Cost-effective and reliable Ni/Cu plating for p- and n-type PERx silicon solar cells yielding efficiencies above 20.5%

Richard Russell[1], Loic Tous[1], Riet Labie[1], Monica Aleman[1], Filip Duerinckx[1], Jurgen Bertens[2], Takeshi Horiuchi[3] & Jozef Szlufcik[1]

[1] imec, Leuven, Belgium
[2] Meco Equipment Engineers BV, Drunen, The Netherlands
[3] Hitachi Chemical Co Ltd, Chikusei, Japan

ABSTRACT

This paper presents the status of imec's work on the use of copper for the main conductor as an alternative to screen-printed silver front contacts in solar cells. This work is motivated not only by the limitations that Ag screen-printed contacts have regarding solar cell efficiency (high contact shading, limited line conductivity, and poor contact resistance to moderately doped emitters), but also by the PV industry's desire to reduce Ag usage for reasons of cost. Despite the potential advantages of Ni/Cu contacts, their commercialization has been limited because of increased process complexity and doubts over the €/Wp advantage and long-term reliability. These three factors all depend on the specific process and toolset and are discussed in this paper. A relatively simple process sequence is described that uses industrial pilot-line tools and consists of: 1) defining the front-contact pattern by ps-UV laser ablation; 2) self-aligned plating of the contacts using Ni/Cu/Ag; and, finally, 3) sintering in N_2 for nickel silicidation. The process sequence is applied to 15.6×15.6cm^2 p-type CZ-Si PERC (passivated emitter and rear cell) solar cells with 120Ω/sq. homogeneous emitters; average cell efficiencies of 20.5% are achieved over more than 100 cells. Cost analysis results are then discussed, indicating that this Ni/Cu process sequence has a lower cost/piece than equivalent screen-printed PERC cells while also providing ~0.5% abs. higher cell efficiency. Thermal-cycling and damp-heat reliability data that meet extended (1.5×) IEC 61215 criteria for single-cell laminates and small modules are reported. The improved efficiency potential of applying this metallization sequence to rear-junction n-type PERT (passivated emitter and rear totally diffused) cells is discussed and preliminary results are given.

Background and motivation for copper-based metallization

There is a strong motivation within the PV industry to decrease the usage of silver in cells; this is driven mainly by the desire to reduce €/Wp costs. For conventional screen-printed solar cells, silver accounts for 30–45% of the wafer-to-cell conversion cost and is the main cost element [1]. Despite efforts to reduce silver usage for front contacting in the last four or five years, this cost element has not generally been reduced in production owing to a doubling of the average yearly Ag price between 2008 and 2012. Furthermore, if the PV industry continues to grow and Ag remains the dominant metallization method, within a few years PV will be the major user of Ag and its share of total Ag production will continue to increase, putting further pressure on Ag prices (Fig. 1). It therefore seems likely that silver will remain a significant cost element for conventional solar cells for the foreseeable future.

> "Copper-based metallization clearly has a potential cost advantage."

Given that copper has a similar electrical conductivity to silver but is less than a hundredth of the price per kg, copper-based metallization clearly has a potential cost advantage. However, the motivation for replacing silver with a copper-based metallization scheme is not just because of the potential cost-reduction arguments and concerns over future Ag prices: contacts based on nickel/copper provide many technological advantages which can increase cell efficiency. Ni/Cu contacts provide ~2.5× higher electrical conductivity than Ag paste, lower contact resistance at low Ns [3] and no restriction on line widths (because of the self-aligned nature of plating).

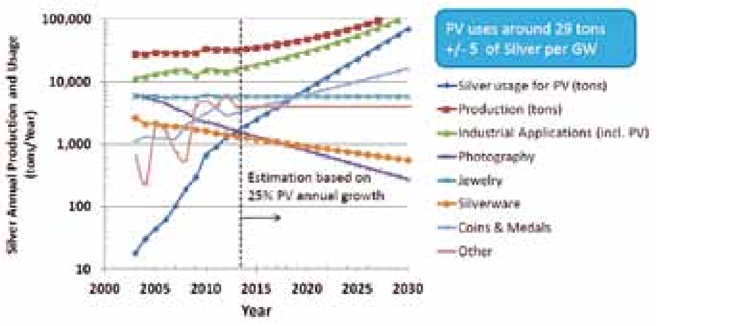

Figure 1. Worldwide annual silver production and usage by applications. (Historical data from The Silver Institute, 2013; Future prediction from Verlinden [2].)

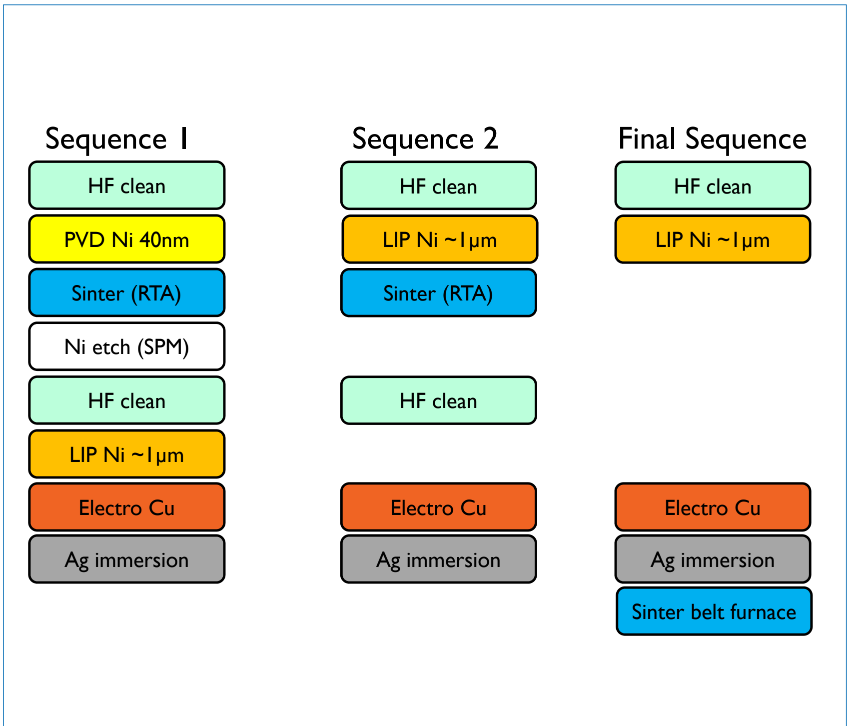

Figure 2. Metallization process evolution at imec.

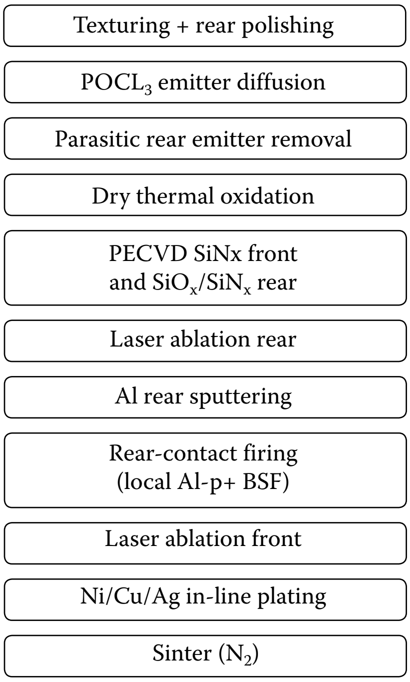

Figure 3. i-PERC cell process flow with Ni/Cu metallization.

Contacts of this type are typically sintered between 250 and 400°C, which is significantly lower than the temperature of 750–850°C required for Ag paste contacts, enabling passivation schemes degraded by high temperatures to be used as well as providing superior rear dielectric/Al reflectance in the PERC (passivated emitter and rear cell) cell since no melting of the rear Al occurs on contact formation.

Despite the potential advantages of Ni/Cu contacts, their commercialization has so far been limited, with the notable exception of BP Solar between the years 1992 and 2008 [4]. Reasons for the limitation include the increased process complexity and the availability of suitable low-cost production techniques and tools. In BP Solar's process, cells were laser grooved and subsequently nickel plated, sintered to form nickel silicide for low contact resistance and contact adhesion, then copper plated and a thin layer of Ag deposited for solderability. Although this metallization process provided highly conductive, low contact resistance metallized fingers with low shading, the downside from the point of view of production was that it relied on electroless Ni and Cu plating, with the process flow being interrupted by Ni sintering between plating steps. The low plating rate (compared with typical electroplating) of the electroless plating solutions created an undesirably large amount of work-in-progress. Electroless plating solutions have the reducing agent in the electrolyte and need to be well controlled, and require frequent dosing and bath changing, which leads to significant waste disposal costs. Even though some development work in copper electroplating was carried out in 2004 [5,6], the process was not introduced into production at BP Solar, one issue being the suitability of available production equipment at the time. Despite these issues, BP Solar sold ~150MWp of modules of the Ni/Cu laser-grooved buried contact process. An early, large 1MWp installation in Toledo, Spain, commissioned in 1992 but still operational today, provides evidence that long-term reliability is possible using Cu-based metallization.

Some of the early obstacles to achieving a viable low-cost Cu metallization process have been surmounted by recent advances in plating and dielectric patterning techniques. Bias-assisted light-induced Ni/Cu plating and suitable production electroplating tools now provide increased plating rates and stable baths which can operate for long periods of time as a result of consumed metal ions being replaced from metal anodes, greatly reducing effluent treatment costs. New cost-effective patterning techniques such as laser ablation, laser doping and patterned etching have also made possible new metallization strategies which do not rely on Ag screen printing.

It is therefore not surprising that there has been a recent re-emergence of interest in copper plating. Over the last year at least six companies (Kaneka, TetraSun, Silevo, Schott Solar, Hyundai heavy industries, SunTech) have reported solar cell efficiencies of over 20% (some significantly higher) with the incorporation of Cu metallization. However, it is not achievable cell efficiencies that will trigger a major switch to copper metallization but rather the demonstration of a clear reduction in the cost of the energy produced over the lifetime of modules compared with other metallization technologies. Convincing the PV community of the possibility of long-term module reliability with Cu-based contacts may now be the biggest hurdle to overcome for the widespread introduction of Cu metallization.

Copper metallization development at imec

At imec the focus has been on investigating the cell efficiency potential, module reliability and €/Wp cost potential for Ni/Cu contacts on i-PERC cells using industrial pilot-line processing tools. Initially, sputtered Ni layers were used to guarantee good uniformity, and nickel silicidation was performed before copper plating, which, as expertise grew, progressed to a simpler Ni/Cu metallization sequence as shown in Fig. 2. The final simplified sequence has the advantage of a minimal number of process steps and allows one-stop in-line plating.

All results reported here use the

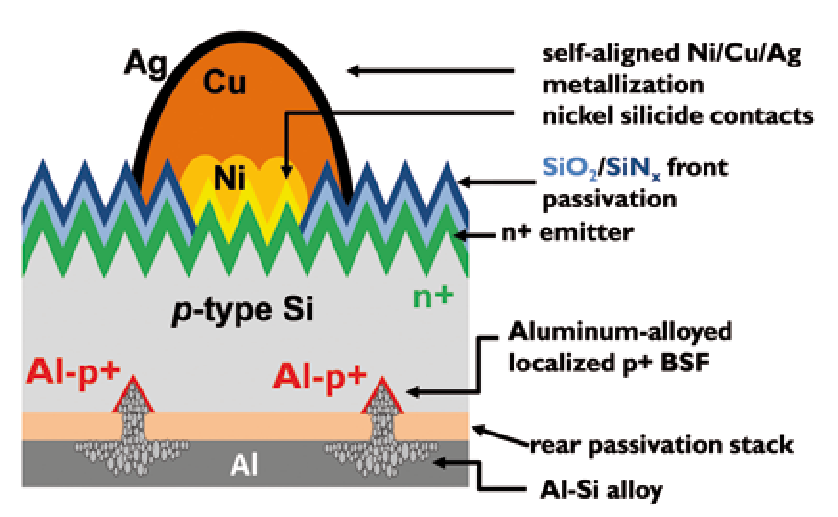

Figure 4. Cell structure of Ni/Cu i-PERC cells.

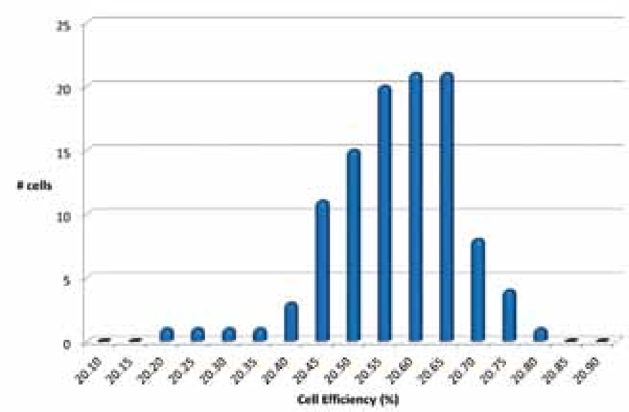

Figure 5. Cell efficiency distribution from a 109 Ni/Cu i-PERC cell run.

	J_{sc} [mA/cm^2]	V_{oc} [mV]	*FF* [%]	*Eff* [%]
Average	38.8	661.3	80.0	20.54
CoV	*0.26%*	*0.18%*	*0.25%*	*0.49%*
Best cell	39.1	663.3	80.3	20.79

Table 1. Ni/Cu i-PERC cell results for 156mm MCZ wafers (averages over 109 cells). (*CoV* = coefficient of variation = std dev/mean %.)

simplified sequence, with the Ni/Cu/Ag plating being made in an industrial pilot-line plating tool from Meco, and the final nickel silicidation step in a belt furnace from BTU; both tools have throughputs of greater than 100 6″ cells/hr. The full i-PERC process sequence using Ni/Cu metallization is shown in Fig. 3, with the final cell structure depicted in Fig. 4.

In this plating sequence Ag is still used, albeit only a 100–200nm, thin, dense layer deposited by displacement plating, adding minimal cost. Ag is preferred over, for example, Sn because the final sintering step is above the melting point of Sn. Since the cell rear remains metallic Al in this process, conventional solder tabbing is not possible in module fabrication. This is a problem which is common to many high-efficiency cell structures, but several solutions already exist, such as the use of conductive adhesives, Schmid's TinPad technology [7] sputtering additional layers, or displacement plating of a zinc layer on the Al, enabling further rear plating. The use of a non-Ag-containing conductive adhesive film from Hitachi Chemical for module tabbing is reported here.

Cell results

In 2012 imec reported top efficiencies (confirmed at Fhg-ISE Cal lab) of 20.3% on 125mm CZ-Si substrates and 20.5% on magnetic Czochralski Si (MCZ Si) [8] using the Ni/Cu i-PERC process described in Russell et al. [9].

Before the process was transferred to 156mm wafers, a power loss analysis (in mW/cm^2) gave a detailed quantification of the loss mechanisms limiting cell efficiency [10]. The analysis showed that the three main contributors lowering cell efficiency were: 1) recombination losses at V_{oc} (3.35mW/cm^2) mainly from recombination at the front metal contacts; 2) optical losses (2.99mW/cm^2) mainly from high shading and non-optimal rear reflectance; and 3) recombination losses (1.33mW/cm^2) as a result of a non-ideal diode. On the basis of this analysis, performance improvements for several process changes were estimated using PC1D, predicting that cell efficiencies greater than 21% should be feasible, as discussed in Tous et al. [10].

Several performance-improving process changes have already been incorporated into the process flow for 156mm wafers [11]. Other potential improvements – in particular, improving rear-side reflectivity and lowering rear-contact recombination by replacing local Al back-surface field (BSF) contacts with local epitaxially grown B BSF contacts – are under development, with promising results being reported [12]. Current cell efficiencies obtained at imec using MCZ-Si 156mm wafers are shown in Table 1, with a tight cell efficiency distribution as shown in Fig. 5. With only one electrically failed cell (not included), these results demonstrate a repeatable, robust Ni/Cu process capable of providing high cell efficiencies. All 109 remaining cells yielded efficiencies above 20% (average of 20.5%), with the best cell achieving 20.8%.

> "Results demonstrate a repeatable, robust Ni/Cu process capable of providing high cell efficiencies."

Adhesion and reliability data

A summary of imec's current reliability test data is presented here (more details can be found in Russell et al. [9]). Cells were made for reliability testing according to the i-PERC process flow as described. Single- and multi-cell laminates were made either by using a non-Ag-containing conductive adhesive film from Hitachi Chemical for tabbing or by conventionally soldering Sn/Ag/Pb-coated ribbons at five points along the cell length at 320°C. Note that, in order to allow some cells to be conventionally soldered, these cells had an additional 2μm-Al/40nm-Ni/150nm-Cu layer sputtered on the rear after rear-contact firing; this was necessary because in the standard i-PERC process flow the cell rear remains metallic aluminium, which cannot be soldered to by conventional means.

Pull-tab adhesion

Table 2 presents adhesion results for three cell types: 1) Ag screen-printed i-PERC cells as a control group; 2) Cu-metallized i-PERC cells; and 3) Cu-metallized i-PERC cells with an additional 2μm-Al/40nm-Ni/150nm-Cu layer sputtered on the rear to allow rear-side conventional soldering. The results in Table 2 represent averages taken over 20 or 50 measurements for the maximum 45-degree pull strength registered at a test point normalized to the metallized contact width (N/mm).

Single-cell laminates put on test

Eighteen 25×25cm^2 Tedlar/EVA/1cell/EVA/glass laminates were prepared for either thermal-cycling (–40 to 85°C) or damp-heat (85% relative humidity, 85°C) tests. Cells were pre-conditioned to approximately 5kWh/m^2 to remove any light-induced degradation before testing.

The ribbons were conventionally soldered onto cells or else connected via a non-Ag-containing conductive adhesive film technology from Hitachi Chemical. Standard Ag screen-printed cells (Ag sp/Al BSF with Ag rear busbars) tabbed by soldering and Ag screen-printed i-PERC cells (Ag sp/Al) tabbed by conductive adhesive film were included as control groups. Copper-metallized i-PERC cells had rear surfaces of either metallic Al (Cu/Al) or metallic Al/Ni/Cu/Ag (Cu/Al Ni Cu Ag) and were tabbed either using conventional soldering or via a conductive adhesive film from Hitachi Chemical. The single-cell laminates put on test are summarized in Table 3.

Multi-cell modules put on test

Two modules were made (size for 60 × 156mm cells), one for thermal-cycling and the other for damp-heat testing in accordance with IEC 61512 specifications at an external accredited test site. Within each module there were five individual cell strings consisting of eight or ten cells, each string electrically separated from the others, allowing each string to be measured individually. Four different cell-type/tabbing technology combinations were put on test, as indicated in Table 4. The cells were sister cells from the single-cell laminate tests and the same tabbing conditions were used.

Reliability test results

Summaries of the average results for copper-metallized cells and for Ag screen-printed cells are given in Tables 5 and 6 respectively.

Many of the single-cell laminates in damp-heat testing showed significant progressive J_{sc} loss dominating cell efficiency losses, particularly for the copper-plated cells. These laminates had obvious EVA discolouration and were tinted brown. As this affected both Ag- and Cu-metallized cell laminates, and no such J_{sc} loss was seen in the damp-heat Ag or Cu 10-cell string tests, the cause is believed to be related to the batch of EVA or Tedlar used for the laminates. The IEC 61215 test pass criterion is ≤5% P_{max} loss after 200 thermal cycles (–40 to 85°C) or 1000 hours damp-heat exposure (85°C, 85% relative humidity) [10]. In the tests, a total of 16 copper and 12 silver-paste metallized single/multi-cell laminates were subjected to thermal cycling (–40 to 85°C) or damp-heat ageing (85°C, 85% relative humidity). All laminates passed 300 thermal cycles or 1500 hours damp-heat exposure, which corresponds to one and a half times the IEC 61215 test specification, with no evidence of one metallization type being superior to any other. Although more complete testing is required and is planned, the results are clearly encouraging.

"All laminates passed 300 thermal cycles or 1500 hours damp-heat exposure, which corresponds to one and a half times the IEC 61215 test specification."

Estimates of the cost of ownership advantage of Ni/Cu plating

While the developed Ni/Cu-plating process certainly has the potential for yielding higher efficiencies compared with a reference screen-printing process, it can also deliver substantial advantages with regard to cost of ownership (COO). COO calculations were carried out by imec for a hypothetical PERC-type production line comparing screen-printed Ag- and Ni/Cu-plated front contacts. In both cases, the assumed output of the line was roughly 2100 cells/hour. Included in these calculations were investment costs, floor space, consumables/materials, utilities, labour, downtime and yield losses.

At first sight, the Ni/Cu-plating process appears to have a disadvantage, since it creates additional process complexity and higher capital expenses. This is clear from the fact that a Ag printer/dryer has to be replaced by a trio of systems: a laser, a plating system and a low-temperature sintering furnace. However, in terms of COO, this disadvantage is easily nullified when considering the cost of materials. Ag paste remains very expensive and this aspect is expected to become even more problematic as yearly production capacity increases in years to come. Although considerable efforts worldwide are being made to reduce the amount of Ag used per wafer [13], it is imec's belief that this is only postponing the inevitable switch to the application of Cu.

If all the cost factors mentioned above are taken into account for both metallization possibilities, an advantage of 5.5€¢/cell in favour of the Ni/Cu-plating scenario is estimated. This, however, assumes that a similar emitter is used in both cases. If an adapted emitter is necessary then the advantage can decrease to a level of 3.2€¢/cell, still clearly in favour of the plating option. This means that introducing Ni/Cu plating instead of screen printing in a production line significantly reduces not only the cost per Wp (by working on both the numerator and the denominator of the equation), but also the cost per piece as shown above. This makes Ni/Cu plating one of the few new technologies that can improve both the efficiency and the cost of the technology it aims to replace.

Cell type (front/rear)	Technology	Measurements per side	Av front [N/mm]	Av rear [N/mm]
Ag sp/Al	Conductive adhesive	20	2.5	2.9
Cu/Al	Conductive adhesive	50	2.2	3.3
Cu/Al	Standard soldering	50	2.5	N/A
Cu/Al Ni Cu	Standard soldering	20	2.0	3.5

Table 2. Summary of adhesion results for three cell types.

Cell type (front/rear)	Tabbing	Damp heat No. of cells	Thermal cycling No. of cells
Ag sp/Al BSF	Soldering	2	2
Ag sp/Al	Conductive adhesive	2	2
Cu/Al	Conductive adhesive	2	2
Cu/Al Ni Cu	Conductive adhesive	2	2
Cu/Al Ni Cu	Soldering	1	1

Table 3. Summary of single-cell laminates put on test.

Cell string type (front/rear)	Tabbing	Module 1 Damp heat No. cells in string	Module 2 Thermal cycling No. cells in string
Ag sp/Al BSF	Soldering	10	10
Ag sp/Al	Conductive adhesive	10	10
Cu/Al	Conductive adhesive	8	10
Cu/Al	Conductive adhesive	10	8
Cu/Al Ni Cu	Conductive adhesive	10	10

Table 4. Summary of strings in multi-cell modules put on test.

Ni/Cu metallization applied to n-PERT Cells

Metallization based on Ni/Cu contacts can be applied to many different cell structures. In fact imec has now started to look at applying this metallization scheme to an n-PERT (passivated emitter and rear totally diffused) cell, whose structure is shown in Fig. 6.

In the PERT cell structure, the rear side is totally diffused to form the emitter, which is then passivated by a dielectric layer and locally contacted. The plated front side remains n-type, so no modification is required to the plating process used for Ni/Cu p-type i-PERC cells. However, there are several advantages: 1) no light-induced degradation of final cell efficiencies typical of p-type wafer cells; 2) high minority-carrier diffusion lengths of n-type wafers; and 3) any defect creation during front-contact laser ablation or metal diffusion (during nickel silicidation) is kept away from the

		IEC 61215		Extended IEC 61215	
		200 thermal cycles	1000 hours damp heat	300 thermal cycles	1500 hours damp heat
Cu 1-cell laminates	Av ΔIsc	-0.1%	-2.7%	-0.5%	-2.6%
4 Hitachi adhesive	Av ΔVoc	-0.3%	1.0%	0.2%	1.1%
1 standard solder	Av ΔFF	-0.9%	0.9%	-0.8%	1.0%
	Av ΔEff	**-1.3%**	**-0.8%**	**-1.3%**	**-0.5%**
	Max ΔEff	**-2.2%**	**-4.1%**	**-2.3%**	**-4.6%**
Cu 10-cell strings	Av ΔIsc	2.9%	2.0%	2.4%	1.6%
3 Hitachi adhesive	Av ΔVoc	0.2%	1.2%	0.5%	0.4%
	Av ΔFF	-1.2%	-0.6%	-3.2%	-2.9%
	Av ΔEff	**1.9%**	**2.7%**	**-0.4%**	**-1.0%**
	Max ΔEff	**0.9%**	**0.6%**	**-1.3%**	**-2.6%**

Table 5. Summary of test results: copper-metallized cells.

		IEC 61215		Extended IEC 61215	
		200 thermal cycles	1000 hours damp heat	300 thermal cycles	1500 hours damp heat
Ag 1-cell laminates	Av ΔIsc	-0.1%	-1.2%	-0.2%	-0.9%
2 Hitachi adhesive	Av ΔVoc	0.1%	0.3%	0.2%	0.4%
2 standard solder	Av ΔFF	-0.8%	-0.7%	-0.9%	-1.1%
	Av ΔEff	**-0.8%**	**-1.6%**	**-1.0%**	**-1.5%**
	Max ΔEff	**-1.4%**	**-2.8%**	**-1.6%**	**-2.5%**
Ag 10-cell strings	Av ΔIsc	1.6%	1.7%	0.5%	1.5%
1 Hitachi adhesive	Av ΔVoc	0.2%	0.3%	0.2%	0.3%
1 standard solder	Av ΔFF	0.9%	0.5%	-0.7%	-0.4%
	Av ΔEff	**0.9%**	**2.3%**	**-0.2%**	**1.5%**
	Max ΔEff	**0.9%**	**1.8%**	**-0.2%**	**0.7%**

Table 6. Summary of test results: Ag screen-printed cells.

most sensitive part of the cell – the emitter. This should add up to higher cell efficiencies and a more robust process.

Indeed, imec's PC1D simulations [14] predict that higher cell efficiencies (>0.5% abs.) should be achievable with n-PERT cells if recombination at the front surface can be kept low. As the junction is on the cell rear in the n-PERT design, it is more sensitive to front-surface recombination compared with p-type i-PERC cells, as shown in Fig. 7.

In addition to a higher cell efficiency potential, n-PERT cells also present stronger efficiency tolerance to thinner wafers. This can be explained by the fact that if wafer thickness is decreased, minority-carrier recombination in the bulk (which is a significant recombination loss in rear-junction devices) can be reduced, balancing out optical losses from reduced photon absorption.

Initial n-PERT results on 156mm wafers look very promising [15]. A best cell efficiency of 20.7% (J_{sc} = 38.3mA/cm^2, V_{oc} = 677mV, FF = 79.8%) has already been achieved on 156mm CZ-Si wafers, with higher currents of 38.4mA/cm^2, voltages of 682mV and fill factors of 80.1% being demonstrated on other individual cells.

Summary

Strong pressure exists to decrease silver usage in solar cells in order to reduce €/Wp costs, and significant efforts have been made in this area. The benefits of reduced usage per cell, however, can be neutralized by rising Ag prices. A future scenario in which PV relies on Ag-based metallization and continues to grow significantly to become the dominant market user, creating further pressure on volatile Ag prices, is a concern.

Switching to Ni/Cu-based metallization has the potential to not only reduce costs but also provide higher cell efficiencies, benefiting both sides of the €/Wp equation. It is not surprising then that there has been a re-emergence of interest in Ni/Cu-based metallization schemes. Nevertheless, no significant switch to Ni/Cu has yet been seen: there are concerns about process complexity, realizing potential €/Wp cost reductions and long-term reliability.

A relatively simple Ni/Cu metallization process has been developed at imec which uses industrial plating techniques and tools that were not available to the earlier Ni/Cu adopters, providing more robust and cheaper processing than previously possible. When this metallization process is applied to 6″ i-PERC cells, high average cell efficiencies ~20.5% (109 cells) with a tight distribution are demonstrated. Cost calculations estimate that the metallization process is cheaper at the €/cell level than Ag screen printing, with the added benefit of higher efficiency. Reliability data show that modules made from these cells pass damp-heat and thermal-cycling IEC 61215 extended tests. While not enough to fully demonstrate the long-term reliability of imec's Ni/Cu-based metallization scheme yet, it is a good starting point, with further testing planned.

For the future, imec is applying its Ni/Cu metallization expertise to rear-junction n-type cells, as it is believed that they have a higher efficiency potential and offer increased process robustness. It is also believed that a strong focus on reliability is important, because it seems that a significant switch to Ni/Cu-based metallization, as also predicted by the ITRPV roadmap, will be inevitable, provided that concern about reliability can be replaced by confidence.

"It seems that a significant switch to Ni/Cu-based metallization will be inevitable as long as concern about reliability can be replaced by confidence."

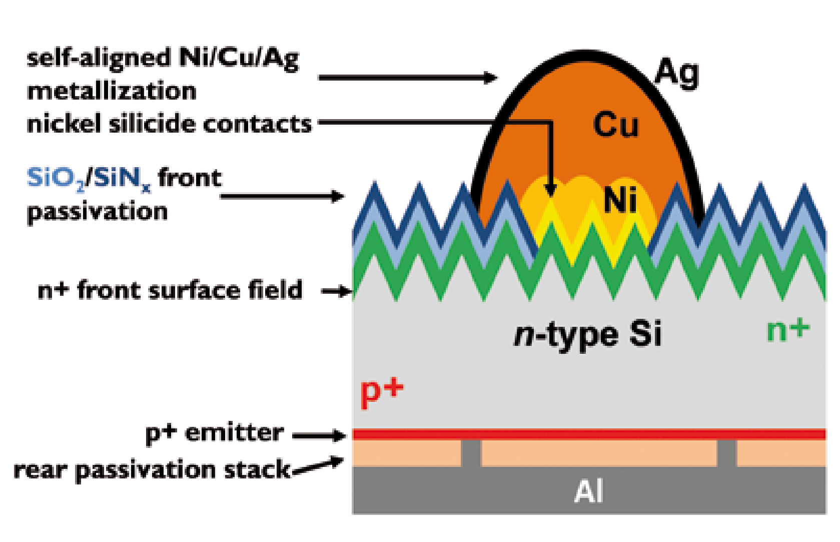

Figure 6. Cell structure of a Ni/Cu n-PERT cell.

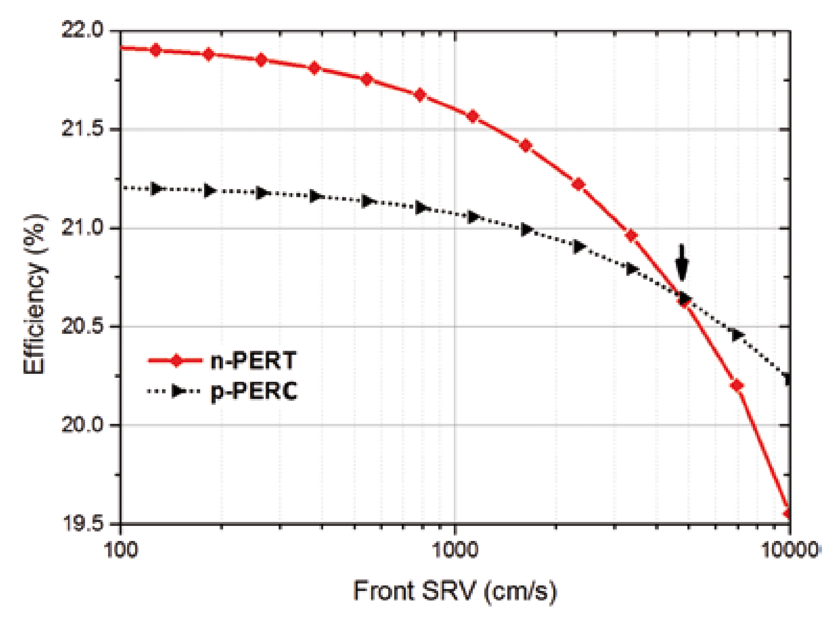

Figure 7. Simulated cell efficiencies for n-PERT and p-PERC cells as a function of front-surface recombination velocity.

References

[1] Mason, N. 2012, 7th PV Fab Managers Forum, Berlin, Germany.

[2 Verlinden, P.J. 2013, *Proc. 28th EU PVSEC*, Paris, France.

[3] Tous, L. et al. 2011, *Proc. 26th EU PVSEC*, Frankfurt, Germany.

[4] Bruton, T. et al. 2003, *Proc. 3rd WCPEC*, Osaka, Japan.

[5] Eager, S. et al. 2003, *Proc. Int. Solar Energy Soc. UK Conf.*, pp. 69–72.

[6] Eager, S. et al. 2002, *Proc. 29th IEEE PVSC*, New Orleans, Louisiana, USA, pp. 62–65.

[7] Campe, H. von et al. 2012, *Proc. 27th EU PVSEC*, Frankfurt, Germany, pp. 1150–1153.

[8] Horzel, J. et al. 2012, *Proc. 27th EU PVSEC*, Frankfurt, Germany, pp. 780–788.

[9] Russell, R. et al. 2012, *Proc. 27th EU PVSEC*, Frankfurt, Germany, pp. 538–543.

[10] Tous, L. et al. 2013, Silicon PV, Hamelin, Germany.

[11] Tous, L. et al. 2013, *Proc. 28th EU PVSEC*, Paris, France.

[12] Récaman-Payo, M. et al. 2013, *Proc. 28th EU PVSEC*, Paris, France.

[13] Muschelknautz, C. et al. 2013, 4th Metalliz. Worksh. Contact. Si Sol. Cells, Constance, Germany.

[14] Tous, L. et al. [submitted for publication].

[15] Aleman, M. et al. 2013, *Proc. 28th EU PVSEC*, Paris, France.

About the Authors

Richard Russell received a bachelor's degree in physics from the University of Exeter, England, and a master's degree in physics from the University of Dundee, Scotland. Between 1990 and 2010 he worked for BP Solar,

mainly on Ni/Cu-metallized laser-grooved buried contact cells. He joined imec in 2011, where he leads copper-based metallization activities within the iPERx platform.

Loic Tous obtained his M.Sc. degree in material sciences and engineering from INSA Lyon, France, in 2009. Since 2010 he has been working towards a Ph.D. degree with imec and KU Leuven in Belgium, where he develops nickel/copper-plated contacts for the front-side metallization of industrial silicon solar cells.

Riet Labie received M.Sc. and Ph.D. degrees in materials science and engineering from KU Leuven in Belgium, in 1999 and 2007 respectively. She began working at imec in 1999 as a researcher on various topics, including electroplating and reliability of solder interconnections for packaging applications and 3D-interconnection schemes with Cu through-Si vias. She joined the silicon photovoltaics department in 2010.

Monica Aleman has been working with c-Si Solar cells since 2004, and began evaluating different schemes for the front-side metallization of p-type Si cells at Fraunhofer ISE. In 2009 she joined imec, where her research has been related to the integration of high-efficiency n-type Si cells.

Filip Duerinckx leads the iPERx platform in the silicon photovoltaics department at imec. He received his M.Sc. in engineering from KU Leuven, Belgium, in 1994, followed by his Ph.D. in 1999. His current area of interest is the performance and economic aspects of p- and n-type PERx silicon solar cells.

Jurgen Bertens obtained his bachelor's degree in physics in 1997 from the University of Fontys Eindhoven. He worked at Dimes (TU Delft) as a process engineer and joined Meco in 2001 as a process developer, working on process and equipment development for advanced metallization of crystalline silicon solar cells.

Takeshi Horiuchi obtained his bachelor's degree in chemistry in 1990 from the University of Chiba, Japan. He then began working for Hitachi Chemical, specializing in the development of thermo-setting resin. After gaining experience in ACF development for display electrode connection, he worked on conductive film (CF) development based on ACF technology for PV, as well as on PV market development.

Jozef Szlufcik received his M.Sc. and Ph.D. degrees, both in electronic engineering, from Wroclaw University of Technology, Poland. He joined imec in 1990, where he led research in low-cost crystalline silicon solar cells. From 2003 to 2012 he held the position of R&D and technology manager at Photovoltech in Belgium. He is currently the director of the silicon photovoltaics department at imec.

Enquiries

Richard Russell
imec
Kapeldreef 75
B3001 Leuven
Belgium

Tel: +32 16 28 76 68
Email: Richard.Russell@imec.be
Website: www.imec.be