Metallization and interconnection for high-efficiency bifacial silicon heterojunction solar cells and modules

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Abstract

Silicon heterojunction (SHJ) solar cells demonstrate a high conversion efficiency, reaching up to 25.1% using a simple and lean process flow for both-sides-contacted devices, and achieving a record silicon solar cell efficiency of 26.7% in back-contacted configuration. In addition, the field advantages of SHJ cell technology are a native bifaciality and low thermal coefficient providing impressive energy yield. Finally, the technology demonstrates potential cost reduction as it is perfectly suited for thin wafers integration. The SHJ technology is therefore today triggering strong interest in the PV industry, appearing on the roadmap of different cell manufacturers, with several production lines and pilot lines being installed worldwide. One limiting factor of the technology is related to the metallization: due to temperature restrictions on hetero-contacts, the standard firing through silver paste needs to be replaced by low curing temperature paste. This type of pastes yield fingers with higher bulk resistivity (two to three times the one obtained with high temperature cured silver pastes) and lower adhesion after soldering. In this paper, materials, processes and costs figures will be reviewed for the metallization and module integration of SHJ solar cells, with a focus on copper plating benchmarked to silver screen-printing, for varying module interconnection technologies.

Introduction

The first publications of silicon heterojunction (SHJ) solar cells emerged at the end of the 1980s and beginning of the 1990s by Sanyo in a Japanese and a British patent relating to their HIT (heterojunction intrinsic thin-layer) cell technology [1,2]. Already in 1992, the HIT cell conversion efficiency was above 18% [3]. Important milestones for the technology were the two world record conversion efficiencies for Si-based solar cells obtained on interdigitated back-contacted (IBC) SHJ configuration, with 25.6% and 26.7% in 2014 and 2017, respectively [4,5].

SHJ technology are bifacial by nature and present a low temperature coefficient in the range of -0.23% to -0.3%/°C [6,7]; these two elements improve the energy yield and reduce the levelized cost of electricity (LCOE) [8]. The reliability of SHJ is confirmed in the field as the first HIT modules were produced in 1997 and data show no degradation of SHJ module after 14 years [9].

Today, even if SHJ module technology is still a niche market, the production level is promisingly increasing as several companies around the world have chosen this technology to differentiate from the mainstream. These companies are usually new comers that want to use a new technology with expected higher potential than mainstream. Thus, in 2018, about 2 GW of capacity was reported to be SHJ technology with the main player still being Panasonic, the founder of the technology in the 90s. Panasonic has about 1 GW capacity in Japan and Malaysia and has established an agreement with TESLA for the implementation of a Gigafactory in Buffalo based on SHJ cells, allowing it to at least double its production capacity.

In Europe, several players have chosen SHJ technology: in Russia, HEVEL, formerly producing thin film silicon modules, has shifted its production facility to SHJ with a capacity of about 200 MW [10]. In Italy, ENEL Green Power, one of the biggest renewable electricity companies, decided to invest in the technology in Catania (Sicilia) at a level of about 200 MW. One of the main reasons for this choice is the capacity of SHJ to reduce LCOE to a level that can't reach mainstream technologies.

In Asia, more and more players are considering SHJ. Among them, NSP (Neo Solar Power) has implemented a 50 MW line in Taiwan to evaluate properly the potential and cost reduction capabilities of SHJ. In China, Hanergy and Jinergy are true believers of the technology, investing at a level of hundreds of MW each. Recently, Tongwei has announced its intention to invest in the manufacturing of the technology to a level of 500 MW with Three Gorges Capital Holding.

These announcements are creating an ecosystem that will be able to bring cost down on the material as well as the equipment side, enabling SHJ to hold an increasing part of the PV market.

The process steps of the SHJ cells are simple and require temperatures below 250°C (Figure 1). Initial steps consist of n-type monocrystalline silicon wafer texturing and cleaning (with wafer as thin as 120 microns); followed by PECVD of intrinsic hydrogenated amorphous Si (a-Si:H) deposition

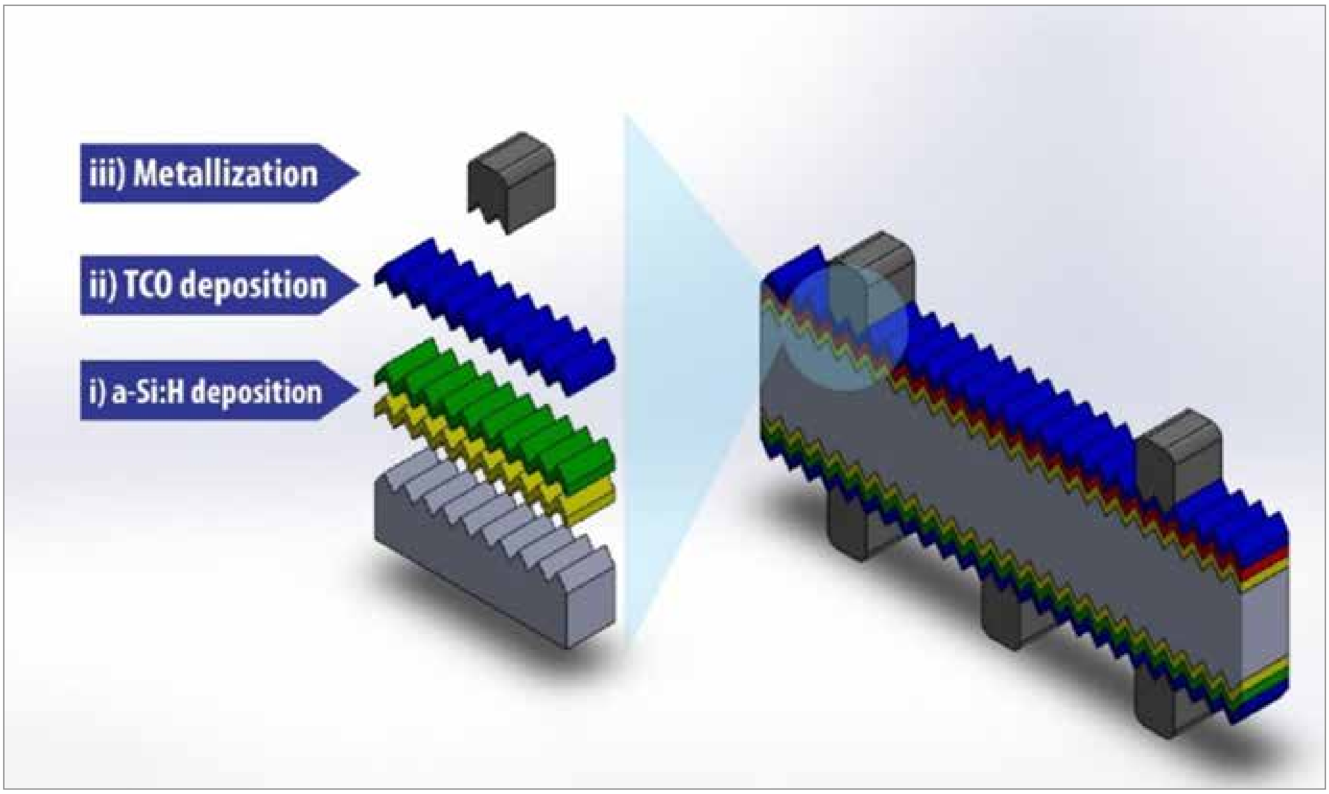

Figure 1. Manufacturing steps and schematic cross-section of a finished bifacial silicon heterojunction solar cell.

on both sides. On respective sides, phosphorus and boron-doped a-Si:H layers are deposited. Then the wafer is coated on both sides by sputtering with a transparent conductive oxide (TCO) that acts as an anti-reflective coating (ARC) and lateral electrical transport layer. To improve conductivity, metal grids are deposited on the TCO usually by screen-printing [11], and specific silver paste needs to be used as the curing temperature should be below 250°C. The bulk resistivity of the fingers printed with low curing temperature (LCT) silver paste is strongly improving with the years but is still about two times higher than firing through silver paste (figure 2). For standard soldered ribbons interconnection, relatively thick busbars (between 25 and 35 microns) need to be printed for reaching the requirement of ribbon peel test (usually 1 N/mm). Finally, as a similar TCO contact is done at both the front and back sides, LCT silver paste is screen-printed on both sides, which steps up again the silver consumption compared to Al backside metallization of p-type cells. These three reasons increase the silver consumption for standard metallization and interconnection (M&I) applied for SHJ solar cells technology, limiting the cost effectiveness of the technology [12]. Thus, innovative approaches avoiding excessive amount of silver are welcomed. The M&I cost for SHJ cells technology is the topic of the presented paper.

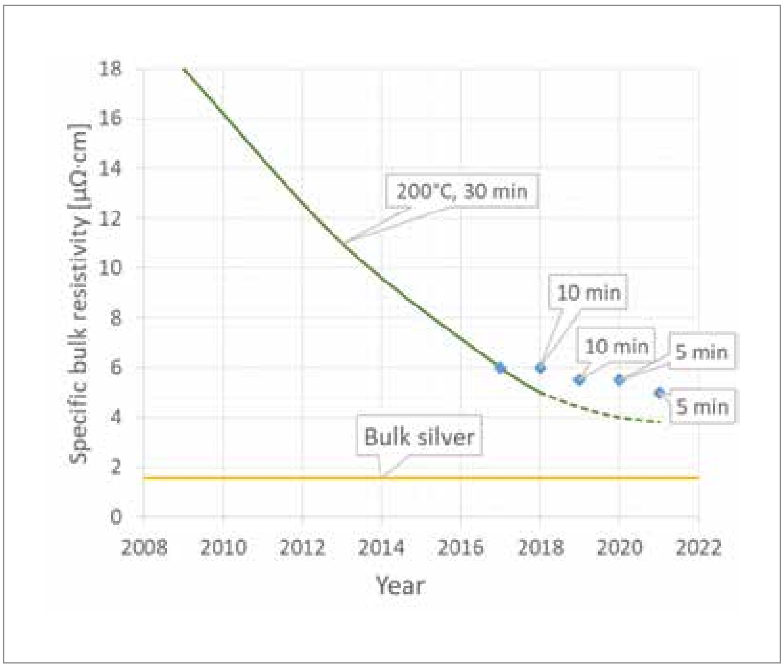

Figure 2. Specific bulk resistivity of low curing temperature silver paste evolution compared to pure silver (horizontal line). Continuous line is from paste measurement after 30 minutes curing at 200°C, dashed line is the forecast for curing 30 minutes at 200°C and diamond are curing at 200°C for shorter time also with forecast (data courtesy of Namics Corporation).

Metallization

In the PV market end of 2017, industrial metallization designs were the following: about 40% with four busbars (4BB), 40 % as well with 5BB, only 10% with 3BB and the last 10% shared between 6BB and wire interconnection. In seven years from now, predictions from [13] indicate that 5BB could have about 50% of the market share, 6BB and more could have about 30% and the rest could be covered by busbar-less design: meaning that three and 4BB will have disappeared from the market. Today, 97% of the metallization is done by screen-printing in

	Soldering			ECA-gluing			Wire interconnection	
	4BB	5BB	6BB	4BB	5BB	6BB	Certified	Optimized
Front mg	165	155	145	75	70	65	40	20
Back mg	255	220	190	170	135	110	60	40
Total mg	420	375	335	245	205	175	100	60

Table 1. Screen-printed silver paste deposited mass at front and backside for 4, 5, 6 busbars for soldering, electrical conductive adhesive (ECA) gluing and wire interconnection grid design ("certified" can pass five times IEC reliability test and "optimized" for lower silver usage).

the PV industry, most of the rest is plating. Copper electroplating could grow from 3% today to about 8% in seven years [13].

Screen-printing

As discussed in the introduction, screen-printing for SHJ solar cells consumes more silver compared to standard cells due to three reasons. Indeed, the bulk resistivity of the printed material is still higher than the one achieved with standard firing through paste, even though the evolution in low temperature cured material is impressive, as shown in Figure 2. Today, the best silver paste has specific bulk resistivity (ρc) of 6 and 5 μΩ.cm after 10 and 30 minutes of curing at 200°C, respectively. In four years, ρc could be at 5 and 3.8 μΩ.cm for 5 and 30 min of curing at 200°C, respectively. In literature, some pastes have shown already today bulk resistivity from 4 to 4.5 μΩ.cm after only 5 to 10 min at 200°C [14]. The future ρc perspectives extrapolate the value down to 3.5 μΩ.cm in 2020 and 3.0 μΩ.cm in 2022 [14]. As the bulk resistivity is higher, more silver or more busbars are needed on the cells for similar performance. The second limitation is the soldering on LCT silver paste; adhesion can reach 1 N/mm with a minimum BB thickness between 25 and 35 μm. This induces also a higher silver consumption compared to standard paste. The final reason is clearly observed in Table 1: as LCT paste is printed on both sides, consumption of LCT silver paste is important and reaches 420 mg in total for 4BB design. This consumption is reduced to 375 mg and 335 mg for 5BB and 6BB, respectively.

Front side laydown of high temperature silver paste is about 90 mg; in the case of SHJ, the front side laydown for soldering interconnection is about 50% to 80% higher depending on the number of BB due to higher ρc and thicker BB as shown in Table 1 [13]. If the interconnection is done via

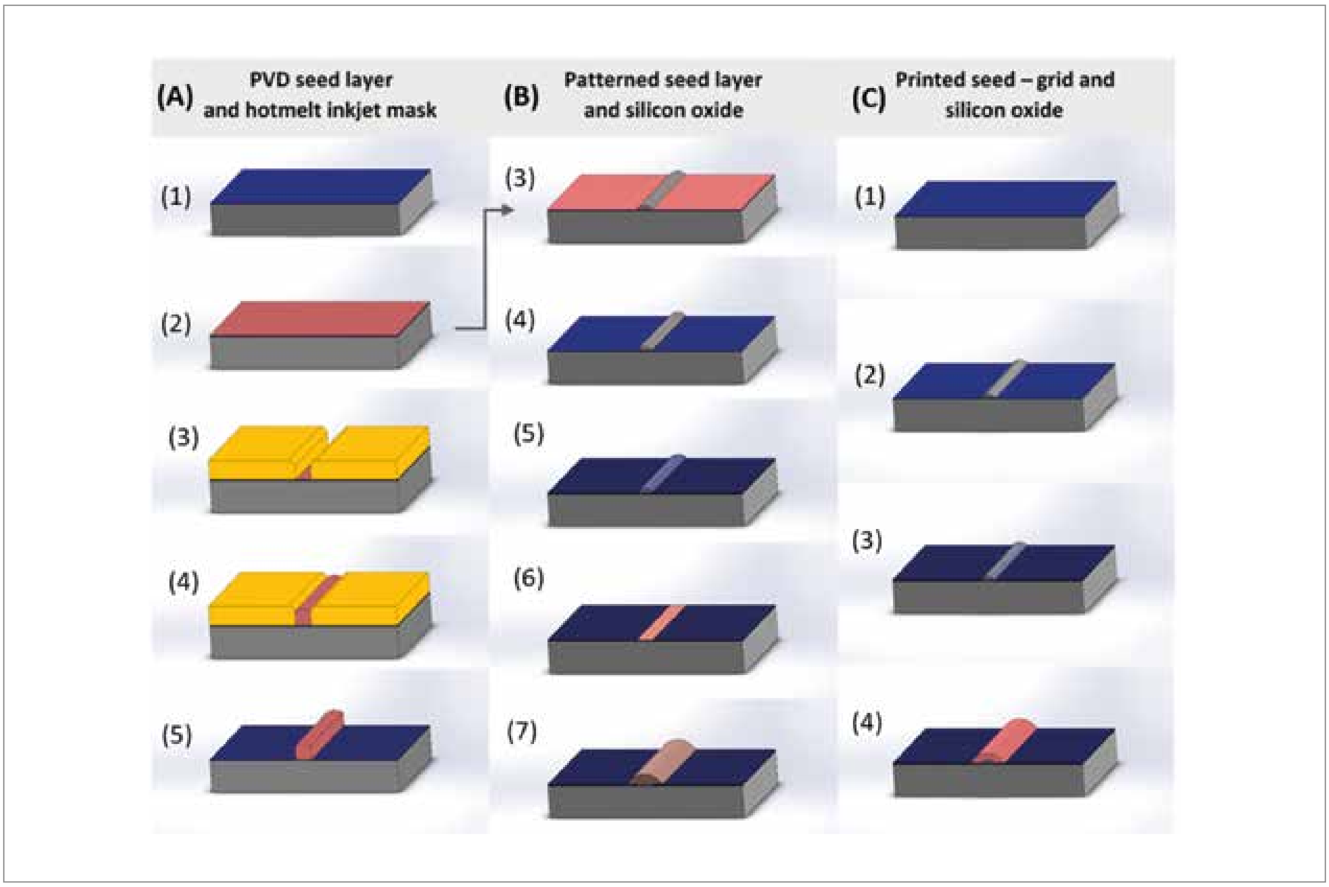

Figure 3. Comparison of process steps for fabrication of seed-layer and masking before copper electro-plating: (A) seed layer + organic mask, (B) patterned seed layer + dielectric and (C) printed seed-grid + dielectric.

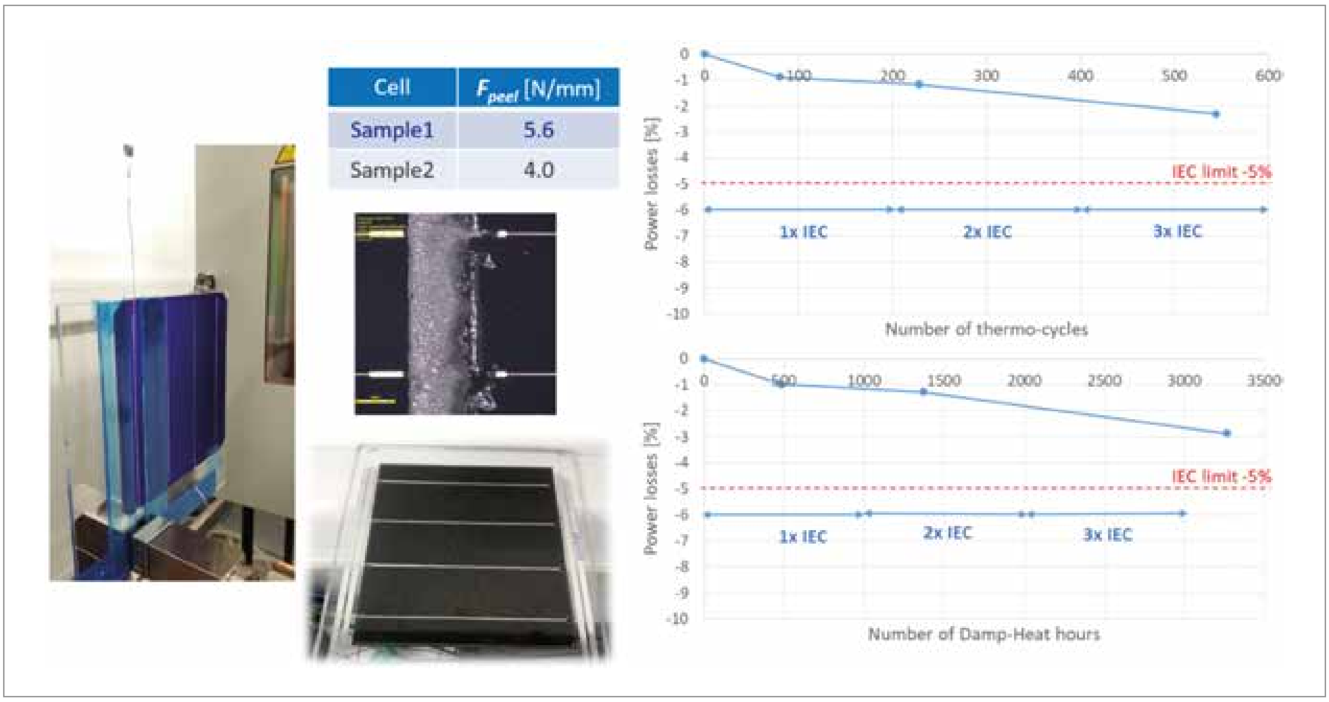

Figure 4. Cells plated with sputtered seed layer and hotmelt inkjet mask and interconnected with soldered ribbons: Peel force test at 180° and thermo-cycles and damp-heat reliability test of small R&D module. Source: CSEM.

gluing the LCT silver paste mass at the front side drops by more than 50% to values as low as 65 mg for 6BB. This saving in paste is possible as busbars are drastically reduced; the gluing using electrical conductive adhesive (ECA) can be done directly on TCO surface and on optimized BB design.

In the case of wire interconnection, busbar-less (BB-less) design is used with ultra-fine fingers (silver line) dropping the laydown to 40 or 20 mg. The wire interconnection uses 12 or more wires, which strongly reduces the power loss in the finger due to charge transportation as compared to 4 to 6BB [15]. As the ohmic loss in the finger is heavily reduced, the silver mass can be strongly decreased. The laydown of 20 mg gives module with high performance but the reliability might be affected with today's paste and wire interconnection.

The silver mass at the backside is always higher compared to the front side because the number of fingers is higher to reduce the power loss in the backside TCO to optimize the cell fill factor (FF).

Copper electroplating

Owing to the impressive improvements in screen printing and the reduction of silver price the share of plating in production is much lower than originally predicted [13,16], with Sunpower and IBC cells being the main contributor. Plating activities for SHJ solar cells (or similar) have been reported by several companies such as Panasonic [4], Kaneka [17], Choshu Industry Co. LTD [18], Tetrasun [19, 20], Silevo and Sunpreme [21].

Having the advantage of the intrinsic bifaciality of heterojunction cells and taking into account the fast increasing market share of bifacial cells [13] we focus on processing routes enabling simultaneous plating on both sides. This implies sufficient lateral conductivity along the wafer surface. Basically three processing routes are conceivable: first (3A), the deposition of a seed layer over the entire wafer surface and an organic plating mask (figure 3A) or a conductive "seed-grid" and a dielectric layer to prevent metal deposition on the TCO, where the conductive seed-grid is formed either through patterning of a sputtered seed layer (figure 3B) or by printing of a metal paste (figure 3C).

For the first processing route (figure 3A), the seed layer is usually deposited by PVD (A2) and consists of a stack comprising a barrier or adhesion layer and a conductive layer [22]. The type of masking (A3) determines the shape and dimensions of plated lines. The simplest is a screen-printed mask (non-photosensitive organic resist) with rather wide openings, usually above 70 μm [23] and with bevel edges leading to increasing finger width as the thickness of plated copper increases. This method is applicable to cells without constraints for shadowing by metallization, like for IBC cells. With photolithography, narrow and rectangular fingers (~20 μm) can be defined. However, even though photolithography is used for mass production of (low-cost) printed circuit boards, for solar cells photoimaging-free alternatives are needed for further cost reduction. A non-photosensitive liquid photoresist, applied by spraying and patterned by inkjet printing of a functional liquid, has been described for metallization of busbar-less cells for SmartWire interconnection [24], with finger width 20-25 µm and finger height 5-10 µm. Another photoimaging-free method is inkjet printing of a hotmelt ink [25]. It requires only one process step for patterning, with geometries of plated lines comparable to photolithography [26]. After copper and finish layer (for example silver or tin) plating (A4), the organic mask is removed and the seed layer is etched back (A5). CSEM has develop further this process sequence to obtain up to a 24.1% record 4BB cell efficiency [26], high peel force of standard PbSn coated ribbon soldering and good coupon module reliability even after three times IEC (see Figure 4).

In the second processing route (Figure 3B), the processing sequence can start with a blanket seed layer. Onto the seed layer a grid pattern is deposited by inkjet printing of an UV-curable ink (B3) and the seed layer blanket in between the grid is etched away (B4). Subsequently a dielectric layer like silicon oxide or silicon nitride is deposited for instance by PECVD over the entire surface (B5), including also the UV-ink. The dielectric serves at the same time as an additional antireflective coating, giving the possibility for TCO thickness reduction. The openings in the dielectric are formed through removal of the UV-ink (B6), simultaneously exposing the seed layer grid for the plating of copper and finish layer (B7).

The third processing route (figure 3C), is based on a seed-grid formed by simple screen printing or inkjet printing of a metal paste or respectively a metal ink (C2). Because of the rough surface of the printed metal the subsequently deposited dielectric layer (C3) is non-continuous on the seed-grid. Plating selectively occurs (C4) where the printed grid is present underneath the dielectric. The industrial feasibility of this process sequence has been confirmed by Kaneka, moreover the module stability during damp-heat ageing has been significantly improved through the dielectric, a PECVD-SiOx layer [17].

Numerous variations of the processes described above have been reported and new processes are being developed with the aim to further simplify the process sequence and to reduce cost [27].

Cell interconnection

Interconnection of SHJ cells was for a long time the critical point as standard soldering is not well adapted on LCT silver paste. Due to this limitation new approaches of cell interconnection were tested and developed for SHJ cells like gluing of ribbon using electrical conductive adhesive (ECA) or wire interconnection well adapted to SHJ cells proposed by Meyer Burger and called SmartWire Connection Technology (SWCT).

Soldering

Usually, the silver busbar peels off the TCO surface after standard soldering with force bellow 1 N/mm. To reduce the stress between the cell and the ribbon, solder based on BiSnAg can be used as shown by Isofoton 10 years ago for standard c-Si solar cell [28, 29]. As the melting temperature of BiSnAg is about 40°C lower compared to PbSn, the stress between cell and ribbon is reduced as well as the silver leaching from the busbar into the solder. Nowadays some companies are proposing bismuth based solder and dedicated flux for PV application [30, 31]. Paste manufacturers also improved the paste formulation to enable standard PbSn soldering on the LCT busbar paste.

	ECA screen-printing process		
	4BB	5BB	6BB
ECA deposit (mg 2 sides) - reliable	80	100	120
ECA deposit (mg 2 sides) - optimized	32	40	48

Table 2. Electrical conductive adhesive deposit done by screen-printing process for 4, 5 and 6 busbars ("reliable" pass two time IEC reliability test).

Figure 5. Busbarless cells and the GridTouch measurement, the SWCT concept and bifacial record module for 60 and 72 SHJ cells at 1 Sun.

Ribbon gluing

Nowadays the ribbon interconnection can be attached with electrical conductive adhesives (ECA) or conductive films using production tools while keeping the same reliability as for the soldered ones [32-36]. ECA is a conductive glue composed normally by silver particles; for cost reduction other metals are used like Ni, Cu or Sn based alloys [37, 38]. ECA can be applied by screen-printing, dispensing or valve jetting. The conductive films are composed of preformed conductive adhesive in foil shape. Beside silver screen-printing paste saving, the second advantage of ribbon gluing is the possibility of using textured ribbons (like the light-capturing ribbons from Ulbrich), which allows the recycling of the light falling on the ribbon and increases the module power up to 2% relative [39, 40]. The silver paste saving is balanced by the use of ECA, that has a similar price, as shown in Table 2. For reliable process, 10 mg of ECA per ribbon are needed to date, whereas only 4 mg can be used after

	Print + Soldering			Print + ECA-gluing			Print + SWCT		Plating + soldering		
Cell Efficiency (%)	4BB	5BB	6BB	4BB	5BB	6BB	Certified	Optimized	4BB	5BB	6BB
	22.4	22.5	22.7	23.0	23.1	23.2	22.8	23.0	22.7	22.7	22.7
CTM performance	1.01	1.01	1.01	1.00	1.00	1.00	1.01	1.01	1.01	1.01	1.01
Module power (Wp)	398	400	403	404	406	408	405	408	403	403	403
Module power Bifi20 (Wp)	470	472	476	477	479	482	478	482	476	476	476

Table 3. Performance of the cells done by screen-printing and plating with different grid design, module with 72 cells in glass/glass configuration and the respective cell-to-module (CTM) factor. Module power is calculated for a bifacial module with 20% power from the backside due to the albedo (Bifi20). Module bifaciality is 90%.

important process optimization (module reliability under investigation).

Wire interconnection

Wire interconnection has been implemented by different major solar manufacturers such as LG and Hanwa Q CELLS. The major gains are reduction of power loss in the metallization grid, reduced interconnection shadowing, improved module reliability against cell cracks and increased power output by more than 3% relative [8, 41]. SWCT from Meyer Burger is composed of low melting temperature alloys coated on copper wire that are supported by a polymer foil, which was initially developed by day4 Energy [42] (see Figure 5). In the last years, an important development has been done to reduce the cost of the wire and adapt the foil-wire assembly to improve the performance as well as the reliability, enabling power output higher than 335 Wp for 60 cells and 410 Wp for 72 cells and module passing five times IEC for thermo-cycles (1,000 cycles between -40°C and +85°C) without noticeable degradation and five times IEC for damp-heat (5,000 hours at 85°C and 85% relative humidity) [43, 44]. As a validation of the strong improvement in the Meyer Burger interconnection technology, SWCT equipment was ordered last May by Panasonic in Osaka for interconnection of its HIT cell technology [45].

Cell and module power

The cell efficiencies and module power shown in Table 3 have been measured experimentally on R&D runs of a few hundred cells from paired wafers in the case of printed cells. In the case of plated cells, the values are based on a few dozen cells based on paired wafers with printed cells. The module power is based on a smaller size module and extrapolated to 72-cell modules in the case of plated cells. Cell efficiencies are increasing with busbar numbers for printed cells as the power loss in the fingers is reduced; this is not the case for plated cells as the finger line resistance is lower. For the ECA-gluing case, the cell efficiency is higher thanks to reduced shadowing from fine busbars. In the case of busbar-less cells (SWCT), the contacting for cell measurement is done with GridTOUCH from Meyer Burger: the efficiency is then corrected as effective efficiency to account for wire shadowing in the module [46]. Thanks to light reflection inside the module, shadowing of textured ribbons and wire is reduced by 40% and 30%, respectively.

Cost methodology

The cost calculation is done for seven years of amortization for the equipment price and includes standard consumables such as silver paste, screen and squeegee for screen-printing. In the case of plating, the cost depreciation and consumables for all processing steps have been considered, including seed layer deposition, patterning, plating chemistry and waste treatment. Most of the country-dependent costs such as manpower, land, electricity and interest rate are being excluded.

The costs of both metallization and interconnection are in the range of €0.022/Wp to €0.049/Wp (see Figure 6). These values are between 7 and 16% of the module price if one considers standard modules. Today's price for modules based on multi-Si cells is about €0.3/Wp; as modules based on SHJ cells can be considered as high-efficiency bifacial module (about 18% relative higher efficiency compared to multi-Si) the price can be increased due to higher energy yield and reduced surface and balance-of-system (BOS) costs of the PV installation [13].

By using standard soldering about 90% of the costs is due to the LCT silver paste. With ECA-gluing the silver paste cost is nearly divided by two but some of the reduced costs are transferred to the ECA glue and textured ribbon coated with silver. Finally the cost reduction of passing from standard soldering to ECA-gluing is in the range of -8 to -15% for 6 to 4BB, respectively. By optimizing the process of ECA deposition and using silver-free textured ribbons, the metal and interconnection cost will be reduced again by about -20% (figure 7).

SmartWire Connection Technology enables the silver cost to be divided by four or by seven in the case of a certified bill-of-materials (passing five times IEC reliability test) and optimized processes still at R&D stage, respectively. Compared to standard soldering the absolute cost saving for the metallization and interconnection (M&I) is about €-0.02/Wp or about -10 eurocents/wafer or €-7/module. The second interesting point with SWCT is that the silver cost represents less than half (or less than a third with the light process) of the M&I total

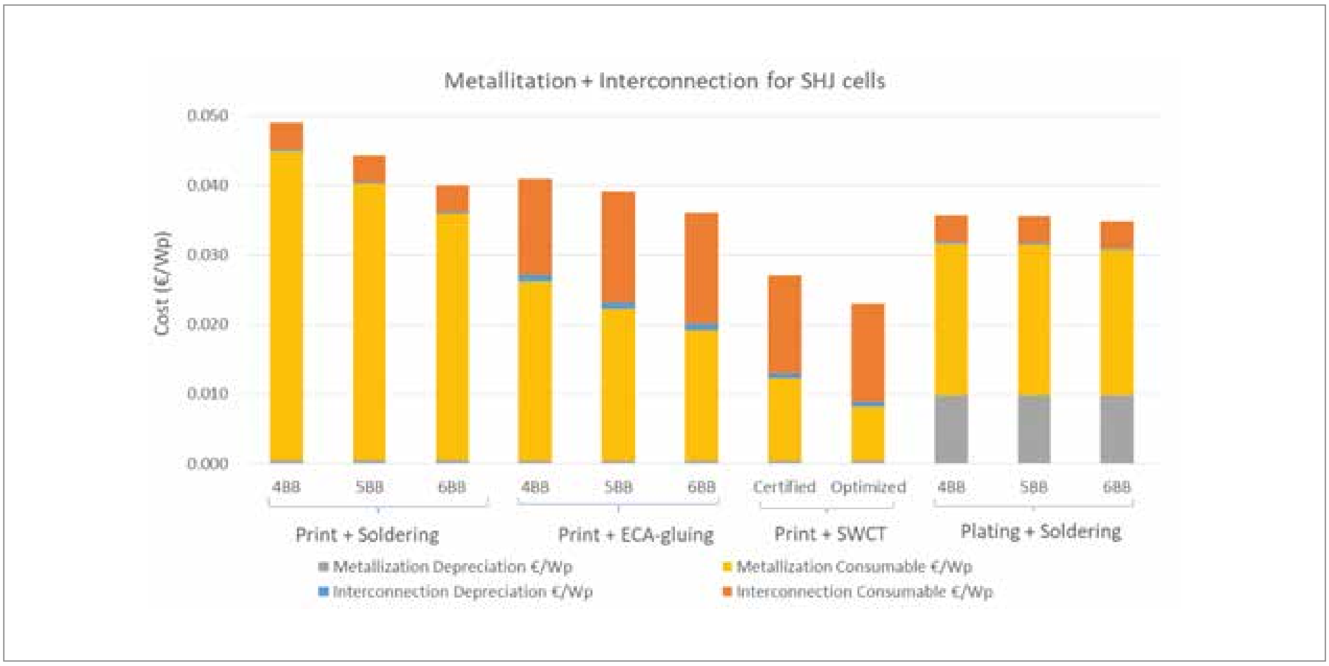

Figure 6. Metallization and interconnection (M&I) cost comparison for the different technologies for bifacial modules. First group is for low curing temperature silver paste screen-printing (SP) and standard soldering, then SP + electrically conductive adhesive (ECA) gluing of textured ribbons, third group SP + SmartWire ConnectionTechnology (SWCT) and finally copper plating using PVD seed layer with hotmelt inkjet mask process.

cost, so the silver price variability on the PV module cost will be reduced.

To remove totally the silver variability of the PV module, copper electroplating will be the solution. A plating process with sputtered seed layer and hotmelt inkjet mask is included for comparison. Today's price for this process is better than standard soldering and competitive with screen-printing and ECA-gluing of textured ribbons. Alternative processing routes are described in the plating section.

Cost comparison for three plating sequences

The calculation is based on cost figures provided by equipment and chemistry suppliers, partially on literature values [12] and on calculations implementing experience from our R&D pilot line. As already mentioned for screen printing, only depreciation for equipment (over seven years) and costs for materials, consumables and waste water treatment are included.

The considered processes are:

A. first a PVD seed layer with hotmelt inkjet mask (figure 3A)
B. a patterned PVD seed with a silicon oxide layer deposited by PECVD (figure 3B)
C. an inkjet-printed seed-grid, also with silicon oxide (figure 3C).

First, it is worth commenting that the depreciation cost is significantly higher than for screen printing mainly due to several process steps being involved: PVD, inkjet-printing and plating and chemical steps (figure 6 and 8). Additionally, the actual production volumes for these equipment types are small and the price consequently higher compared to screen printers.

For the A process the biggest portion of the consumables is the price for hotmelt-ink. The ink

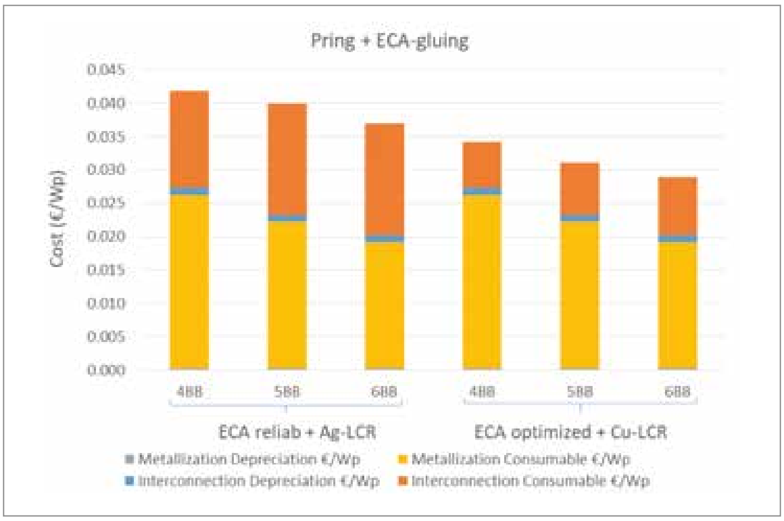

Figure 7. Metallization and interconnection (M&I) cost of screen-printing + ECA-gluing of light capturing (LCR) silver-coated ribbons passing two times IEC (ECA-reliab) versus optimized deposition of ECA and silver-free LCR ribbons.

consists mainly of commonly available waxes and a huge potential for cost reduction with increasing production volumes and more competition in the market may be assumed.

For the second process with patterned PVD seed, one more piece of equipment is required – PECVD for the dielectric layer – further increasing the capex. On the other side the cost for consumables is reduced, still with potential for reduction by volume effects e.g. for UV-curable ink.

For the last process also inkjet-printing of silver nanoparticles ink is considered for the sake of comparability with the other two processes utilizing an inkjet printer. The consumption of

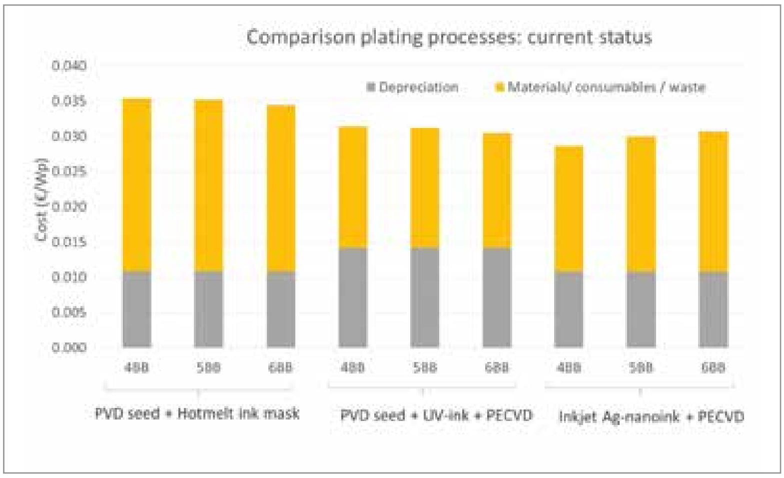

Figure 8. Metallization only cost comparison of three different masking processes for copper-plating (current status).

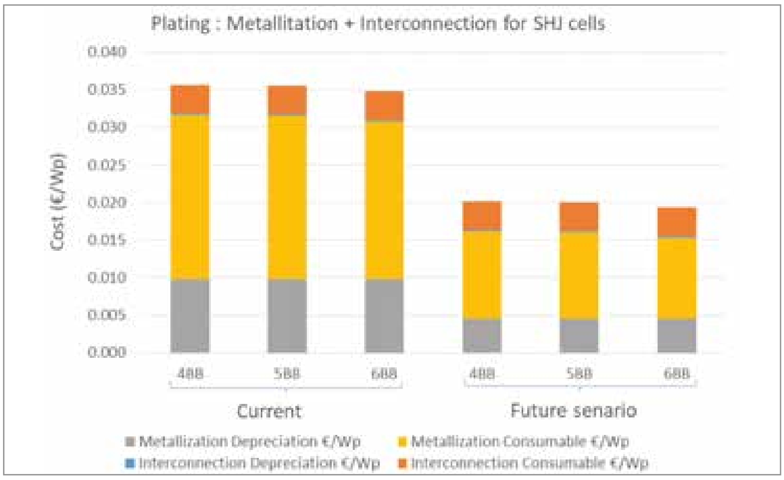

Figure 9. Future scenario with 50% average cost/Wp reduction for copper plating equipment and process using PVD seed layer with hotmelt inkjet mask process.

the nano-ink is extremely low, even below 10 mg for the front side of a busbar-less cell [25], but the price of the nano-ink is at the R&D stage. Here the processing cost increases for 5 or 6 busbars because of higher ink consumption, contrary to the other two processes with a slightly lower price for 5 or 6 busbars, because of thinner required copper plated fingers and consequently slightly shorter plating line.

As demonstrated by Kaneka, screen-printed silver paste can be used in spite of nano-ink, with paste consumption at 20 mg for the entire seed-grid on the front [17], which entails not only lower paste cost but also cheaper equipment. The value for efficiency has been kept constant for all processes at 22.5%. A small gain in Jsc is achievable with plated fingers defined by hotmelt ink; the difference with screen printing depends on the layout and achievable printed line width for the given layout (number of busbars). On the other side, the round shape of the plated line done over a thin dialectric mask (Figure 3 B and C) reduces the optical finger width in the module, similar to screen-printed fingers [47].

In Figure 9, an optimistic future scenario is shown, supposing average price/Wp (which includes cell efficiency and throughput increase with equipment and consumable price reduction) reduction by 50% for equipment as well as for materials and consumables simply by volume effects and continuous process improvement, once the implementation of plating in production has gained a bit more momentum. Such evolution has been seen for screen printing during the last seven years, with savings even higher than 50% taking into account the reduction in silver paste consumption (-60%), the equipment throughput increase (+50%), cell efficiency improvement (+18% relative) and the silver price decrease between 2011 and 2018 (-60%). [13, 48-50]. This supposed cost reduction places the plating + standard soldering as the cheapest M&I option for SHJ PV bifacial module. Nevertheless, as plating is not already implemented for metallization in SHJ cell production, some more R&D work needs to be done on the topic, to improve and develop the best option in term of efficiency, reliability and cost approach. But the conclusions of this work show the cost reduction potential of this metallization technology to make it competitive for high efficiency SHJ cells and modules.

Conclusion

When new technologies enter the market, like silicon-heterojunction (SHJ) solar cells and modules for the PV market, new opportunities and challenges are present. In the aforementioned case, the metallization and interconnection (M&I) combined processes could be a nice opportunity for new technologies – in particular for the light-capturing (LCR) ribbons attached with electrical conductive adhesive (ECA) interconnection that can save today 10% of cost for 5BB cell design with 6 Wp gain on a 72-cell module and up to 30% with process optimization.

SmartWire Connection Technology was developed with a strong emphasis for the SHJ technology in the last years, and this technology reduces the cost of M&I by 50% thanks to silver consumption divided by four in the case of reliable modules and by seven in the case of the light-silver approach. The power gain for a 72-cell module is 5 and 8 Wp in the case of the reliable module and light-silver approach, respectively.

In spite of the high complexity of plating there are processing routes available already today with costs comparable to screen printing for ribbon interconnection. Further cost savings are possible simply by volume effects and continuous process improvements, provided the implementation of plating in production would finally start. But the hurdle is high: different technologies, high investment, only small amounts of data on reliability. A technological need will be necessary to make the decision for plating like in case of IBC cells. The high conductivity of copper lines would also enable a reduction in the number of cell segments for shingling, and thus a reduction in laser cutting steps.

The silver consumption for PV accounts for 7.5% of the world silver supply and the production capacity is supposed to be at least three times higher in 2025 [13]. The higher demand may lead to a higher silver price and give an additional stimulus for copper plating.

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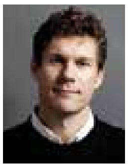
About the Authors



Antonin Faes received his PhD in 2010 for his work on solid oxide fuel cells at the Interdisciplinary Centre for Electron Microscopy (CIME) and the Industrial Energy System Laboratory (LENI) at EPFL. In 2012 he joined the CSEM PV-center in Neuchâtel, where he is responsible for c-Si solar cell metallization and interconnection activities, with a particular focus on silicon heterojunction solar cells.

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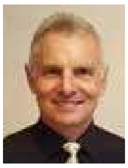

Armand Bettinelli received his PhD in 1987 for his work on cofiring of alumina and tungsten at the Strasburg University. He worked in the industry as Process or Technical manager in the field of High and Low T° Cofired Ceramics then Plasma Display Panels. In 2005 he joined the CEA-INES centre, where he works as senior expert for c-Si solar cell metallization and interconnection, for both homo and heterojunction c-Si solar cells.

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