Characteristics and development of interdigital back contact solar cells

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Abstract. Silicon-based solar cells are an important field for the development of the photovoltaic industry. The grid electrode on the front surface of the traditional silicon solar cell causes shading loss. However, the positive and negative electrodes are placed on the back surface of the interdigitated back contact (IBC) solar cell, which causes no shading loss and improvement of photoelectric conversion efficiency. The core of the IBC silicon solar cell is the interface control, field effect control and the design of the positive and negative electrode patterns on the back. Different manufacturing processes ensure the accuracy of the grid electrode and reduce production costs. This paper systematically introduces the structure and interface characteristics and development history of IBC solar cells, and looks forward to the development trend and application prospects of IBC solar cells.

1. Introduction

Due to the continuous exploitation and consumption of traditional petroleum resources, environmental pollution and energy crisis have become increasingly serious. As a renewable energy method, solar cells have the advantages of wide application scenarios and low maintenance costs compared to wind power and biomass power generation. In this case, solar cells have obvious advantages[1]. Crystalline silicon has the advantages of stable performance, abundant reserves, mature technology and non-toxicity, occupying more than 90% of the photovoltaic market[2]. In order to further deploy and develop renewable energy, it is necessary to improve the photoelectric conversion efficiency of silicon-based solar cells.

Traditional silicon-based solar cells have some problems in the design process: (1) The grid electrode of the illuminated surface produces shadows and causes shading loss; (2) The front-end diffusion layer of the battery increases the series resistance[3]; (3) Limit the doping concentration of the battery base area in order to ensure the service life of the device; (4) The battery needs a reasonable heat dissipation structure design[4]. In response to these issues, Schwartz and Lammert proposed interdigitated back contact solar cell (IBC) in 1975[5-6]. At present, in the civil market, the photoelectric conversion efficiency of 400W special finger back contact solar cells produced by SunPower company in the United States is 22.6%[7]. This solar cell has 8% more energy per watt than conventional silicon solar panels of the same size arrays (approx. 1.64m², 280 W multi, 17.0% efficient).

However, IBC silicon solar cells still face many challenges in reducing production costs and improving device photoelectric conversion efficiency. Current research on IBC batteries focuses on the doping of the front and back of the battery, the design of electrode patterns and the selection of
silicon materials to improve battery performance and increase service life and reduce production process steps to reduce cost[8]. In this paper, combined with the development process of silicon-based solar energy, the structural characteristics of interdigital back contact solar cells and the optimization methods of front and rear surfaces are reviewed in detail. This paper also looks forward to the future development direction.

2. Structural characteristics of IBC silicon solar cells

Figure 1.[9] is a two-dimensional planar structure diagram of a homogeneous junction interdigital back contact solar cell. Its structural characteristics are that there are not grid like electrodes on the front side, and the positive and negative electrodes are cross arranged on the back surface of the cell. Compared with the traditional silicon-based solar cell, there is no metal electrode in the front side of IBC cell. Therefore, there is no need for low resistance contact to reduce the charge recombination of the front surface, no shading loss and maximizing the absorption of sunlight improves the battery Jsc. However, when light is emitted from the cell surface, the photo-carriers generated in the monocrystalline silicon region on the front surface of the cell need to diffuse to the back p-n junction to form photocurrent. Therefore, the diffusion distance of a few carriers in the material needs to exceed the length of the device. Compared with the traditional p-type solar cells, the minority carrier lifetime of n-type materials is longer than that of p-type materials, and the decay rate is low. Therefore, the front silicon substrate of IBC is n-type doping.

2.1. Positive surface light trapping structure

The light loss of IBC solar cells is mainly due to the transmission light loss caused by the small cell thickness and the light loss caused by the front surface light reflection. In order to reduce the light loss, the structure design of reducing light reflection and increasing the path of light in the absorption layer are carried out on the light inlet surface of the solar cell. At present, the cells usually manufactured by inkjet printing[10], wet chemical etching[11], laser etching nanoimprint[12], lithography[13] and so on. Light trapping structures include pyramid structure[14] and inverted pyramid structure[16], honeycomb honeycomb structure[17] and V-grooves[15] and nanowire type, etc.
2.2. Positive surface passivation

On the surface of the silicon wafer, the periodicity of the crystal is destroyed and dangling bonds are generated, which makes the crystal surface have a large number of defect levels in the band gap; in addition, the deposition of dislocations, chemical residues and surface metal will introduce defect levels. These all make the surface of the silicon wafer a recombination center.

The front surface structure after texturing can improve the absorption rate of incident light, but it will increase the surface recombination rate. Therefore, it is necessary to passivate the surface to reduce the recombination rate of photo-carriers on the surface, so as to obtain effective photocurrent[18]. There are two basic techniques for reducing the recombination rate on the surface of solar cells. One is to reduce the surface state density[18]. The higher the surface defect density, the higher the surface coincidence rate. Therefore, in theory, the solar cell surface recombination rate can be greatly reduced by depositing or growing an appropriate passivation layer. For example, thermally oxidized SiOx[20] is a good material for surface passivation of crystalline silicon cells, because there are a large number of fixed positive charges in thermally oxidized silicon dioxide. These fixed positive charges will produce field-effect passivation and reduce defects on the surface of silicon wafers. The second is to reduce the concentration of free electrons or holes on the surface of the solar cell[19]. The bonding process of electron and hole is the key to surface recombination. The closer the surface electron and hole concentration is, the higher the recombination rate is. Conversely, if the concentration of either electron or hole is greatly reduced, the recombination rate will also decrease accordingly.
2.3. Back surface doping
IBC silicon solar cells generally have two heavily doped regions, p+ (emitter) and n+ (back surface field), on the back side of the IBC silicon solar cell. These two doped regions are alternately arranged in a cross pattern. The emitter is used to collect hole carriers and the back surface field is used to capture electrons. Because the mobility of electrons in the medium doping region is about three times that of holes. Generally, the emitter area of the IBC solar cell is larger, and the larger the emitter area makes the distance of the hole to the emitter shorter[21], so there will be a considerable proportion of electrons to reach the back field through transverse transmission, which reduces the coincidence loss and increases the Jsc. Since the positive surface field can reduce the lateral resistance of majority carriers, the area of the emitter region or the width of the entire pattern period can be further increased by optimizing the characteristics of the front surface field.

2.4. Back surface passivation
In order to suppress the recombination of carriers on the back surface of the IBC solar cell, it is generally necessary to add a SiOx[20] passivation layer between the back surface of the silicon substrate and the metal electrode, and then achieve local contact between the electrode and the silicon substrate through local corrosion. The contact area of the electrode and the doped region and the pattern scheme need to consider the carrier recombination and current collection efficiency and internal series resistance.

2.5. Electrode pattern structure on the back surface
The positive and negative electrodes of IBC silicon solar cells are located on the back of the cell, and show finger cross shape. Through the holes on the passivation layer, they contact with the silicon plate, and the doping and contact patterns are various.

In 1984, Swanson[22] et al. Proposed a new type of back contact solar cell. The pattern of doping and contact on the back surface of the cell is not a strip of positive and negative electrodes, but a point contact solar cell with orderly arranged and distributed point electrodes. The point contact design reduces the area of the doping area and increases the area of the passivation layer, which improves the output voltage and photoelectric conversion efficiency of solar cells. As shown in Figure 3, the two layers of metal aluminum electrodes on the back of the solar cell contact with the PdSi point of n+ region and p+ area respectively, and the two layers of metal aluminum are separated by Al2O3. It is characterized by no need to print insulating layer, the main fine grid is printed once, and the battery process is simple; when making components, the metal foil is used to interconnect the cells, and the accuracy requirement is lower than that of the non-main grid type. In 1984, the photoelectric conversion efficiency of point contact solar cells prepared by Swanson reached 19.7%. Giuseppe Galbiati[23] et al. proposed the Screen-printed IBC-zebra solar cell process in 2018. This process does not need photolithography, and only needs a mask to conduct gas-phase diffusion, which reduces the metallization loss and improves the passivation of phosphorus and boron doped regions. The IBC solar cells with Ag point contact by screen printing brush are prepared. The photoelectric conversion efficiency exceeds 22.3% and the VOC reaches 668mv.

![Figure 3 Cross-section schematic of Point back contact IBC solar cell][22]

James M. Gee[24] et al. Proposed a new back contact mode in 1993. This back contact concept is called emitter write through (EWT). Its structure is shown in Fig. 4. The solar energy electricity can
wrap the emitter on the front surface through laser drilling to make it contact with the electric shock on
the back surface. EWT solar cell manufacturing process is based on embedded contact cell technology.
This EWT solar cell can achieve 18% and 21% efficiency on the area (100 cm2) polysilicon and
monocrystalline silicon solar grade silicon substrate, respectively.

Figure 4 (a) Cross-section schematic of Double-Junction Emitter Wrap-Through Cell; (b) Schematic
of Emitter Wrap-Through Cell[24].

Holger Knauss[25] introduced a new metallization wrap through (MWT) back contact solar cell in
2005. As shown in Figure 5, the collector emitter and contact finger of MWT solar cell are located on
the front of the cell. But n-doped busbars are moved to the back of the solar cell, and the electrical
connection between busbars and fingers is realized by a limited number of laser drilling. Compared
with the traditional silicon-based solar cells, the effective finger length can be reduced by increasing
the number of bus bars, so it is more suitable for large-area solar cell production. The photoelectric
conversion efficiency of MWT solar cells (140 cm2) produced by electroless metal plating process is
17.0%.

Figure 5 Schematic drawing of a Metallization Wrap Trough (MWT) solar

3. The development process and challenges of IBC technology
In 1975, Schwartz and Lammert proposed the concept of back contact. After years of research and
development, people developed interdigitated back contact solar cell. Initially, this type of cell was
mainly used in concentrating systems. In 1984, Swanson et al. reported a point contact cell (PCC)
solar cell similar to IBC, and achieved a conversion efficiency of 19.7% under 88 times concentrator
system. Compared with normal IBC battery, the process is more complex and is not easy to be
popularized on a large scale. In 1985, Verlinden[26] et al. prepared a 21% efficiency IBC solar cell
under standard illumination. In 1997, SunPower and Stanford University developed IBC batteries with
a conversion efficiency of 23.2% in one light. In 2004, SunPower developed the first generation of
large area (149 cm2 ) IBC battery a-300 by using point contact and screen printing technology, with a
battery efficiency of 21.5%.

In 2007, SunPower developed the second generation IBC battery with an average efficiency of
22.4% after optimizing and improving the original a-300 IBC battery process. In 2014, SunPower's
third-generation IBC solar cells on n-type CZ silicon wafers achieved a maximum efficiency of 25.2%.

At present, based on the research of IBC cells, people are also trying to integrate IBC cells with other batteries. For example, Masuko, K[27]. in 2014, combined hit heterojunction solar cells with IBC solar cells in a new structure, called heterojunctions interdigitated back contact (HJ-IBC) solar cells, The photoelectric conversion efficiency (144cm2) is 25.6%. Kunta Yoshikawa[28] et al. prepared a large area (180 square centimeter) c-Si solar cells in 2017. The solar photovoltaic conversion efficiency of a-Si / c-Si HJ solar cells was more than 26%, as shown in Figure 7, reaching 26.6%. In this paper, through simulation and loss analysis, it is pointed out that the theoretical limit of photoelectric conversion efficiency of solar cells with this structure is 29.1%.

Figure 6 Cross-section schematic image of the HJ-IBC

According to the NREL efficiency chart, as shown in Figure 7, the theoretical photoelectric conversion efficiency of the HJ-IBC cell in the silicon-based solar cell part exceeds 27.6%, confirming the development potential of this HJ-IBC solar cell [29].

Figure 7 Schematic of Best Research-Cell Efficiency
Although IBC solar cell has many advantages, it also faces many challenges: (1) Higher requirements for the matrix material, the higher minority carrier life. Because IBC battery belongs to the back junction battery, a higher minority carrier diffusion length is needed in order to make the photogenerated carriers as few as possible or not to be recombined before reaching the back p-n junction. (2) The passivation of the front surface of IBC battery is required to be high. If the front surface recombination is high, the photocarriers will be recombined before reaching the back p-n junction, which will greatly reduce the conversion efficiency of the battery. (3) The process is complex. In the production process, the mask and lithography technology are needed many times. In order to prevent electric leakage, the gap area between the p area and n area needs to be very accurate, which undoubtedly increases the process difficulty. (4) The cost of IBC is much higher than that of traditional crystalline silicon battery due to its complicated process.

Because of the above challenges, the industrialization of IBC battery is full of obstacles. At present, CLP has completed the research and development process of IBC battery core technology, and is actively exploring the industrial development of IBC battery.

4. Future prospects
The future development of IBC batteries mainly has two aspects: (1) the efficiency improvement of IBC batteries; (2) the industrialization of IBC batteries.

In order to improve the efficiency of IBC battery, the following aspects can be considered: (1) optimizing the contact area of back electrode to reduce the contact resistance; (2) in order to prevent the battery from short circuit and achieve the best performance, it is necessary to find the proper width of the intrinsic region in the p + and n + regions on the back of the battery; (3) Using n-type silicon wafers with high bulk life as the substrate, good passivation layers are prepared on the front and rear surfaces to maintain a high minority carrier lifetime; (4) the back reflector should be considered when introducing the back passivation layer. At the same time, in order to further reduce the overall composition of IBC battery, some research reports have combined passivation contact technology with IBC to develop TBC (tunneling oxide passaged contact back contact) solar cell; some have combined amorphous silicon passivation technology with IBC to develop HBC solar cell.

5. Conclusion
The positive and negative electrodes of silicon-based solar cells are placed on the back surface of solar cells. The IBC solar cells have no shading loss and excellent interface performance, which improves the photoelectric conversion efficiency. Based on the original basic structure of IBC battery, the performance structure of the front and back of the battery is optimized, such as the design of the front surface light trap structure and the reduction of the carrier recombination degree in the doping area; the design of the positive and negative electrode arrangement on the back surface to reduce the resistance and improve the carrier collection efficiency. As a new structure, IBC solar cells can also be combined with heterojunction solar cells. The theoretical photoelectric conversion efficiency of the obtained HJ-IBC solar cells is as high as 29.1% and the laboratory efficiency is 26.3%. In order to shorten the distance between theoretical efficiency and practical efficiency, it is the research direction of new silicon-based solar cells in the future. This kind of battery will broaden the application field of silicon-based solar cells and contribute to solving the energy crisis.

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