Industrialized high-efficiency mono PERC cells

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Abstract

Passivated emitter and rear cell (PERC) technology can significantly increase the absolute efficiency of PV cells by over 1.2%. Since PERC processing is also compatible with current cell processing, and does not incur overly high manufacturing costs, many PV manufacturers are focusing on developing the industrialization technologies for PERC cells. This paper describes industrial p-type mono five-busbar (5BB) PERC cells with an average efficiency of 21.6%. Compared with standard aluminium back-surface field (Al-BSF) cells, the absolute efficiency has increased by 1.3%, and the open-circuit voltage (V_{oc}) has increased by 25mV, demonstrating that an aluminium oxide passivation film by atomic layer deposition (ALD) has excellent rear-side passivation performance. Furthermore, PERC cells have more concentrated efficiency distributions, which means they are able to achieve more than 300W module power in 60-cell standard modules. TongWei has set a target of achieving the mass production of PERC cells with an efficiency of over 22%. This paper also presents a loss analysis for current TongWei PERC cells, along with a roadmap of future efficiency development.

Introduction

The deployment of renewable energy, especially solar, is becoming ever more popular. It is estimated that with every 1% increase in PV cell efficiency, electricity costs would decrease by 7%; therefore, improving solar cell efficiency is very important for reducing the average electricity-generating cost of solar and driving it towards grid parity. While wafer products are becoming higher quality, and progress is being made on the development of cell processes, equipment and materials, the efficiency of standard mono Al-BSF solar cells is approaching its limit.

Process improvements for conventional Al-BSF cells are mostly performed on the front side of the cells. Studies have shown that the rate of rear-side recombination is still quite high in the case of Al-BSF cell structures, and only 60–70% of the IR radiated light that reaches the Al-BSF could be reflected. These are the two intrinsic factors that prevent further increases in Al-BSF cell efficiency; however, solar cells based on the passivated emitter and rear cell (PERC) concept could effectively solve these two problems. Studies have also shown that if the BSF metal electrodes of conventional Al-BSF cells are replaced by passivation layers or stacked layers along with many small local busbar electrodes, the rear-side recombination rate could be dramatically reduced to below 200cm/s, while at the same time the long-wavelength spectral response in the over-800nm waveband would be improved, resulting in a density increase in short-circuit current (I_{sc}). Because of the excellent passivation performance on the rear side, V_{oc} rises substantially. PERC cells could therefore significantly improve the solar cell conversion efficiency [1].

The PERC concept was introduced by Blakers and Wang [2], with a reported laboratory conversion efficiency of 22.8%; in 1999 Zhao et al. [3] pushed this up to 24.7% – a world-record laboratory conversion efficiency. The lab preparation for PERC cells deploys several technologies, including photoetching, evaporation, thermal oxidation passivation and electroplating. All these technologies could result in higher PERC cell performance, but inevitably in higher costs as well.

Since the initial advances, the industrialization of PERC cells has experienced slow progress, and it was not until 2010 that significant headway was made. The success of the industrialization of PERC cells is due to a variety of different elements, including the rear-side passivation process. The processing requirements for PERC cells are met by the aluminium oxide deposition, the laser grooving, the conductive aluminium pastes for rear-side passivation, and the development of front-side Ag pastes for conductive contacts on PERC cells.

PERC cells are increasingly favoured by many cell manufacturers because of their high conversion efficiency, their developed technology, and their good compatibility with conventional cell production processes. Almost all Tier-1 PV companies have plans for PERC mass production. In fact, in the next one to three years it is estimated that PERC will become the standard technology configuration for c-si cell manufacturers. Many major cell manufacturers – such as Q CELLS, SolarWorld and Trina Solar – have already begun mass production of PERC solar cells. In addition, more PV manufacturers are migrating their conventional Al-BSF lines to PERC cell lines. The ITRPV roadmap [4] estimates that PERC capacity will reach 25GW by the end of 2017.

TongWei Solar is a dedicated cell manufacturer with 6GW mono- and poly c-si cell production capacity. With the use of advanced cell manufacturing equipment and technologies, over 20.3% conversion efficiency has been achieved for conventional mono c-si cells, and over 18.6% for poly c-si cells. The company's S2 plant in Chengdu was the first to implement smart manufacturing, with expectations of achieving 12GW mono and poly c-si

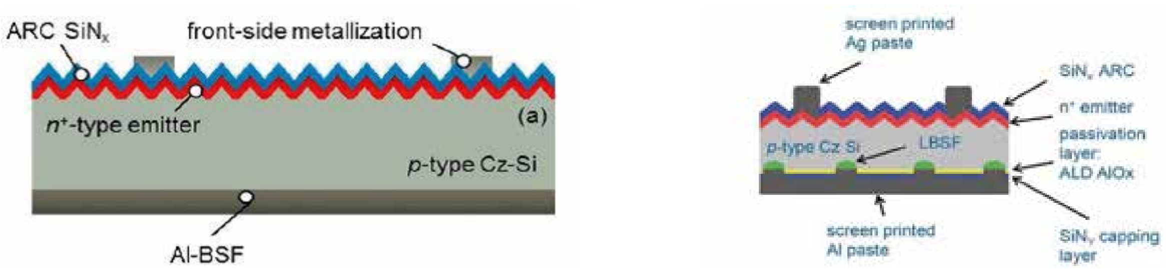

Figure 1. Comparison of the structures of conventional Al-BSF cells and PERC cells.

cell production capacity by the end of 2018. This paper describes the progress of the industrialization of TongWei Solar PERC cells, along with efficiency loss analyses of these cells. Future developments in order to achieve 22% conversion efficiency are also discussed.

Mono PERC cell manufacture

Conventional Al-BSF cells require processes that include texturing, diffusion, etching, plasma-enhanced chemical vapour deposition (PECVD), screen printing and firing tests. The PERC cell front-side processes are the same as those for an Al-BSF cell, while on the rear side an aluminium oxide passivation film is used to form a passivation layer; by using local metal contacts, the rear-surface recombination rate is greatly reduced. With a polishing process on the rear surface of the wafers, and a second deposition of SiN film on the aluminium oxide passivation film, the reflection of the incident light on the rear surface can also be improved, thus increasing V_{oc} and I_{sc} and resulting in an enhanced cell conversion efficiency.

TongWei Solar's PERC cells utilize aluminium oxide ALD for the rear-side passivation. Al_2O_3 is chosen as the passivation film, mainly because of its high density of fixed negative charge, which has excellent stabilizing properties for both field effect and chemical passivation performance. Low-cost nanosecond laser grooving and subsequent Al paste screen printing and firing are all used to form the PERC structure. Fig. 1 shows a comparison of the structures of conventional Al-BSF cells and PERC cells. From this figure, it can be seen that upgrading from conventional Al-BSF cells to PERC cells requires only the addition of aluminium oxide coating equipment for the rear sides and laser grooving equipment, as well as some fine-tuning of each process to suit the PERC cells.

Fig. 2 shows TongWei Solar's 5BB PERC cell, featuring:

- Uniformed pyramid texture by alkaline texturing on the front and polished mirror structure on the rear.
- Negative pressure diffusion to form uniform emitters with high sheet resistances.
- Optimized SiN coating on the front side and additional thin oxidization process, resulting in an improved potential-induced degradation (PID) performance and better consistency in appearance of the cells.
- Aluminium oxide passivation film realized by NCD's atomic layer deposition (NCD-ALD) on the rear side, and PECVD deposition of the SiN protective film.
- DR Laser's nanosecond laser grooving on the rear passivation film.
- Printing on the rear side using Al paste, to form an aluminium local back-surface field (LBSF) structure.
- Printing using high-quality low-temperature Ag paste, for better electrode adhesion and current collecting.
- Light-induced regeneration (LIR) with fast online light injection, to ensure that light-induced degradation (LID) is <1.5% on PERC cells.

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A 6-inch (156.75mm × 156.75mm) CZ solar-grade boron-doped monocrystalline wafer, with a resistance of 1–3Ω·cm and a thickness of 180–190μm, was selected to undergo the manufacturing processes shown in Fig. 3. The *I*–*V* testing for the electrical properties of the wafer was carried out on a HALM machine, in compliance with the Fraunhofer ISE third-party cell-testing standards.

Fig. 4 shows the PERC cell efficiency distribution profile of a single mass-production line, with an average mass-production efficiency of 21.61% and an optimum single-cell efficiency of >21.9%. The narrow Gaussian distribution of the cell efficiencies proved that the current PERC processes have excellent stability properties. Compared with the performance of cells from the control group (i.e. Al-BSF cells processed using the same single production line), the PERC cells fabricated with the current processes

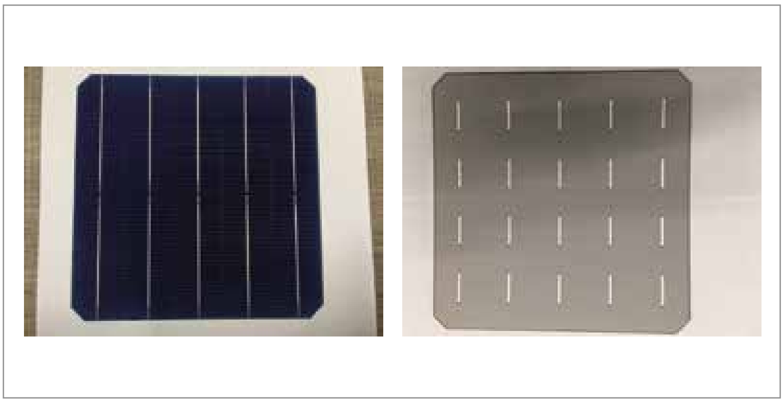

Figure 2. TongWei Solar's 5BB PERC cell.

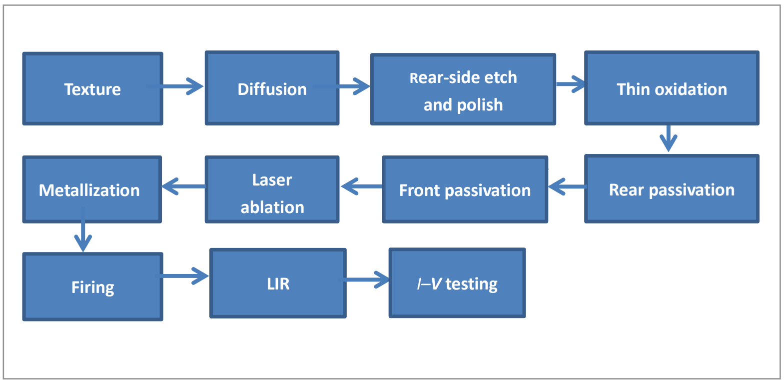

Figure 3. Manufacturing processes for PERC cells.

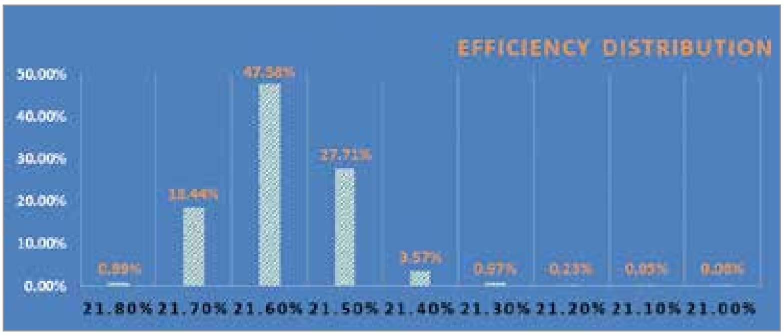

Figure 4. Efficiency distribution of PERC cells.

ΔV_{oc} [mV]	ΔI_{sc} [mA]	ΔFF [%]	ΔEff [%]
25	300	−0.5	1.3

Table 1. Absolute differences of the parameters for the PERC cell compared with the Al-BSF group based on the same wafers.

achieve 1.3% additional conversion efficiency and an extra 25mV in V_{oc} (see Table 1), indicating that the performance of the aluminium oxide passivation process on the rear-side passivation is excellent. In addition, the rear-side polishing and the deposited SiN anti-reflection film contribute to the internal reflection of the incident light, resulting in an increase of 300mA in I_{sc}. However, the fill factor (*FF*) of the PERC cells is 0.5% lower than that of the conventional Al-BSF cells, mainly because of the change of the conduction path of aluminium LBSF contacts; this results in a series resistance (R_s) that is higher for PERC cells than for conventional Al-BSF cells, and thus a lower *FF* (Table 1).

Reliability controls for product performance have been introduced within the cell processing line at TongWei Solar; these controls utilize 100% EL detection, 100% LID pre-regeneration and inline welding tension monitoring, in order to ensure the stability of the PERC cell processes and high reliability. With the distributed printing process used in PERC cells, pastes with high adhesion could be chosen for the front-side busbars to improve cell performance while maintaining the weld quality, and hence to guarantee the long-term reliability of PERC modules. Fig. 5(a) shows the electrode adhesion test results for the PERC cells: the peel strength was >2.5N/shift for the front-side busbar, and >4.9N/shift for the rear-side busbar.

Fig. 5(b) shows the LID attenuation results for the PERC cells. Six cells within each shift were measured at random time points, and the measured attenuation values for each batch were below 1.5%, meeting the current mainstream cell product specifications. PERC solar cells in TongWei's main efficiency band were used in the standard 60-cell modules, resulting in over 300W per module on average.

P-type mono PERC cells efficiency roadmap

SolarWorld and Trina Solar have both reported cell conversion efficiencies above 22% [5] for their industrialized screen-printed PERC solar cells. From efficiency simulations, it is expected that a conversion efficiency of greater than 24% on PERC technology could be realized by further reducing electrical and optical losses, as claimed by some studies [6].

TongWei has set a short-term goal of achieving an efficiency of more than 22% for mass-produced PERC cells. Table 2 shows the values for the relevant electrical parameters required in order to reach this target.

The ideal fill factor FF_o is close to 84% for cells with 21.6% efficiency, without taking into account the series resistance, parallel resistance and recombination losses. However, if the ideality factor $n = 1$, on the assumption of the current levels of series and parallel resistance the theoretical *FF* for R_s could reach 81.4%, but the actual *FF* for R_s is only about 80.68%, according to Table 1. Therefore, some of the loss in *FF* arises from the ideality factor. Fig. 6(a) shows the decrease in *FF* as the ideality factor n increases: a higher value of n indicates a higher emitter recombination loss, which needs to be further optimized.

Fig. 6(b) shows the correlation between the *FF* and R_s for PERC cells: a strong negative correlation can be observed. To further increase the *FF* in the efficiency-improving processes for future PERC cells requires a further reduction in losses brought about by R_s and n.

In order to push the V_{oc} of cells up to 680mV,

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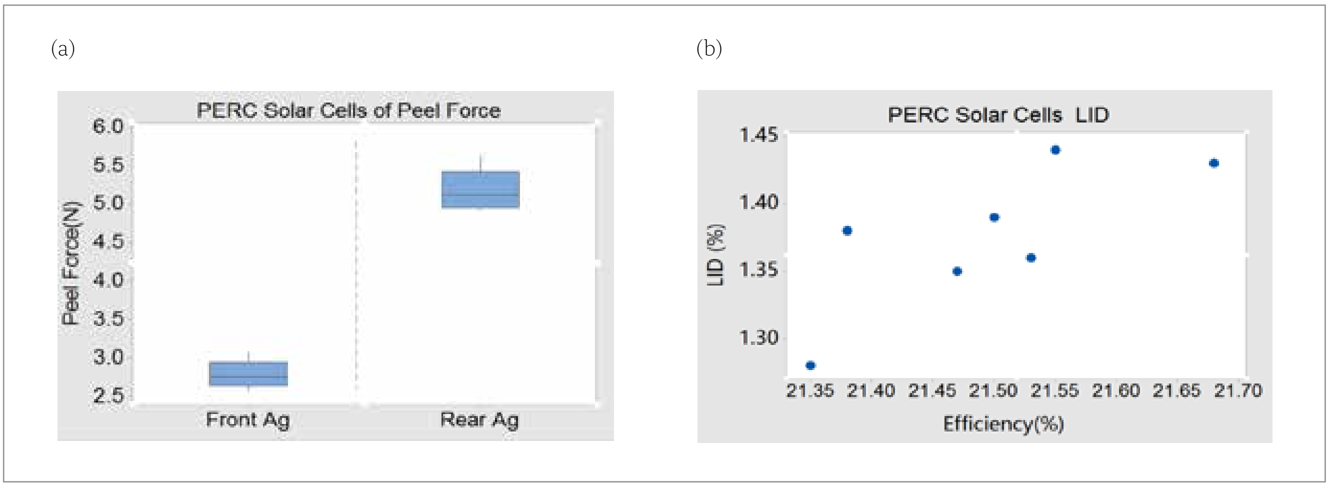

Figure 5. (a) The electrode peel strength testing conditions are: the angle used is reversed 180 degree, peeling speed is 300mm/min, ribbon width is 1.0mm, welding process temperature is 360°C, welding worktop temperature is 50°C, and the result is calculated by the average value of 5 busbars' pulling force; (b) LID test results for PERC cells.

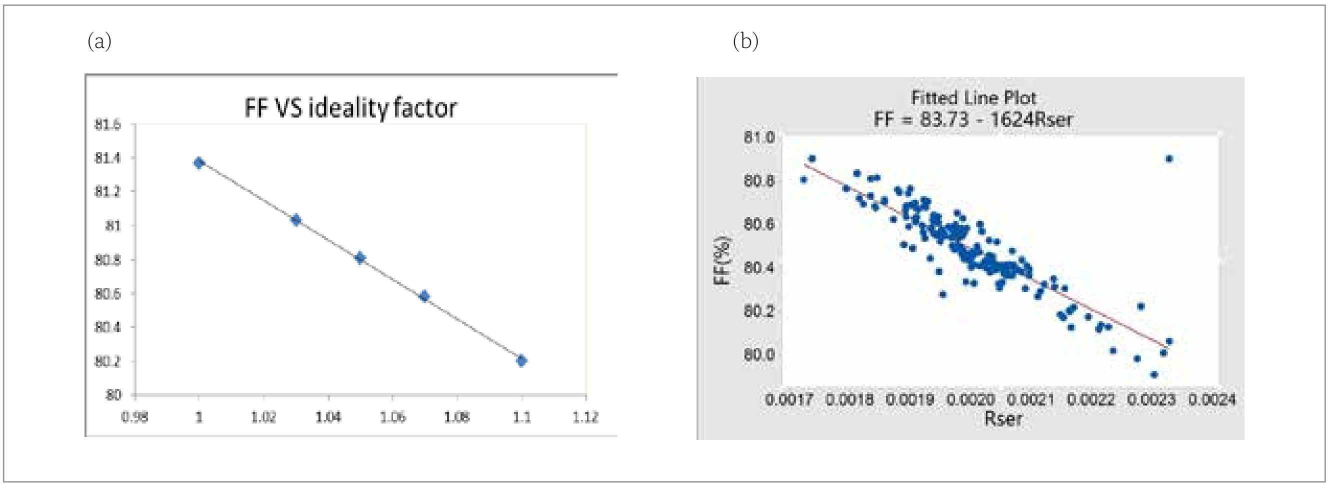

Figure 6. (a) Relationship between *FF* and ideality factor *n*; (b) correlation between *FF* and R_s.

	I_{sc} [A]	V_{oc} [V]	*FF* [%]	$\Delta\eta$ [%]
Baseline	9.767	0.670	80.68	21.61
Target	9.820	0.676	81.40	22.11

Table 2. *I–V* parameters for current PERC cells and for simulated target cells.

it is necessary to further reduce the value of J_o. Studies have shown that the existing J_o that affects PERC cells efficiency mainly lies in the emitter recombination and Ag-Si contact recombination [7–8]. The key to further increasing the V_{oc} of PERC cells therefore relies on a combination of various methods: emitter structure doping with low recombination rates, enhancing the surface contact characteristics, and improving wafer quality. Provided the contact resistances are sufficiently maintained, I_{sc} could be increased by reducing shading and conductive resistance through a better aspect ratio of the printed busbars, and by further optimizing the texture process, polishing process on the rear side and matching up, as well as the coating process of the front and rear sides.

On the basis of the above analysis, Fig. 7 shows the paths of improvement for PERC cell efficiencies for each operational process, to achieve >22% mass-production efficiency through further optimization of processes, such as emitter doping, front and back conductive path design and passivation process improvements. At the same time, further reductions in the LID of PERC cells will also be the main focus in the future.

Conclusion

A mass-production efficiency of 21.60% for PERC p-type mono cells has been achieved at TongWei Solar; cell efficiency has a narrow distribution band in mass production, demonstrating excellent process stability and quality reliability. ALD aluminium oxide technology yields outstanding

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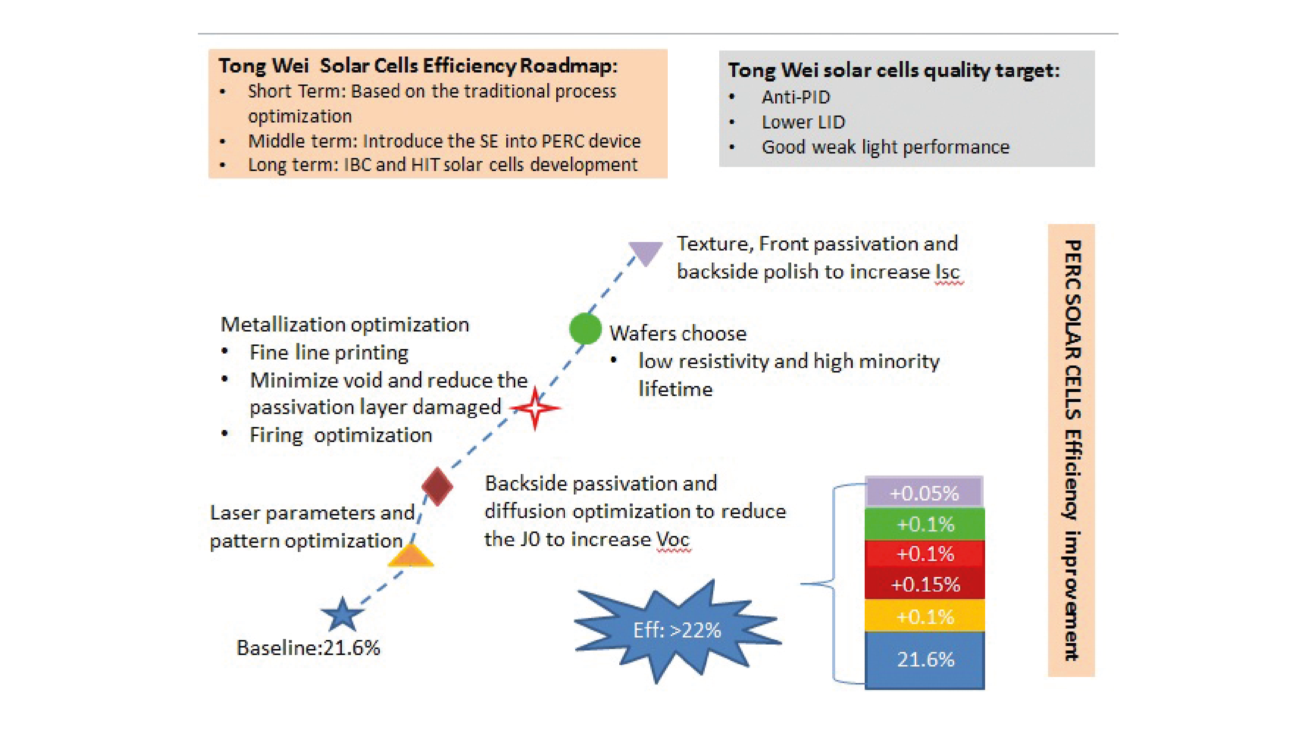

Figure 7. TongWei PERC cells efficiency roadmap.

passivation properties, increasing V_{oc} by 25mV. However, in order to achieve 22%+ efficiency for PERC solar cells in mass production, it is noted that further investigation regarding passivation and emitter doping processes is required, and that the metallization process needs to be optimized and high-quality wafers are necessary.

Acknowledgement

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About the authors

Lead author Dr. Zhang Guanlun worked at TSMC as an R&D manager, and then joined Motech in 2011, where he led several technical research activities, including increasing the efficiencies of conventional mono cells as well as of Motech PERC mono cells. In 2015 he also developed methods to significantly reduce the LID of mono cells and PERC cells to ~1%. He is currently the R&D vice president at TongWei and heads the team working on PERC processing technologies for further increasing c-si cell efficiencies.

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