The monoPoly technology platform: Rapid implementation of passivating contacts in PERC/T production lines

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Abstract

Passivated emitter and rear cell (PERC) solar cell design is the industry standard for high-volume solar cell manufacturing today. The next challenge for the PV industry is to find a low-cost cell upgrade technology platform that can be easily retrofitted in existing production lines to modify the front side and enhance the rear. The monoPoly™ technology platform, developed at SERIS together with its strategic industry partners, offers an attractive solution and paves the way for the adoption of passivating contacts in large-scale manufacturing. This platform requires only one tool upgrade for most PERC/T production lines, has one less process step than a standard PERC production process, and yields a +1%$_{abs.}$ efficiency boost over a standard PERC process. The authors believe that monoPoly will enable the PV industry to mass produce cells with efficiencies exceeding 24% in their existing lines in the near future.

Background

Global PV production continues to be dominated by p-type crystalline silicon (c-Si) solar cell technologies [1]. In particular, the passivated emitter and rear cell (PERC) solar cell design has been well established since the 1990s. Although PERC is currently the most popular, the GW-level adoption of this cell design in mass production has taken more than 20 years; this was mainly because of the unavailability of high-throughput equipment and process technology that could effectively passivate p-type surfaces in multi- and monocrystalline silicon wafer solar cells. By 2009, the development and commercial deployment of AlO_x for the passivation of p-type surfaces using high-throughput deposition schemes disrupted the (then mainstream) alloyed aluminium back-surface field (Al-BSF) technology, and PERC technology saw continuous growth in manufacturing in the 10 years that followed.

Today, PERC cells have demonstrated efficiencies exceeding 22% in mass production. However, as mainstream silicon PV progresses towards efficiencies greater than 24%, the challenge lies in boosting the solar cell's open-circuit voltage (V_{oc}) beyond 700mV – which is not easy to do for cells with screen-printed and fired contacts. Apart from the bulk material (which the authors believe can be improved), the major voltage loss in most PERC/T solar cells arises from metal contact recombination at the front and rear surfaces, as well as partially from recombination loss at the phosphorus-diffused front surface. Passivating contacts using doped polycrystalline Si (poly-Si) materials provide an elegant solution to all these problems.

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The first reports on passivating contacts for solar cells date back to the 1970s with structures such as SIPOS (semi-insulating polycrystalline Si), first used in transistor applications [4–7] and subsequently in PV applications [8–12]. The latter typically include full-area thin-film stacks that passivate the c-Si surface while selectively extracting only one type of charge carrier (i.e. either electrons or holes). There were only a few publications on the application of poly-Si for silicon solar cells during the period 1990–2010. It is likely that the first commercial application of poly-Si contacts was by SunPower in their interdigitated back contact solar cells [14].

There has been renewed interest in poly-Si passivating contact schemes since 2013, as evidenced by the excellent results obtained by Fraunhofer ISE with TOPCon technology and ISFH with POLO technology) [16–20]. These were soon followed by reports from other institutes e.g. ECN with PERPoly and SERIS with monoPoly™ [22,23]. The concept of poly-Si-based passivating contacts in c-Si solar cells is 30–40 years old [8–12], and it could well be that a known method of deposition such as low-pressure chemical vapour deposition (LPCVD) was exercised by early adopters because of its legacy in microelectronics and the fact that tools were readily available. But, as was the case for PERC/T production lines, the passivating contact cell design now has the following requirements:

1. A production technology platform that has a smaller number of steps and enables ultrahigh deposition rates (>100nm/min).

2. A truly single-sided process that can be retrofitted to current solar cell lines.

3. Compatible with screen-printed (and fired) contacts and bifacial cell designs.

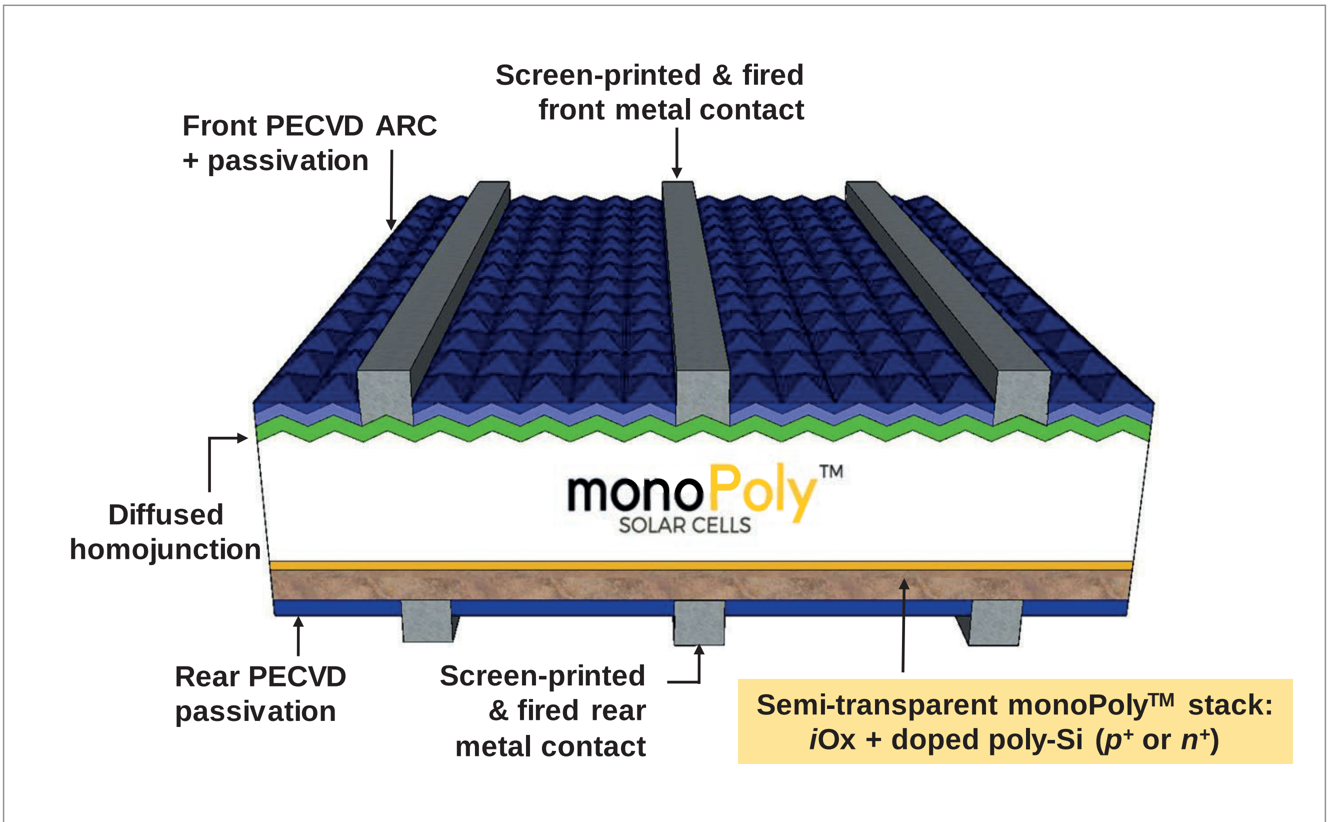

Figure 1. Schematic of a bifacial monoPoly c-Si wafer solar cell with a rear semi-transparent and thin electron-selective passivating contact, and screen-printed (and fired) front and rear metallization.

4. Cost-competitive when compared with standard PERC technology (the most important). This includes low (or no) maintenance and faster return on investment (ROI).

5. Sufficiently transparent layers, which can therefore be used for the front and rear, and which can be used for double-side contacts or all-back-contact designs.

This paper presents the monoPoly platform – an ideal combination, in the authors' opinion, of all these requirements. The monoPoly technology platform is an upgraded PERC/T production methodology that incorporates the single-side ('**mono**facial') application of a screen-printed and fired '**poly**crystalline-based' passivating contact which follows a very lean industrial process flow; moreover, the process can be retrofitted to existing production lines by adding one high-throughput polysilicon tool [26].

The monoPoly technology has achieved conversion efficiencies beyond 23.5% on M2-size wafers, with V_{oc} near 700mV and short-circuit current densities (J_{sc}) of more than 41mA/cm^2 because of the semi-transparent nature of the layers. This technology platform is applicable for the rear side as well as for the front of today's silicon wafer solar cells (Fig. 1).

monoPoly layer properties

The monoPoly stack consists of an interfacial oxide (SiO_x) capped by an n$^+$- or p$^+$-doped poly-Si layer. The SiO_x layer is grown in situ together with the in situ-doped poly-Si layer. Here the focus is on n$^+$-doped poly-Si (n$^+$:poly-Si) deposited by inline high-throughput, single-side plasma-enhanced chemical vapour deposition (PECVD). The properties of these layers are twofold: outstanding passivation and semi-transparency.

Outstanding passivation

The surface passivation quality of the interfacial SiO_x/n$^+$:poly-Si stack on symmetrical n-type planar Cz-Si samples is summarized in Table 1. Excellent surface passivation properties (both at the c-Si-surface and the metal-doped poly-Si interface) are obtained, and this corresponds well to similar reports by other research groups for passivating contacts [27–29]. A TEM micrograph of 230nm-thick n$^+$:poly-Si is also shown in Fig. 2(a).

Table 1. Summary of recombination properties for symmetrical test samples.

	τ_{eff} at 1×10^{15}cm^{-3} [μs]	iV_{oc} at 1 Sun [mV]	J_o per side at 1×10^{16}cm^{-3} [fA/cm^2]	$J_{o,metal}$ per side [fA/cm^2]	$J_{o,metal}$ on solar cell [area-factored]
No deliberate oxidation step	1,680	711	8.9	-	-
In situ oxidation	3,080	730	3.0	20	~2

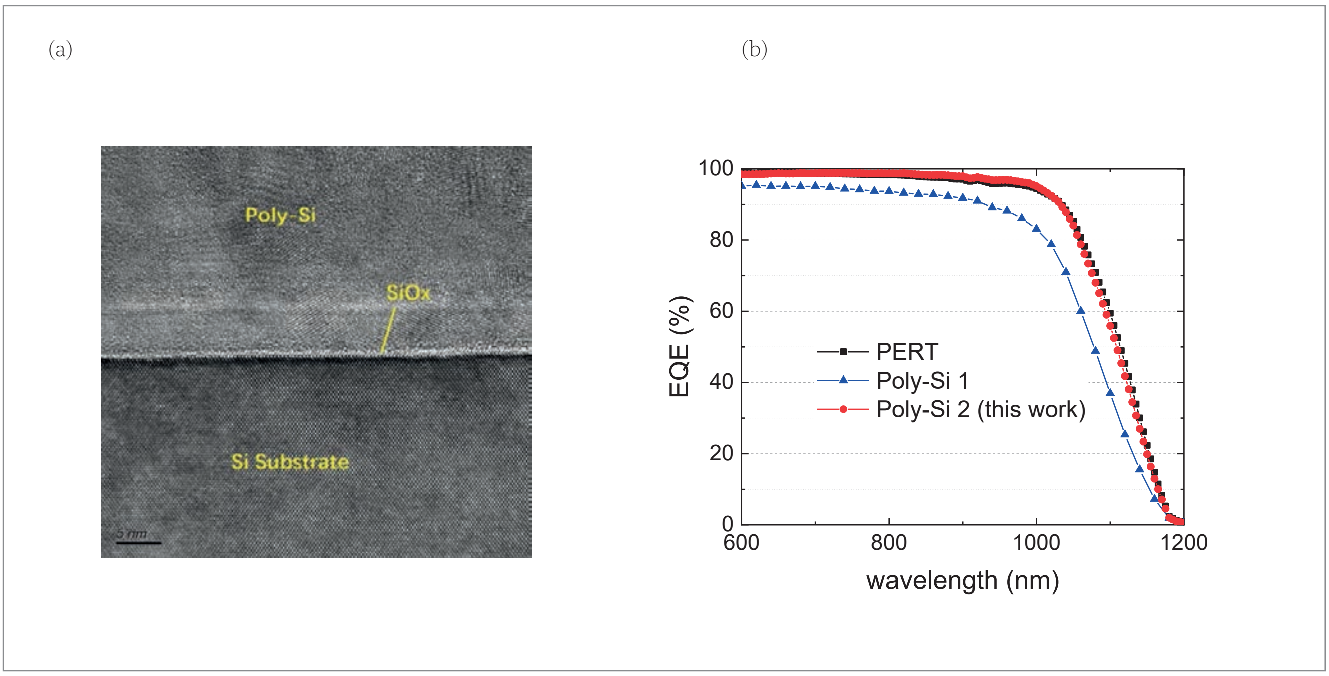

Figure 2. (a) TEM micrograph of the monoPoly stack. (b) External quantum efficiency (EQE) curves for a standard n-type passivated emitter rear totally diffused (PERT) cell with a homogeneous diffused BSF and two poly-Si layers with different optical properties, which affect the near-infrared (NIR) parasitic absorption in a cell. Poly-Si 2 is the optimized stack used in the monoPoly technology.

Semi-transparency

It is well known that poly-Si layers are highly absorbing as compared to c-Si. This is potentially detrimental to a solar cell, since it can lead to a loss in generated photocurrent when using doped poly-Si at the rear instead of a standard homogeneously diffused c-Si for the back-surface field (BSF). Fig. 2(b) presents comparisons of the quantum efficiency for 1) a standard n-type passivated emitter rear totally diffused (PERT) cell structure with a homogeneous diffused rear BSF ('PERT'); 2) a cell with a standard LPCVD-deposited poly-Si layer at the rear ('poly-Si 1'); and 3) a cell with a 'semi-transparent' monoPoly layer ('poly-Si 2'). The layer thickness and doping levels were kept similar for groups 2) and 3). The optimized and semi-transparent poly-Si 2 layer at the rear shows a much lower near-infrared (NIR) absorption that is on a par with that of the standard diffused PERT cell.

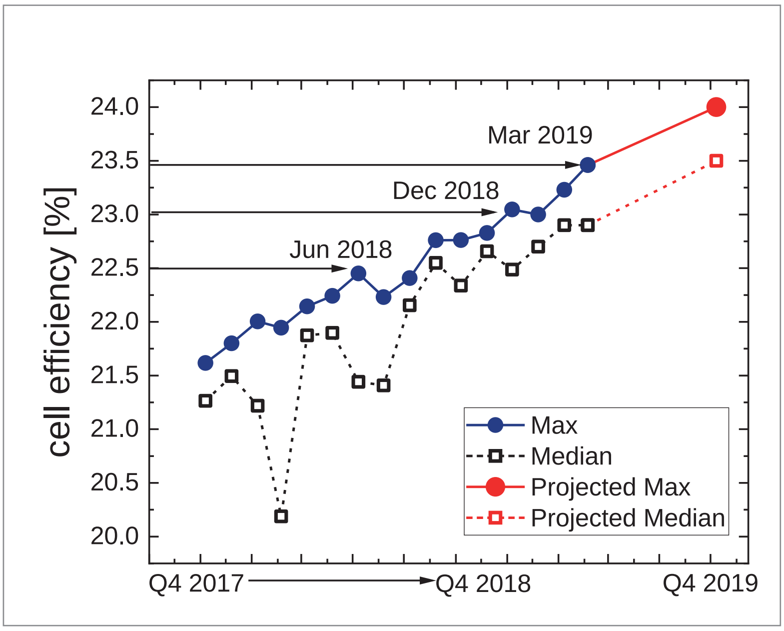

Figure 3. The rapid progress made in improving cell efficiencies for SERIS' n-type monoPoly solar cells.

Application of monoPoly layers at the rear side of n-type bifacial solar cells

The monoPoly stack fabricated using inline PECVD (Meyer Burger, Germany) – when used as the rear passivating contact in an n-type bifacial monoPoly solar cell – yielded excellent cell voltages of greater than 695mV and a peak V_{oc} of 698mV. The rapid progress in the development of this technology (as a result of clever optimization of the inter-related fabrication processes) is highlighted in Fig. 3. Fig. 4 presents comparisons of the *I–V* parameters of 1) standard n-type PERT (nPERT) cells with a diffused BSF; 2) monoPoly cells with and without the interfacial SiO_x; and 3) after further optimizations. The front and rear dielectric passivation for all groups was carried out using MAiA – a patent-protected process (stack) and equipment from Meyer Burger.

A reduction of the rear n^+:poly-Si thickness to ~120nm gave a peak V_{oc} of 697mV together with a boost in fill factor (*FF*) due to improved conductivity and uniformity in the poly-Si layer, resulting in a peak cell efficiency of 23.5% and

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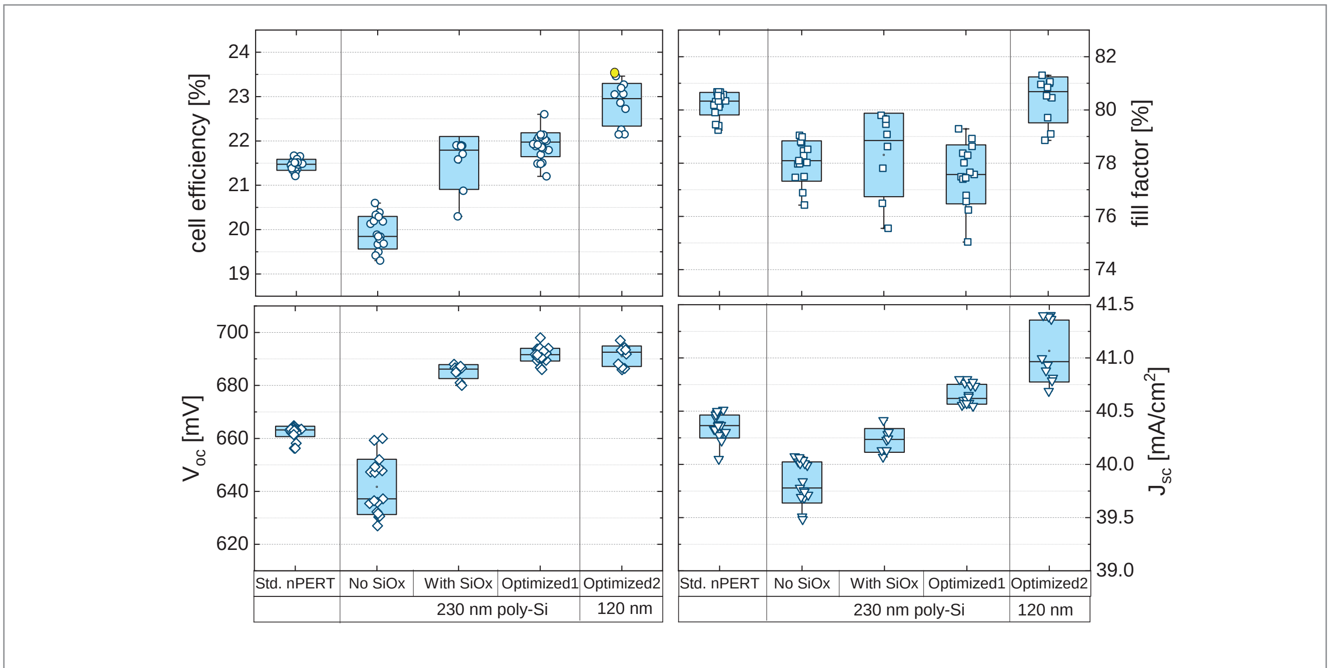

Figure 4. Batch *I–V* characteristics of n-type Cz-Si bifacial nPERT and monoPoly solar cells with a rear n^+:poly-Si/SiO_x passivating contact stack fabricated by industrial PECVD with screen-printed front and rear contacts (in collaboration with Meyer Burger, Germany).

a batch median of 22.9%. The reduced poly-Si thickness will, in addition, lead to savings in operational cost and higher throughput in a high-volume production environment, both of which are important in reducing the cost of cell production. If a 100nm/min process is translated to high-volume manufacturing, then this would mean the deposition of the layer for an entire tray in around one minute; this in turn translates to a very high throughput, which has not yet been achieved in the industry. Further optimization of the n^+:poly-Si layers is expected to further improve the *FF* values to more than 81.5% with a tighter distribution. The authors predict that these improvements, together with additional optimization of the front emitter and front metal pastes, will enable cell V_{oc} values greater than 720mV and efficiencies above 24% to be achieved in mass production.

Table 2 summarizes state-of-the-art *I–V* parameters for lab-type cells (mostly monofacial) and provides a striking comparison with commercially relevant screen-printed large-area (>6”) solar cells (mostly bifacial) with high-temperature fired contacts. An attempt has been made to include selected module results available from various resources. This summary is the most comprehensive (to the authors’ knowledge) at the time of publication. The module powers shown in Table 2 needs to be carefully recognized, as there is limited knowledge (known publicly) about the actual area of the module, cell gaps, module technology used and importantly the accountability of bifacial gains and method of measurement; therefore, these values are intended not for comparison purposes but rather for literature review.

monoPoly technology platform: retrofitting to existing PERC/T production lines

The introduction of passivating contacts to large-scale solar cell manufacturing is very appealing but at the same time challenging. It requires that the passivating contact be thermally stable when metallized with screen-printed industrial fire-through pastes. Moreover, high-throughput and low-cost deposition schemes for the passivating contacts are necessary.

The typical process flow (without a selective emitter) for standard pPERC and nPERT is presented in Fig. 5 for comparison purposes. The pPERC process has a laser step after passivation, whereas the nPERT process has an additional diffusion and wet-chemical clean to form the rear BSF. (It should be noted that the ‘mandatory’ stabilization tool widely used in PERC manufacturing lines today has not been included.) Furthermore, both processes use standard screen-printed metallization with high-temperature firing to form the metal contacts.

Over the past two years, SERIS and its key industry partners (including those involved in wet chemistry, boron diffusion, metal pastes and passivation layers) have been fine-tuning SERIS’ proprietary monoPoly passivating-contact solar cell technology platform for mass production, which has produced a peak cell efficiency of 23.5%. The monoPoly process – presented in Fig. 5 – is an eight-step simple and lean process flow that can be easily adapted to existing PERC/PERT production lines, with one additional tool required while maintaining the same number of total process steps. This passivating contact process uses a unique ‘patent-pending’ PECVD process and equipment, enabling a streamlined method of manufacturing. The same lean process is used for the front-side monoPoly application (not shown here in this paper).

	Eff. [%]	V_{oc} [mV]	J_{sc} [mA/cm^2]	*FF* [%]	Cell details	Module power	Module details
Small-area cells (≤ 100cm²)							
Fraunhofer ISE	25.7 [2]	724.9	42.5	83.3	n-type, rear poly-Si	–	–
ISFH	26.1 [3]	726.6	42.6	84.3	n-type, IBC	–	–
EPFL	22.6 [13]	719.6	38.8	80.9	p-type, both sides SiC_x	–	–
TU/e Delft	23.0 [15]	701	42.2	77.8	n-type, IBC	–	–
Georgia Tech	23.8 [21]	711.9	41.23	81.1	n-type, rear poly-Si	–	–
ANU	24.7[k]	704.8	42.4	82.6	n-type, rear poly-Si	–	–
Large-area cells (≥ 234cm²)							
ECN + Tempress	22.4 [24]	696	–	–	n-type, rear poly-Si	–	–
ISFH	22.3 [25]	714	38.5	81.1	n-type, both sides poly-Si	–	–
Georgia Tech	21.4 [27]	674	39.6	80.0	n-type, rear poly-Si	–	–
GCL	22.95[a]	698	40.3	81.6	n-type, rear poly-Si	–	–
Jinko	24.2[b]	724	40.7	82.4	n-type, rear poly-Si	469W (72)[f]	250.2cm², 5BB, half-cut
Jolywood	23.3[c]	705	40.8	81.1	n-type, rear poly-Si	330W (60)[g]/ 390W (72)[g]	246.21cm², 12BB, full-size
Trina	24.58[d]	–	–	–	n-type, rear poly-Si	355W (60) [30] / 425W (72)[h]	M4-258.25cm², 9BB, half-cut
REC	–	–	–	–	–	330W (60)[i]	M2-244.32cm², 5BB, half-cut
LG	–	–	–	–	–	340W (60)[j]/ 400W (72)[j]	M4-258.25cm², 12BB, full-size
SERIS + Meyer Burger	23.5[e]	697	41.4	81.3	n-type, rear monoPoly	345W (60)	M4-258.25cm², SWCT, half-cut

[a]Presented at PVCellTech 2019, [b]Press Release Jan. 2019, [c]Presented at nPV Workshop 2019, [d]PV Magazine May 2019, [e]Presented at 9th Silicon PV 2019, [f]PV Magazine Jun. 2019, [g]Presented at 9th Silicon PV 2019, [h]Trina website Jun. 2019, [i]REC N-Peak White Paper (REC website), [j]PVCellTech 2018 and LG NeON 2 V5 Product Brochure, [k]PVQAT, China 2018.

Table 2. Summary of global state-of-the-art efficiencies of passivating contact cells and some selected module powers.

monoPoly module results

Having an independently verified module result is a testament of a promising commercially applicable technology. Since monoPoly is a new technology which, importantly, uses a new inline PECVD process, it is important to test the cells at the module level. The initial results obtained using the facilities at Meyer Burger for modules with 60 M4-size monoPoly passivating-contact solar cells, which yielded a power output of more than 345W (certified by TÜV Rheinland), are presented here. This power output corresponds to an open-circuit voltage of 41.2V, a short-circuit current of 10.5A and a fill factor of 79.5% for a 60-cell module (*I–V* parameters presented in Table 3) with a white backsheet and using Meyer Burger's proprietary smart-wire interconnection technology (SWCT). The results are outstanding for an initial experiment and demonstrate a clear potential for the monoPoly platform to achieve a module power well above 350W with SERIS' latest 23.5% cells, irrespective of the module interconnection technology. It should be noted that the results (for both cells and modules) are obtained in pilot conditions and are expected to further improve when trialled in a mass-production environment.

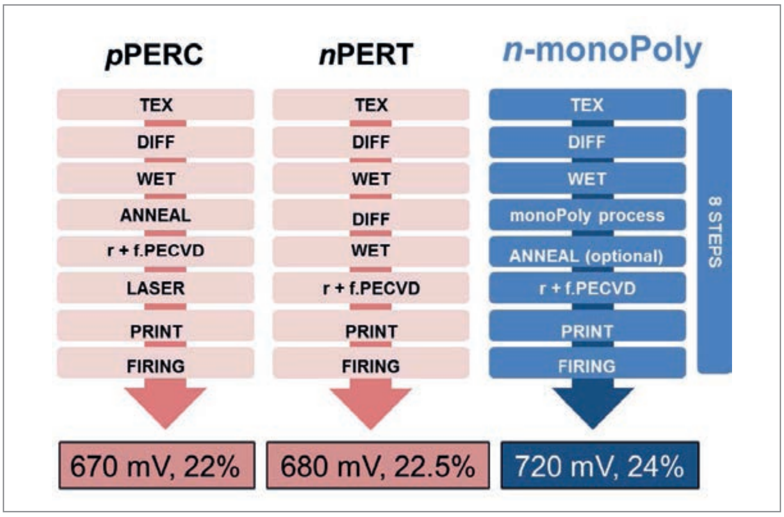

Figure 5. Comparison of the standard PERC and PERT process flows with the simple eight-step process flow for the fabrication of monoPoly solar cells, where the oxide and doped poly-Si can be deposited by PECVD, LPCVD or APCVD.

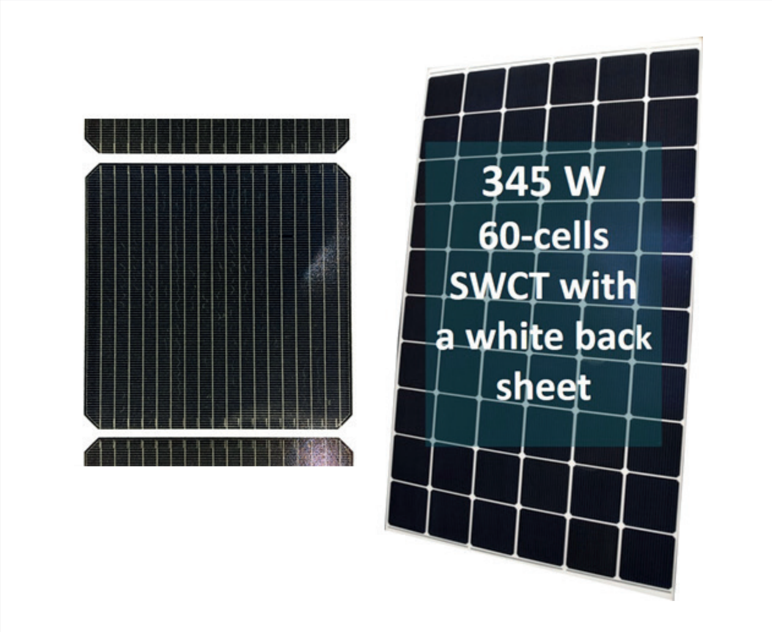

Figure 6. Preliminary module integration of monoPoly cells using smart-wire interconnection technology (SWCT) with 60 full-size cells (in collaboration with Meyer Burger, Germany).

P_{max} [W]	V_{mpp} [V]	I_{mpp} [A]	V_{oc} [V]	I_{sc} [A]	FF [%]
345.1	34.72	9.94	41.24	10.53	79.5

Table 3. Summary of module *I–V* parameters for a 60-cell monoPoly module.

Summary

This paper has presented SERIS' monoPoly technology platform, a comprehensive solution for the adoption of passivating-contact solar cell technology in the c-Si PV industry. A simple eight-step process flow was outlined using well-established processes, a new industrial PECVD tool and high-temperature commercial screen-printed metallization. Cell efficiencies of up to 23.5% have been achieved on M2-size wafers, paving the way for the transfer of monoPoly technology to mass manufacturing. Furthermore, initial tests demonstrated a module power of 345W for a module comprising M4-size 60-cell monoPoly cells. The authors predict that next-generation front emitters and tailored screen-printed pastes will take the technology to 24% cell efficiencies.

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References

[1] ITRPV 2017, "International technology roadmap for photovoltaic (ITRPV): 2016 results", 8th edn (Mar.) [http://www.itrpv.net/Reports/Downloads/].

[2] Richter, A. et al. 2017, "n-type Si solar cells with passivating electron contact: Identifying sources for efficiency limitations by wafer thickness and resistivity variation", *Sol. Energy Mater. Sol. Cells.*

[3] Haase, F. et al. 2018, "Laser contact openings for local poly-Si-metal contacts enabling 26.1%-efficient POLO-IBC solar cells", *Sol. Energy Mater. Sol. Cells,* Vol. 186, pp. 184–193.

[4] Mochizuki, H. et al. 1976, "Semi-insulating polycrystalline-silicon (SIPOS) films applied to MOS integrated circuits", *Jpn. J. Appl. Phys.,* Vol. 15, No. S1, p. 41.

[5] Matsushita, T. et al. 1976, "Highly reliable high-voltage transistors by use of the SIPOS process", *IEEE Trans. Electron Dev.,* Vol. 23, No. 8, pp. 826–830.

[6] Matsushita, T. et al. 1976, "Semi-insulating polycrystalline-silicon (SIPOS) passivation technology", *Jpn. J. Appl. Phys.,* Vol. 15, No. S1, p. 35.

[7] Matsushita, T. et al. 1979, "A silicon heterojunction transistor", *Appl. Phys. Lett.,* Vol. 35, No. 7, pp. 549–550.

[8] Fossum, J. & Shibib, M. 1980, "A minority-carrier transport model for polysilicon contacts to silicon bipolar devices, including solar cells", *1980 Int. Electron Dev. Meet.,* pp. 280–283.

[9] Lindholm, F. et al. 1985, "Heavily doped polysilicon-contact solar cells", *IEEE Electron Dev. Lett.,* Vol. 6, No. 7, pp. 363–365.

[10] Yablonovitch, E. et al. 1985, "A 720 mV open circuit voltage SiO_x: c Si: SiO_x double heterostructure solar cell", *Appl. Phys. Lett.,* Vol. 47, No. 11, pp. 1211–1213.

[11] Post, I.R., Ashburn, P. & Wolstenholme, G.R. 1992, "Polysilicon emitters for bipolar transistors: A review and re-evaluation of theory and experiment", *IEEE Trans. Electron Dev.,* Vol. 39, No. 7, pp. 1717–1731.

[12] Smith, D.D. et al. 2014, "Toward the practical limits of silicon solar cells", *IEEE J. Photovolt.,* Vol. 4, No. 6, pp. 1465–1469.

[13] Gizem Nogay, A.I. et al. 2018, "A simple process flow for silicon solar cells with co-annealing of electron and hole selective passivating contacts", *Proc. 7th WCPEC,* Waikoloa, Hawaii, USA.

[14] Smith, D.D. et al. 2014, "Toward the practical limits of silicon solar cells", *IEEE J. Photovolt.,* Vol. 4, No. 6, pp. 1465–1469.

[15] Yang, G. et al. 2018, "High-efficiency black IBC c-Si solar cells with poly-Si as carrier-selective passivating contacts", *Sol. Energy Mater. Sol. Cells,* Vol. 186, pp. 9–13.

[16] Feldmann, F. et al. 2013, "A passivated rear contact for high-efficiency n-type silicon solar cells enabling high V_{oc}s and FF> 82%", *Proc. 28th EU PVSEC,* Paris, France.

[17] Brendel, R. et al. 2013, "Recent progress and

options for future crystalline silicon solar cells", *Proc. 28th EU PVSEC*, Paris, France, pp. 676–691.
[18] Feldmann, F. et al. 2014, "Passivated rear contacts for high-efficiency n-type Si solar cells providing high interface passivation quality and excellent transport characteristics", *Sol. Energy Mater. Sol. Cells,* Vol. 120, pp. 270–274.
[19] Feldmann, F. et al. 2014, "Carrier-selective contacts for Si solar cells", *Appl. Phys. Lett.,* Vol. 104, No. 18, p. 181105.
[20] Haase, F. et al. 2017, "Interdigitated back contact solar cells with polycrystalline silicon on oxide passivating contacts for both polarities", *Jpn. J. Appl. Phys.,* Vol. 56, No. 8S2, p. 08MB15.
[21] Rohatgi, A. et al., "Fabrication and modeling of high-efficiency front junction n-type silicon solar cells with tunnel oxide passivating back contact", *IEEE J. Photovolt.,* Vol. 7, No. 5, pp. 1236–1243.
[22] Stodolny, M. et al. 2016, "n-type polysilicon passivating contact for industrial bifacial n-type solar cells", *Sol. Energy Mater. Sol. Cells,* Vol. 158, pp. 24–28.
[23] Duttagupta, S. et al. 2018, "monoPoly cells: Large-area crystalline silicon solar cells with fire-through screen-printed polysilicon contacts", *Sol. Energy Mater. Sol. Cells,* Vol. 187, pp. 76–81.
[24] Stodolny, M. et al. 2019, "Review and outlook of doped and undoped LPCVD poly-Si based passivating contacts for industrial Si solar cells", *Proc. 9th SiliconPV*/nPV Workshop, Leuven, Belgium.
[25] Peibst, R. et al. 2018, "Building blocks for industrial, screen-printed double-side contacted POLO cells with highly transparent ZnO:Al layers", *IEEE J. Photovolt.,* Vol. 8, No. 3, pp. 719–725.
[26] Nandakumar, N. et al. 2019, "Approaching 23% with large-area monoPoly cells using screen-printed and fired rear passivating contacts fabricated by inline PECVD", *Prog. Photovolt: Res. Appl.,* Vol. 27, No. 2, pp. 107–112.
[27] Tao, Y. et al. 2017, "Carrier selective tunnel oxide passivated contact enabling 21.4% efficient large-area n-type silicon solar cells", *Proc. 44th IEEE PVSC,* Washington DC, USA, pp. 1–5.
[28] Stodolny, M.K. et al. 2017, "Material properties of LPCVD processed n-type polysilicon passivating contacts and its application in PERPoly industrial bifacial solar cells", *Energy Procedia,* Vol. 124, pp. 635–642.
[29] Krügener, J. et al. 2017, "Improvement of the SRH bulk lifetime upon formation of n-type POLO junctions for 25% efficient Si solar cells", *Sol. Energy Mater. Sol. Cells,* Vol. 173, pp. 85–91.
[30] Chen, Y. et al. 2019, "Mass production of industrial tunnel oxide passivated contacts (i TOPCon) silicon solar cells with average efficiency over 23% and modules over 345 W", *Prog. Photovolt: Res. Appl.,* 10.1002/pip.3180.

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