WHITE PAPER

INCREASED ENERGY YIELD THROUGH BIFACIAL TECHNOLOGY

1. INTRODUCTION

Unlike monofacial cells, bifacial solar cells not only collect sunlight on the front side, but they also collect light on the back side that is reflected from the surface beneath the solar panel and from the environment. Although bifacial technology was developed in the late 1970s, bifacial solar cells have remained a niche product in the photovoltaic market due to high production costs. In September 2015, the Institute for Solar Energy Research Hamelin (ISFH) and SolarWorld AG presented a novel manufacturing process for an economically viable bifacial cell and module technology. [1]

The process is based on technology used in high-performance PERC cells (passivated emitter and rear cell) which SolarWorld has successfully integrated into volume production.[2] In the development of the new bifacial product *Sunmodule Bisun*, SolarWorld has profited from this technological expertise and series production experience.

Bifacial technology is time-tested. In the early 1980s, Cuevas et al. reported an increase in module output of 50 percent by using special light-concentrating systems and solar panels featuring bifacial solar cells.[3] Most current bifacial developments are based on complex solar cell architectures on the basis of n-type [4, 5, 6] silicon substrates or heterojunction solar cells.[7, 8] These result in high production costs due to their vast consumption of expensive silver paste.[9] As a result, the market share of bifacial modules has remained very low. For 2015 the forecast was only 5 percent.[10]

2. EARLY HISTORY OF RESEARCH

In 1977 a research group from Spain[11] and Mexico[12] presented research papers on bifacial cells that the first European Photovoltaic Solar Energy Conference in Luxembourg. These first publications described an experimental bifacial solar cell with an efficiency of only 7 percent.[12] The structure of these cells are based on back-junction cell architecture with one or more junctions, similar to integrated back-contact cells and heterojunction cells.[13]

On the 1970s and 1980s, many research teams and scientists worked on various bifacial cell designs, achieving efficiencies between about 12 and 19 percent.[13] In 1980 Andres Cuevas et al. discovered that no mirrors or concentrators were necessary to produce approximately 50 percent more power than conventional solar panels, if the rear side of solar panels could simply collect diffuse light reflected by light-colored surfaces.

3. CURRENT STATE OF BIFACIAL TECHNOLOGY

Since that discovery, numerous scientists and manufacturers have worked to improve bifacial solar cell technology by collecting diffuse light from the rear side of the cell. Still, many modules available on the market integrate either n-type wafers or heterojunction cells.

Silicon heterojunction cells consist of crystalline silicon substrates covered with thin layers of differently doped amorphous silicon on both sides.

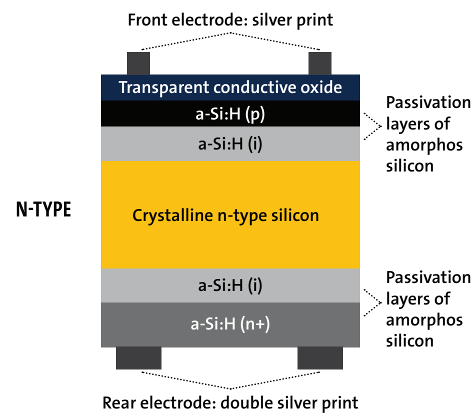


FIGURE 1: *Schematic cross section of a standard monofacial silicon heterojunction cell [9]*

Compared with solar cells based on p-type wafers, which in 2015 represented more than 90 percent market share,[10] heterojunction cells and cells on n-type substrates have higher production costs. Reasons for this cost difference, compared with conventional p-type mono or multi cells, include the high consumption of expensive materials, such as silver paste, as well as expensive manufacturing processes. For example, the production cost of a commercial available heterojunction cell is about 60 U.S. cents per watt, while the production cost for a p-type standard cell is below 35 U.S. cents per watt. Even p-type monofacial cell with advanced cell architecture costs about 20 U.S. cents per watt less than a heterojunction cell.[14]

A comparison of the production costs for two cells made with n-type wafers and p-type wafers leads to similar results (compare Table 1). Manufacturing bifacial cells based on heterojunction technology can require three to six additional manufacturing steps, e.g. rear side texturing, rear side diffusion or etch removal, depending on the machinery and the production line of the cell manufacturer. For this reason, only a few manufacturers worldwide produce small quantities of bifacial cells.

High cost and lower manufacturing volumes have held bifacial cell technology to a niche in the solar market with a market share of less than 5 percent.[10]

SILICON CELL TYPE	COST RANGE [U.S. CENTS/WATT-PEAK]
n-type	50-60
p-type mono	34-40
p-type multi	28-32

TABLE 1: *Cost of various monofacial silicon cells in U.S. cents per watt-peak*

4. THE NEW APPROACH

The new bifacial cell technology introduced by SolarWorld AG and ISFH has the potential to clear the path for future mass bifacial solar module production. The bifacial cell developed by SolarWorld is based on a p-type monofacial substrate using PERC technology. In contrast to conventional crystalline cells with full-area aluminum back surface fields, PERC technology adds an additional passivation layer to the rear side of the cell. This additional layer increases the cell's ability to capture light because it reflects an additional portion of the light back into the cell. Figure 2 illustrates the schematic concept of PERC technology.

SolarWorld successfully transferred PERC technology to series production in 2012. Since the launch of the Sunmodule Plus with PERC mono cells in January 2013, SolarWorld has made great strides in the development of PERC technology. A new world record of 22.04 percent[15] cell efficiency using industrial p-type silicon recently demonstrated the technology's strength.

The new bifacial solar cell was developed on the basis of mature PERC technology. Figure 3 shows a schematic cross-section of a monofacial (A) and bifacial (B) PERC cell. In contrast to the PERC cell, the bifacial solar cell has an opening in the screen-printed rear contact to allow light to reach the active region of the cell from the back. The full-area aluminum screen printing of the PERC cell has been replaced with an optimized grid, similar to the front contact; the thickness of the rear passivation layer was reduced to increase light transmittance.

No additional steps are required for the bifacial cell manufacturing process based on p-type PERC technology. Only three manufacturing steps must be slightly modified to produce a cell that can harvest sun energy on its front and rear: rear-side passivation, contact laser opening and rear-grid printing. Although it seems simple, integrating this technology in the standard manufacturing line requires optimally adjusting a total of 18 additional process parameters to produce a high-quality cell and achieve a perfect result.

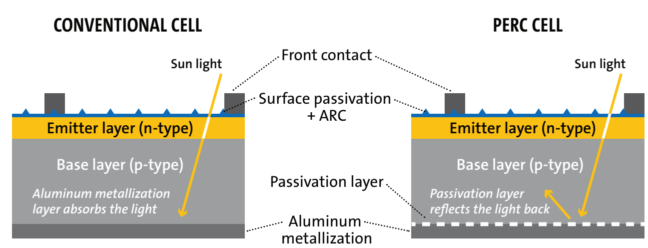
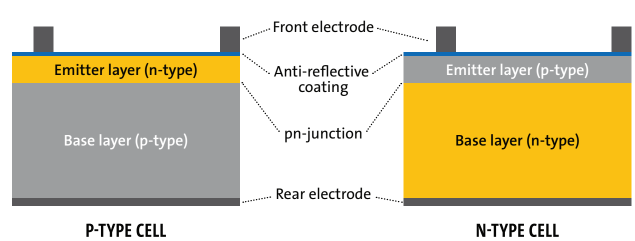


FIGURE 2: *Schematic diagram of conventional cell structure and PERC cell*

P-TYPE AND N-TYPE SILICON CELLS

To optimize the electrical properties of semiconductors, a small percentage of foreign atoms are deliberately introduced (doped) into the crystal structure of the material. Doping increases the number of charge carriers in the crystal structure, which are either free electrons or free holes. If doped silicon contains mainly free electrons, it is known as n-type. If it contains mainly free holes, it is known a p-type. A solar cell contains both p-type and n-type material. As depicted in Figure 1, the ratio between the two materials defines whether it is identified as a p-type wafer or an n-type wafer. P-type cells are based on p-type wafers with a very thin layer of n-type material. In n-type cells, the architecture is reversed. Currently, these are mainly used in the production of high-efficiency solar cells. P-type cells also achieve relatively high efficiencies and have proven to be very cost-efficient. Thus this is why p-type cells are currently dominating the PV market– with a share of more than 90 percent in 2015.[10]



The use of standard materials – for example, p-type silicon – and standard manufacturing processes makes possible the industrialized mass production of bifacial cells. As a result, they are less expensive and therefore more suitable for the mass market.

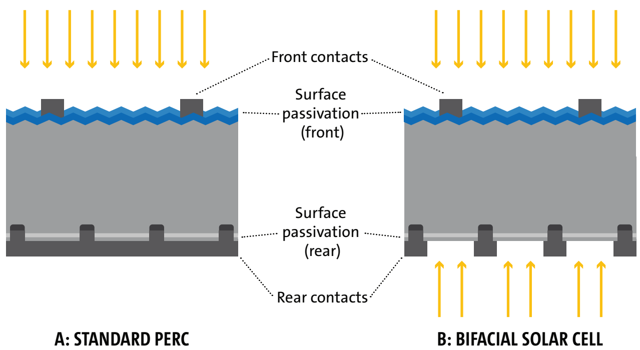


FIGURE 3: *Schematic cross-section of a PERC structure (A) and a bifacial solar cell (B)*

5. THE SUNMODULE BISUN

Bifacial solar cells have the advantage of producing more energy by using reflective incidental light from the rear along with light from the front of the module. With the transparent rear sides, glass-glass modules therefore provide the ideal module technology for bifacial solar cells. A second glass plate on the rear of the module allows reflected sunlight to reach the cells from the back. In this way, individual modules generate higher yields. Embedding the cells in a glass composite protects them from environmental and mechanical influences. High durability and minimal degradation ensure a maximum service life. Because SolarWorld is among the manufacturers that produce glass-glass modules at an industrial scale, the new bifacial product profits from a mature technological process.

There is a new relevant parameter for bifacial solar modules in addition to the front side maximum power at standard test conditions ($P_{mpp\ front}$): the bifaciality B, which refers to the ratio of the front to the rear power measured under standard test conditions (STC).

$$B = \frac{P_{mpp,\ rear}}{P_{mpp,\ front}}$$

The first generation of bifacial SolarWorld modules have achieved a bifaciality of over 65 percent. Further improvements are expected with ongoing solar cell development.

The transparent and active rear of bifacial modules enable additional energy production. The energy boost of a bifacial solar power system describes the increase in specific energy yield (kWh/kWp) of a bifacial module in comparison to the front side power of a monofacial module of the same performance class (measured under standard test conditions), which has been installed under the same conditions. Direct or diffuse light is reflected from the ground, and a portion is scattered to the rear side of the module (compare Figure 2). The amount of the light that reaches the rear side largely depends on two factors: the reflectivity of the ground beneath the module and the installation height of the module. If a bifacial module is mounted at a height of about 50 cm (distance between the bottom edge of the module and the ground) and above an extremely bright surface, this technology can generate an additional yield of up to 25 percent.[16]

The advantages of the Sunmodule Bisun such as its mechanical resilience, longer service life and additional energy yield make the bifacial module an ideal solution for all commercial, industrial and agriculture applications – particularly in a flat-roof or ground-mounted system. For such installations the module is installed so that sufficient light hits the module's active rear side. In connection with a bright surface beneath the module, e.g., whitewashed concrete or white roofing foil, even more light is reflected on to the module. Figure 4 shows a schematic installation of a bifacial solar module.

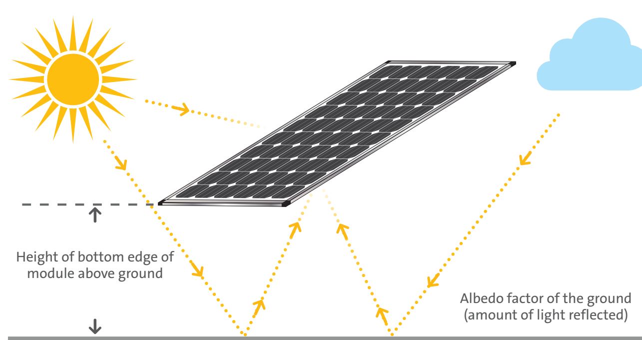


FIGURE 4: *Schematic of a system using bifacial modules*

6. CONCLUSION

Bifacial cell technology is time-tested. Researchers and module manufacturers have been developing this technology over decades. However, due to the relatively high production costs for bifacial solar cells, most currently available technologies have resulted only in niche products, since costs are a crucial factory in the PV market. A new approach to manufacturing bifacial solar cells, which SolarWorld based on PERC technology and introduced in late 2015 – enables relatively cost effective cell production. As a result, it is suitable for industrial production and the mass market.

The Sunmodule Bisun, the new generation of bifacial modules, is available as a glass-glass module consisting of 60 bifacial cells or as a glass-clear backsheet module consisting of 72 bifacial cells with additional energy yield. The size of this "energy boost" depends mainly on the reflective behavior of the surface beneath the module and the installation height of the solar power system. An optimal combination of surface and the highest possible system height makes it possible to achieve an additional energy yield of up to 25 percent. In the field, this technology reduces the cost of energy produced in all applications.

A look into the future shows that in the medium term further improvements could allow bifacial technology to achieve new efficiency world records. Such leaps in technology development help ensure that solar technology will become more affordable and competitive. With this development, the technology can establish itself as the most important source of safe, reliable and sustainable energy supply in the near future.

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