Bifacial solar products light new pathway to future PV

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Abstract

Relatively few experimental and academic studies about bifacial p-type PERC cells have been published to date. This paper looks at the experimental findings from JinkoSolar's large area, industry-grade bifacial monocrystalline silicon PERC (biPERC) cells. These cells are manufactured using mass production tools and in a continuous running condition. The average batch efficiency of these biPERC cells is over 21.8%. Detailed analysis of the electrical parameters and cross sectional microscopic images of these cells will be shown.

As the solar photovoltaic market and technology have improved over the past years, there has been an impressive drop in global PV electricity generation cost. One of the major contributors is the continuous increase in solar cell and module conversion efficiencies. For example, at JinkoSolar, average efficiency for p-type PERC solar cells has reach over 21.8%. At the same time, concerns have also been raised that crystalline silicon PV products efficiencies are approaching a ceiling. As a result, the PV market is eagerly looking for new frontier innovations that could help maintain the current development trend. Bifacial solar cell technology and bifacial modules, which collect light energy from both the front and rear side of the panel, can be this new frontier. Bifacial cell and module technologies use most of the available panel surface area and effectively increase overall power generation efficiency.

JinkoSolar as one of the world's largest solar module manufacturer has been at the forefront on the development of high-efficiency bifacial technologies. Existing data has shown that the output power of a bifacial PV module is significantly higher than standard PV modules. Bifacial module standard test condition power can reach over 320W in a 60-cell module form factor and reach over 380W in a 72-cell module form factor. When applied in an environment with a white painted background, the effective efficiency of bifacial modules can reach as high as 27.3%. When paired with an appropriate tracking system, the power generation capacity of bifacial modules can be over 40% greater than that of conventional modules. In addition, as our bifacial modules utilizing JinkoSolar's Eagle Dual PERC production infrastructure, JinkoSolar's p-type bifacial products solutions greatly improve the module performance while keeping the marginal price increases at a competitive level. Our p-type bifacial PERC solar cell can reach a bifaciality of over 80% in lab environments and over 70% when mass produced.

Bifacial solar cell performance

P-type passivated emitter rear contact (PERC) is a mainstream high-efficiency solar cell technology, where a rear-side passivating dielectric layer is used to reduce the surface recombination power losses and to improve the internal reflection [1]. PERC technology has made huge strides in the market, and is an area where JinkoSolar has also invested in R&D efforts. JinkoSolar's p-type PERC bifacial cell is based on our existing PERC structure. Localized rear contacts are formed through laser ablation on the passivation layer and subsequent screen-printing process. Instead of full area Al contacts, Al fingers and busbars can be screen printed on the rear surface so that reflected light can also be absorbed for higher current output. PERC solar cells have the potential to achieve an average mass production efficiency of >22%. Additionally, bifacial p-type PERC solar cells require less metal on the rear side and different processing recipes, enabling the potential for further future cost reduction.

Surprisingly, despite these advantages, few experimental and academic studies about bifacial p-type PERC cells have been published to date [2]. In this paper, we provide a glance at the experimental findings and understandings for JinkoSolar's large area, industry-grade bifacial monocrystalline silicon PERC (biPERC) cells. These cells are manufactured using mass production tools and in a continuous running condition. The front-side structure of the test samples uses a homogenous junction design rather than the selective emitter technique. The average batch efficiency of these biPERC cells is over 21.8%. Detailed analysis of the electrical parameters and cross sectional microscopic images of these cells will be shown.

Boron-doped Czochralski-grown Si wafers were used in this study. The wafers used have a dimension of 156x156 mm^2, resistivity of 1.5-1.8 Ohm-cm, and thickness of ~200μm. Conventional mass production processes were used as follows: the wafers are first textured with alkaline and cleaned with acid/DI water. Emitter formation was than carried out through $POCl_3$ diffusion. Next, phosphosilicate glass (PSG) and rear phosphorus diffused layers were etched away by a HF/HNO_3 solution. Fourthly, the wafers were coated with surface passivation. Fifthly, anti-reflection layers were deposited by plasma enhanced chemical vapour deposition (PECVD) and atomic layer deposition (ALD). Then, rear surface passivation layers were etched open by a nanosecond laser. Afterwards, front surfaces were screen printed with Ag fingers and busbars. Lastly, Al fingers and busbars were screen printed on rear surface for bifaciality.

A schematic of the bifacial PERC structure is shown in Figure 1.

Figure 2 shows the cross section SEM images at the local rear Al contacts for both the biPERC and PERC cells. The rear contacts consist of (i) screen printed Al (ii) alloyed Al-Si eutectic and (iii) the Al doped p+ layer (Al-BSF). The mechanism of the rear contact formation in a typical PERC cell is described as follows [3]: At the start of the firing process, high temperature ramping causes the printed Al paste to melt. This melted Al also dissolves Si on the wafer surface. At peak firing temperature, a high solubility causes Si to saturate in the melted Al paste. As the temperature decreases, a reduction in the Si solubility causes a large amount of Si to be rejected from the melt until an Al-Si eutectic concentration of ~12.6% wt is reached. This rejected Si will recrystallize at the wafer/melt interface and will be incorporated with a small amount of Al from the melt. This Al is usually in the range of 10^{18} to 10^{19} cm^{-3} and will act as a p-type dopant, forming the so-called high-low p+/p junction known as the back surface field (BSF) [3]. The Al-BSF acts as minority carrier reflectors, which prevent the loss of photo-generated carriers at the rear surface [4-9].

Interestingly, from the SEM images in Figure 2, biPERC cells exhibit a much thinner Al-BSF layer of ~1μm than the PERC cells of ~4μm. The thinner Al-BSF layer may explain the drop in Voc as observed in the biPERC cells. A thinner Al-BSF layer can degrade its effectiveness in passivating and improve the recombination velocity of the rear surface [10]. As observed under SEM, the thinner Al-BSF is believed to be a result of the misalignment between the screen-printed rear Al fingers and the laser opening. This misalignment limits the concentration of available Al dopants during firing, resulting in the thinner Al-BSF. The lack of Al atoms participating in the rear contacts formation can also been seen from the thinner Al-Si eutectic in rear contacts of biPERC cells compared with that of the baseline PERC cells, as illustrated in Figure 3. Further experiments have shown that through improving the alignment and quality of the printing process, higher efficiencies can be achieved.

As a summary, we report industrial

Table 1. Cell parameters of bifacial PERC used in this study.

Parameters	Batch average bifacial PERC (front)	Batch average bifacial PERC (rear)
Efficiency	21.81%	16.58%
FF	80.47%	80.53%
Voc	675mV	666mV
Isc	9.80A	7.55A

Figure 1. Schematic of a bifacial PERC cell used in this study.

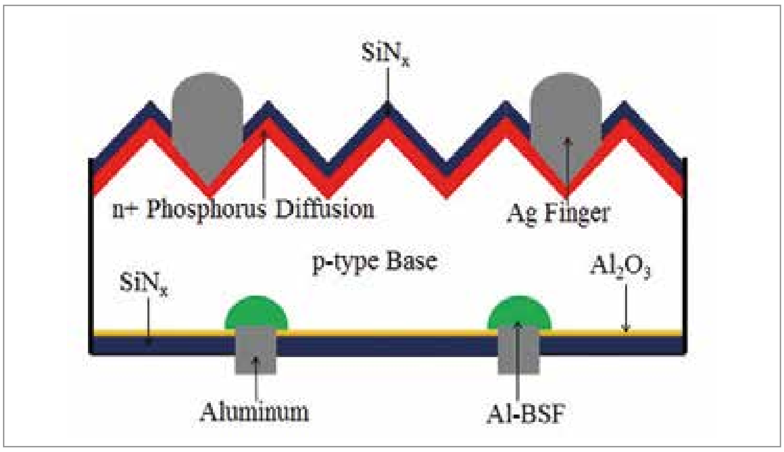
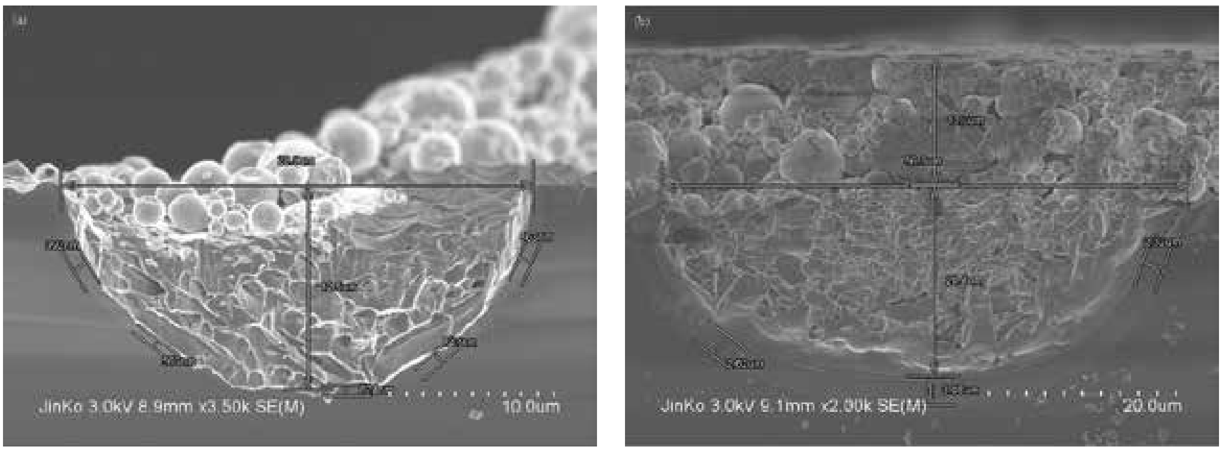


Figure 2. SEM images at the local rear Al contacts for the (a) bifacial PERC cells (b) baseline mono-facial PERC cells.



monocrystalline p-type bifacial PERC cells with an average batch efficiency of >21.8%. Eighty percent of Al paste can be saved from the rear contacts of the PERC cells. Further developments have been applied into the production with improvement in: printing alignment, rear contact design and Al paste contact formation. The average front side-efficiency of biPERC cells can reach more than 21.8% and is expected to reach over 22% when techniques such as selective emitter and rear surface texturing are applied. Additionally, with a bifaciality of 76%, it is expected to have a large room for either improving the front side efficiency or enhance the bifaciality.

Bifacial solar module performance

Depending on the albedo of the installation environment, JinkoSolar's bifacial products can reach an effective power output of 360W in a 60-cell form module. In addition, the Eagle Dual module, utilizing double-glass encapsulation, provides a better reliability with 30-year linear power degradation guarantee. Thus the significant gain in lifetime power generation makes it a tremendously attractive product for the PV market. Highlights of the bifacial products include:

Significant rear side power contribution

The bifaciality factor φ, which is the ratio of the maximum rear surface power and the maximum front surface power under standard test conditions, is a good indicator of the overall power generation performance. Generally, the bifacial p-type PERC module has an average bifaciality value in the range of 65-70%. JinkoSolar's bifacial PERC product applies fine finger technique to reduce the optical shading and the internal resistance. Combining the fine finger technique with a low resistivity welding ribbon, the overall module electrical loss is significantly reduced, allowing for a higher generation capacity. Bifaciality of 80% has been achieved in lab environments and an average bifaciality value of >70% has been measured for the JinkoSolar's bifacial modules in mass production.

Low temperature coefficient and outdoor operating temperature

Two-and-a-half millimeter ultra-thin patterned encapsulation glass is applied on both sides of the bifacial cells to create the bifacial module. With thinner glass, the heat dissipates to the surrounding air more easily compared to conventional modules. In addition, the pattern on the inner side of the glass is designed to scatter incident lights, effectively increasing light trapping and reducing solar-thermal conversion. Based on field test results, the Eagle Dual Module has a temperature coefficient of -0.38%/°c, lower than standard unilateral module of -0.41%/°c. The practical

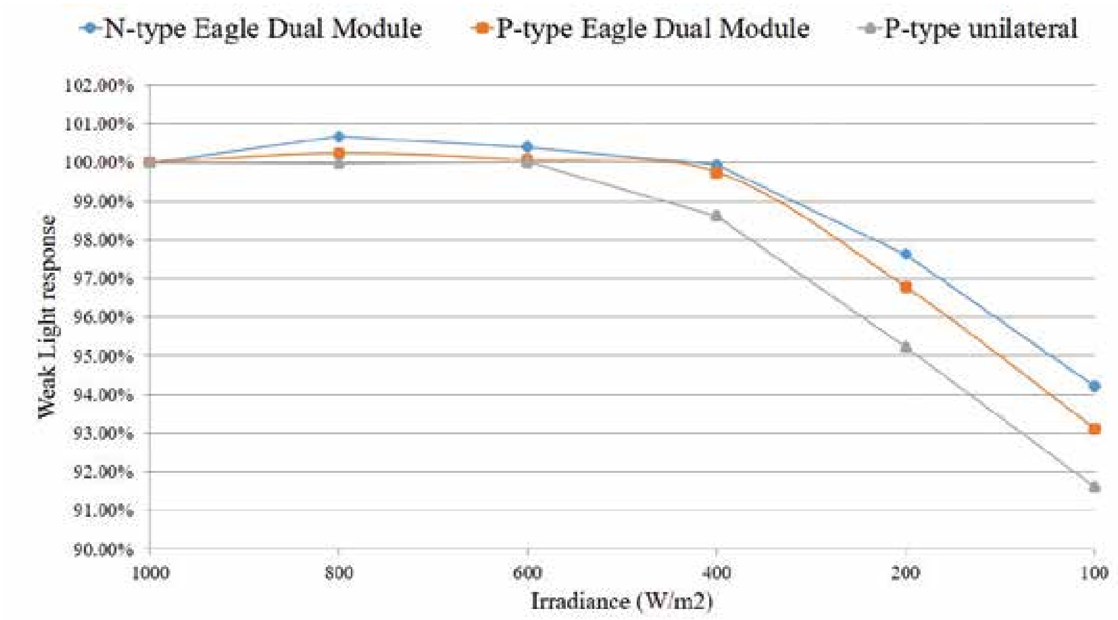


Figure 3. Weak-light response for different modules.

Module type		T_{MAX}/°c	T_{MIN}/°c	T_{Ave}/ °c
Standard unilateral P-PERC	Rear	66.30	63.70	65.60
	Front	61.60	49.00	58.70
The Eagle Dual Module	Rear	67.90	50.30	62.20
	Front	59.60	52.60	57.80

Table 2. Operational temperature for different module types under same conditions.

Degradation Test	DH3000	TC600	TC150-HF30
P-type Eagle module	3.85%	3.43%	3.62%
Degradation Test	DH1000	TC200	TC50-HF10
P-type standard unilateral module	3.92%	3.89%	3.73%

Table 3. Degradation results for different modules.

operating temperature is measured to be 1-3°c lower than standard modules. These results indicate that bifacial modules perform better at limiting thermal related losses, considering all other circumstances are the same.

Excellent weak light response

By adopting a passivation process and antireflection coating on both sides, the p-type biPERC modules are able to capture even more photons. Meanwhile, the thin 2.5mm glass provides better optical transmittance and lower refraction loss. Bifacial products have shown good performance in weak light environments. In-field test data collected at an irradiance level down to 100W-200W/m^2 is shown in Fig.4; significant advantages of bifacial products have been observed over monofacial panels.

Improved module reliability

The double-glass structure utilized in our bifacial products protects the panel from infiltration of oxygen and ambient moisture. This protection enables higher reliability, increasing the outdoor operational lifecycle to 30 years. Frameless design is adopted to eliminate potential-induced degradation of the panel, while durable encapsulation materials are used with high tenacity to protect panels from mechanical stress. Table 3 lists typical degradation test results for PERC bifacial modules. As shown in Table 3, compared to standard module, bifacial modules can endure test conditions three times more strict than standard tests. The dynamic load test for JinkoSolar bifacial PERC modules has shown outstanding performance results with minimal cell cracks. Damp-heat (DH) 3000 test has also shown an excellent result with less than a 5% degradation rate. As a summary, biPERC products have significant advantages of module quality and reliability.

Excellent outdoor generation capacity

All the above mentioned characteristics, such as high bifaciality value, low temperature coefficient, low operational temperature and excellent weak light response, comprehensively contribute to the outdoor performance of JinkoSolar p-type biPERC modules. Field tests on ground surfaces with different albedos show that the Eagle Dual Module

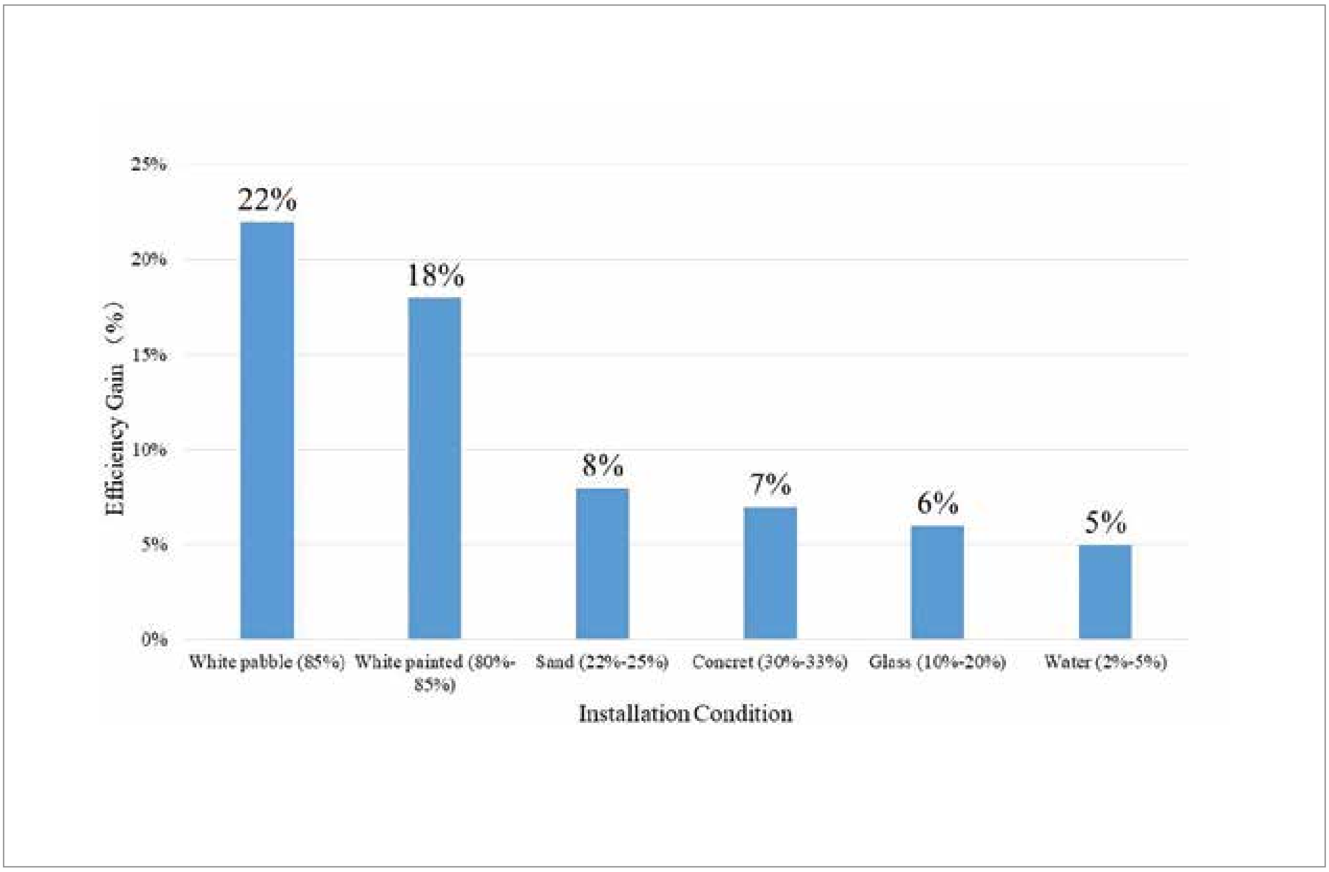


Figure 4. Efficiency gain of p-type Eagle (bifaciality=0.70) in different installation places

enables a 5-25% increase in output when compared to that of a standard unilateral module in a fixed mounting system. In a smart tracking PV system, the output increase is expected to be >40%.

Conclusion

With an excellent panel power generation performance, bifacial technology opens up a new frontier for PV technology. The enhanced PV module efficiency will lead to reductions in levelized cost of electricity. JinkoSolar's bifacial products, both p-type and n-type series, show that cell and module technology upgrades can be achieved at a competitive cost. Increasing market interest for bifacial products, especially from agricultural/fishery solar farms and PV projects in regions with high snowfall or long daylight hours, is writing this new chapter in PV technology.

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