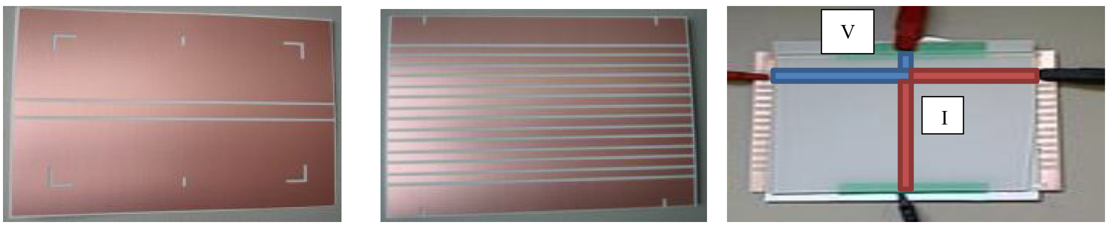

Fig. 2. Construction of the foils and 4-point probe measurement for contact resistance. Base foil (left), tab foil (middle), connection of the probes for measurement (right)

For each sample, two foils were patterned by milling and placed at 90 degrees to each other. At the cross-points of the metal tracks, conductive adhesive was applied by stencil printing. The foils (Tab foil 90° turned and up-side down placed on Base foil) were then laminated on glass with 200 µm of sc-EVA between them, to simulate a contact as normally achieved in a MWT module laminated to glass. The contact resistance of the adhesive to the foil was measured using a 4-point probe method with a Keithly 2430 pulse source meter. Samples included copper conductive back-sheet and aluminium conductive back-sheets with cold sprayed copper at the position of the conductive adhesive dots. As reference a copper based conductive back-sheet without cold spray copper is used.

2.2. Module *manufacturing* for climate chamber testing

In this test, we prepared 2 x 2 cell modules with different aluminium and copper based conductive layers in the conductive back-sheet foil. Small areas of copper were applied using cold spray technology. As reference the copper based material TPC3480 (Isovoltaic AG) was used. 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 3.

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 a lamination profile compatible with both curing of the EVA and conductive adhesive.

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

Half of the modules were tested for 2000 hours in DH (85°C and 85% RH) and half for 400 cycles in TC (between -40 and 85°C). Half way through the test period and at the end the IV characteristics of the modules were measured.

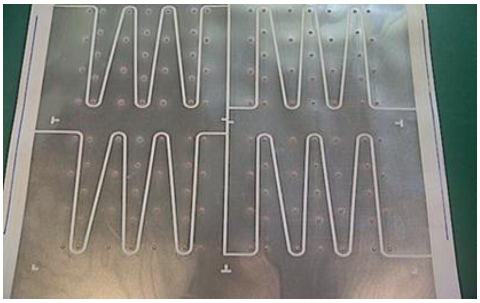

Fig. 3. Patterned aluminium conductive back-sheet foil with locally applied copper pads

3. Results and discussions

3.1 Contact resistances

The contact resistance shows that the contact resistance for the foils with deposited copper are lower than for foils without copper. The reason for this is that the cold spray process is severe enough to remove the oxide layer on the aluminium surface or the surface protection layer (OSP) on the copper surface, resulting in a lower contact resistance.

Table 1. Contact resistances (contact area 2.3 mm^2)

Conductive layer	*Contact resistance*(mΩ)	*Standard deviation* (mΩ)
Aluminium + CS-Cu	0.16	0.04
Copper + CS-Cu	0.25	0.06
Copper	1.4	0.5

Without a cold spray 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 4.

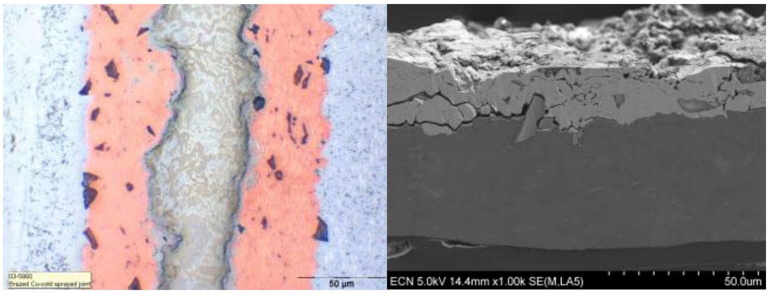

Fig. 4. Cross-section of aluminium foil (bklue), cold spray copper (orange) and conductive adhesive (gray) in the left picture and sprayed copper on aluminium (from top to bottom: copper-aluminium-PET) in the right picture

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 also visible. This aluminium oxide is added to the copper cold spray powder to prevent the powder sticking in the nozzle of the spray gun.

3.2 Module results, Climate chamber tests

For each foil composition, three modules were tested in thermal cycle and three in damp-heat tests according to two times IEC61215. After every 500 hours of testing, the IV characteristics of the modules were measured. The change in power output (P) and fill-factor (FF) during testing under TC and DH conditions are shown in figure 5.

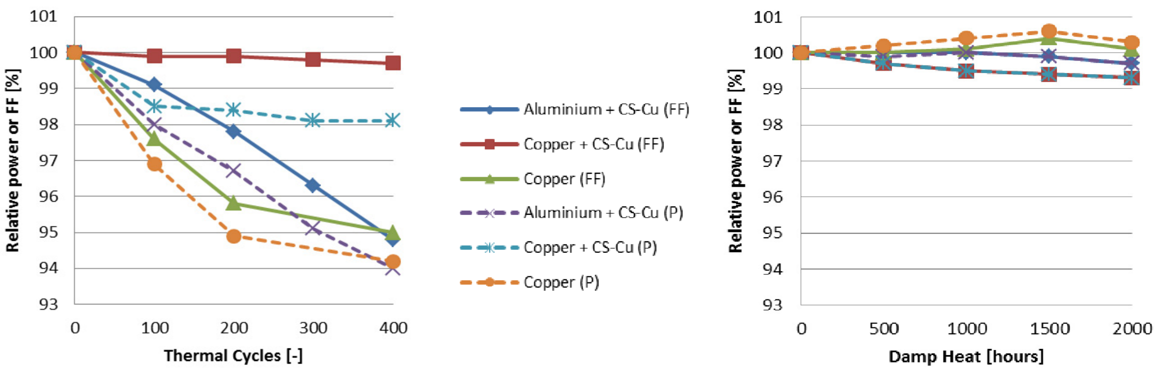

Fig.5. Change in module power (left) and fill factor (right) during thermal cycling and damp heat (2 times IEC)

From these results it is obvious that the decrease in power during testing in TC for aluminium foil with cold spray copper is comparable with copper based foil, also on fill factor level. The degradation for copper based foils seems to stabilise after 200 cycles. This is not visible for aluminium based foils which shows up to 400 cycles a linear decrease per cycle. The degradation is within the limit of 5% after 1xIEC and just at this limit after 2xIEC. 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.

3.3 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 50 micron aluminium. With a copper price of €5.25/kg the conductive part of the back-sheet has a cost of €2.75. The equivalent for aluminium with an aluminium price of €1.24/kg has a cost of €0.31 (metal prices from February 14th 2014).

The Cu pads on the foil (3 mm diameter and 30 micron thick and 1860 dots) only require 3.5 g Cu, which increases the cost of a aluminium based back-contact foil and cold spray copper by only €0.02 (based on copper price). Cold spray is a very simple technology which requires low cost equipment, due to the fact that thecold spray process takes place at atmospheric pressure and the equipment cost of a cold spray tool is less than 50 k€ for an industrial type (powder feeder and spray gun). For automation of the cold spray process, an exhaust system and other safety issues an cost estimation of 150 to 200 k€ is required for equipment. With an annual production for 1 million modules, the foil costs increases by 4-5 €cent due to depreciation of equipment. The expectations are that the price of the copper powder will decrease to around 10-15 €/kg. Even in that case, the price of a Cu coated aluminium based back-contact foil can remain well below €0.50.

Preliminary experiments showed that the Cu cold spray layer for a 60 cells foil requires 375 g copper. This indicates that the copper yield is at the moment approximately 1%. The low price for Al with CS-Cu can only be achieved if there is none, or strongly reduced Cu waste during the process. 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 2. With a copper yield around 50% the price of the aluminium foil with Cu cold sprayed layer decreases by 50%. Typical solutions for reducing the copper usage include decreasing the copper layer thickness, optimizing spray conditions to increase the adhesion between copper powder and aluminium, and hence reduce the bouncing of the particles from the surface. Furthermore, the re-use of copper powder or recycling of non-functionally deposited copper are possibilities to reduce the copper usage. An example of non-functionally deposited Cu is shown in figure 6, where copper is deposited on the mask required for Cu cold spray.

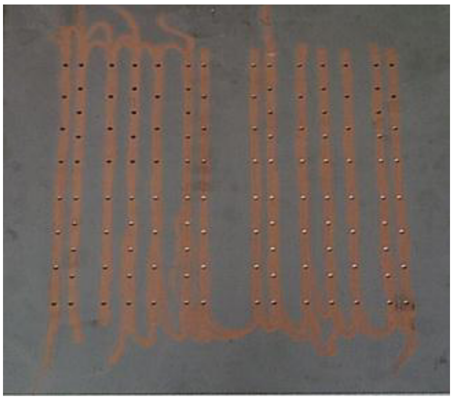

Fig.6. Mask with non-functional copper lanes

Table 2. Effect of copper yield on the price of the aluminium foil with applied copper powder by cold spray technology (production costs of approximately 10€cent per module are included and an estimated powder price of 10 €/kg)

Effective Copper use [%]	*Copper use* *[g]*	*Copper cost* *[€/foil]*	*Cost Al-foil +CS-Cu* *[€]*
1	375	3.75	4.16
5	360	3.60	4.01
25	284	2.84	3.25
50	189	1.89	2.30
75	98	0.95	1.36
95	18	0.18	0.59
99	3.5	0.04	0.45

4. Conclusions

With this study we demonstrated the feasibility of replacing the copper layer in back-contact foil with aluminium foil on which copper was locally applied using the cold spray technology. Using aluminium foil, reliable modules have been produced. 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 2x IEC 61215, demonstrating suitability of the cold spray technology. Cost estimations show that even in this non-optimized experiment this technology results in cost reduction of the module back sheet foil. Economic application of the cold spray technology requires further optimization of the Cu yield.

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