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A Kind of Effective Method to Improve the Conversion Efficiency of the Solar Cell

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Abstract: For the bottleneck problem of the conversion efficiency in silicon-based solar cell, the Metallization Wrap–through (MWT) technology is one of the effective methods based on the analysis of factors affecting the solar cell conversion efficiency. The MWT technology is based on laser perforation and that the bus grid lines in the front surface of the solar cell are moved to the back surface. The effective area on the front surface increases and the conversion efficiency is improved. One of the most important processes in MWT technology is laser perforation and a new perforation scheme using two-dimensional laser array is designed. The high power laser is divided into a number of beams then those beams are arranged in a two-dimensional array. The silicon wafer is placed in a predetermined position by suction cup and is moved by stepper motor. The light barriers are opened by triggering switch and the silicon wafer is exposed. After a series of light, machine, and electric processes a rapid one-time two-dimensional array laser perforation on silicon wafer is formed. This patent is expected to be used in solar cell production department soon.

Keywords: Laser perforation, metallization wrap-through (MWT), patent, two-dimensional array.

1. INTRODUCTION

Global fossil energy is about run out. Oil, coal, and natural gas could be consumed within 45~50 years, 200~220 years, and 50~60 years, respectively, based on the analysis of the proven reserves and according to the current rate of energy consumption. One of the green energy industries the solar cell is an important means for solving the problem of energy crisis [1]. With the rapid development of photovoltaic industry, silicon solar cell is developing rapidly and the annual production of compound growth rate is 54.62%. The market of the crystalline silicon solar cell is relatively concentrated, in recent years, 85% of the solar cell market is occupied by a crystalline silicon solar cell [2]. The primary problem is to reduce the cost of using solar cells and to improve the conversion efficiency of the solar cell [3].

1.1. The Methods of Improving the Conversion Efficiency of the Solar Cell

The PV cells have very low efficiency in converting sun's energy into electrical energy. The optical loss and the electrical loss also add to low conversion efficiency of the solar cell. There are five aspects for improving the conversion efficiency of crystalline silicon solar cell such as the light trap structure, anti-reflective film, the passivation layer, increasing the back field and improving the substrate materials.

First of all is the light trap structure. It adopts the technology of chemical etching and texturing for high-efficiency monocrystalline silicon cell and the reflectivity of the textured surface is less than 10%. If it adopts the technology of plasma etching the lowest reflectivity of the textured surface is only 2%.

The second is anti-reflective film. The thickness of the single anti-reflective film is about 100 nm for TiO_2, SiO_2, SnO_2, ZnS and MgF_2 based on the theory of thin film interference. The reflectivity of the textured surface is reduced with the anti-reflective film is less than 2%.

The third one is passivation layer. It reduces the recombination opportunity of the photon-generated carrier in some area for the passivation technologies. The passivation technologies include hot oxygen passivation, atomic hydrogen passivation, and the surface diffusion passivation with phosphorus, boron, and aluminum. For example, phosphorus is generates, $2P_2O_5+5Si = 5SiO_2+4P$ when the temperature is 600 °C and the $POCl_3$ decomposes into P_2O_5 and PCl_5. The generated phosphorus is spread on silicon and realizes emitter diffusion. The process of the hot oxygen passivation forms silicon oxide film on the front and the back of the solar cell and it prevents recombination of the carriers on the surface. The process of the atomic hydrogen passivation reduces the recombination opportunity of the carriers because there are many carrier recombination centers and the dangling bonds on silicon surface.

The fourth one is increasing the back field. It forms photoproduction voltage with negative voltage in p end in p-type material of solar cell. The polarity of the photoproduction voltage is same as that of two ends of the

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pn junction for cell structure itself. Because there is a back field, the photon-generated carriers are accelerated when the open circuit voltage V_{OC} is increased. The effective diffusion length of carrier increases, the collection opportunity of carrier also increases, and the short-circuit current J_{SC} improves.

Improving the substrate materials; The high quality silicon material is selected such that n type silicon life is long; the reaction of boron oxygen is small after the pn junction has been made; the electrical conductivity is high, and the saturation current is low.

1.2. The Research Process of the Solar Cell with Back Contact

The Metallization Wrap–through (MWT) technology that developed successfully in 2009 by Dutch Energy Research Center (ECN) was demonstrated in Shanghai world expo in the "The China-Dutch photovoltaic high-end conference" in October 2010 [4, 5]. The effective conversion efficiency of the polycrystalline component is 17% and that of single crystal component is 19% in traditional solar cells. The comprehensive efficiency in theory can reach 25%. MWT technology will introduce the bus grid lines on the traditional front surface which accepts the sunlight onto the back surface. The shading area on the surface reduces. The MWT technology of ECN has been incorporated with the corporations of Solland, Schott, Canadian, and JA Solar. ECN developed the n type double surfaces technology in single crystal and it cooperated with Yinli Solar for developing PANDA solar cell. The technology adopts the phosphorous-doped silicon breaking the traditional thinking for the development of the p type cell. The life of the minority carriers in the phosphorous-doped silicon is 5~8% longer than that of the p type cell. The double surfaces design is with phosphorous-doped back electric field structure and the thickness of the silicon wafer can be less than 180 μm. Compared with the traditional aluminum back field it does not need to bend cell and the pass percentage is 96.5%.

Back contact solar cell provides a potential advantage compared to traditional solar cells. The light activity area increases when all the contact grid lines on front surface are removed and the photon-generated current increases. The specific advantage for MWT technology is in three aspects [6, 7].

The first one is that the loss of the front surface reflection reduces and the loss of the shadow in main grid lines reduces as well. The contact resistance between the semiconductor and metal grid and the recombination opportunity of photon-generated carriers are reduced. The average conversion efficiency is up to 20%.

The second one is that the initial attenuation is almost zero for n type monocrystalline silicon component while that of p type monocrystalline silicon component is 2%.

The finally one is that the temperature coefficient of n type monocrystalline silicon component is lowered by 6~9% than that of p type monocrystalline silicon component.

Reference [8] reported a new MWT solar cell. It adopts a chemical coating contact of Cu and Ni. The n type main grid lines on front surface are moved to the same location of the back surface and are connected by fine grid lines on the front surface by MWT technology. The p type area and n type area on the back surface are separated by the ditches. The schematic diagram is shown as Fig. (**1**).

The design idea is that the collected transmitters and the connected grid lines are in the front surface of the cell. The n type bus lines are removed to the back of the cell. The Ohmic contact between the bus lines and grid lines is by a certain number of holes which are drilled by laser of Nd: YAG (neodymium-doped yttrium aluminum garnet) with the wavelength of 1064 nm. The design idea is particularly suited for large chip area and the loss of the shadow reduces because there are no more main grid lines on the front surface.

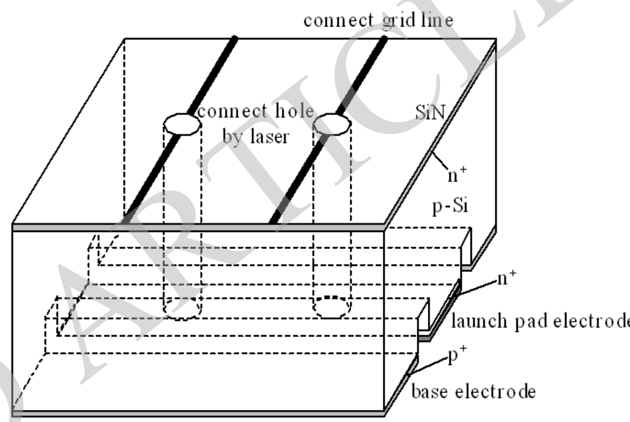

Fig. (1). The schematic diagram of new solar cell with MWT.

2. MWT TECHNOLOGY AND ITS PROCESS

MWT technology and its process include laser perforation, texturing, p diffusion and removing PSG, the front surface reflector reduction, the back surface screen printing busbar and filled channel, the front surface screen printing fine grids and the back surface contact with p type, sintering, front and the back surface partition back edge partition. The technical difficulties lies in the laser perforation, etching ditches which are aligned with the holes and the repeatability of the process, the size of the holes and controlling of its shape, the laser damage to the silicon substrate, the filling technology for holes with metal electrode and so on as shown in Fig. (**2**).

(a) The laser perforation is the most important step. For the silicon wafer with the size of 125 mm×125 mm, there are 150 holes which will be made by laser and the aperture is only 80 μm.

(b) The texturing process is with acid or alkali solution after laser perforation and the removal of the surface damage by laser.

(c) The process of p diffusion and removing PSG is by phosphorus diffusion in emitter electrode. The square resistance is 20~75 Ω when $POCl_3$ is used as the phosphorus source and diffuses with tubular diffusion furnace. The phosphorus silicon glass (PSG) is removed with HF after diffusion.

(d) The process of the front surface reflector reduction is by forming silicon nitride thin film. The silicon nitride thin film is as passivation layer and an anti-reflection film on the surface is formed with the method of PECVD or of sputtering technique.

(e) The process of the back surface screen printing busbar and filled channel is performed by filling with metal in holes. There are two main grid lines for n type contact.

(f) The process of the front surface screen printing fine grids and the back surface contact with p type is the process of the second screen printing. The fine grid lines are printed on the front surface and the main grid lines of p type contact are printed on the back surface.

(g) The sintering process is the process at certain temperature range after screen printing.

(h) The process of the front and the back surface partition back edge partition is the process of etching ditches for separation of the base electrode and launch pad electrode. The ditches on the front and the back surfaces were drilled by laser. There are two ditches as shown in Fig. (**1**) for separation of the front and the back surfaces [9].

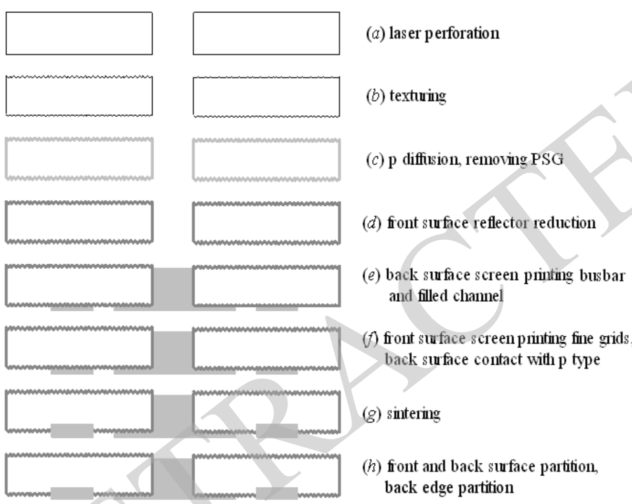

Fig. (2). The production process of solar cell with MWT.

Reference [10] reported a model of MWT solar cell that it composed with the conductive back board, the conductive adhesive, the cell of sealant package, and the glass. Reference [11] designed diamond fine grid lines with MWT technology.

3. APPLIED PATENT

The patent whose application number is 201110096515.2 and the license number is CN102208486B reported eight major processing steps. The fourth states "The conductive holes were made in crystalline silicon substrate by laser". There are 36 holes in a silicon wafer and the diameter is 0.100 mm. The patent whose application number is 201310008854.x and the license number is CN103035771A reported ten major processing steps. The fifth states "The holes were drilled on silicon surface after the SiN_x deposition by UV laser" and the wavelength of laser is 355 nm. The diameter is 0.120~0.200 mm. Those patents do not state the concrete schemes on how to realize the solar cell on silicon surface by laser perforation.

3.1. One-Time Two-Dimensional Array Perforation Device on a Silicon Wafer by Laser

The applied patent is for solving the problem of two-dimensional array rapid perforation on a silicon wafer by laser and provides an effective method with MWT technology in solar cell manufacturing process.

The technical schemes include four points. The system setup diagram is as shown in Fig. (**3**).

The first one is that the high power laser has been divided into a number of lights with fiber and those lights are distributed on optical fiber templates according to the two-dimensional array. The focused lens is placed at the ends of each fiber as shown in Fig. (**4**) and the focus is on the silicon corresponding to perforation position.

The second one is that there are two light barriers between the optical fiber templates and silicon wafer. The light barriers could be removed for blocking the light before laser perforation.

The third one is an important step. First a silicon wafer is placed at silicon base A as shown in Fig. (**5**) by a suction cup. The first silicon wafer is moved directly below the laser one-time array perforation device, which is silicon base B, by stepper motor. The light barriers move at relative directions, and the second silicon wafer is placed at silicon base A.

The last one is that the light barriers close to block the light after the laser exposure. The first silicon wafer is held by the second suction cup and is moved to silicon base C. The second silicon wafer is moved directly below the laser one-time array perforation device, as silicon base B, by stepper motor and the third silicon wafer is placed at silicon base A, in turn.

3.2. Specific Implementation

A silicon wafer is placed at the silicon base A by the first suction cup and then to base B, where a light barrier opens up and irradiates vertically on the silicon wafer, as shown in Fig. (**3**).

The second stepper motor closes the light barrier and the silicon wafer is moved from base B to base C by the first stepper motor. Another silicon wafer is placed on silicon base A and the cycle continues.

There are two problems. The first problem is how to open the light barriers when the silicon wafer is moved from the silicon base A to the silicon base B. The second problem is the accumulated error in the process of constant rotation of the belt and how to eliminate it.

For the first problem; the light barriers are moved in the relative direction as the silicon is moved from base A to base B by a stepper motor.

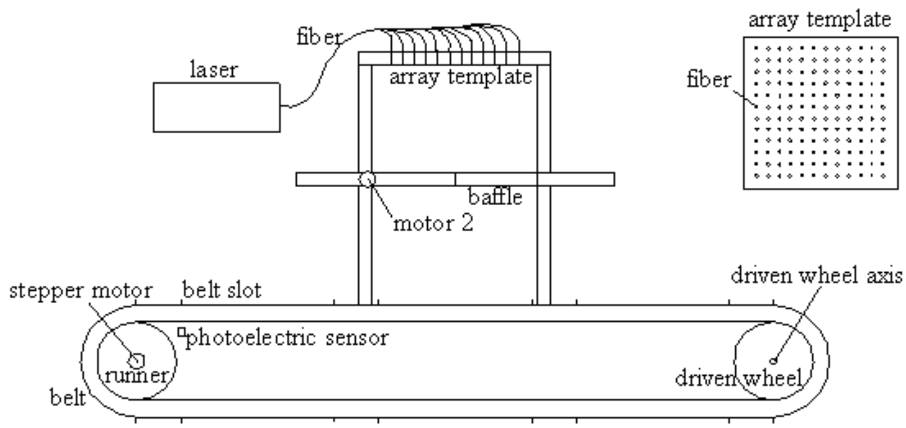

Fig. (3). The system setup diagram.

For the second problem; there are eight silicon bases in the pulley and four limiting positions in each silicon base for the size of silicon wafer of 12.50 cm×12.50 cm. The space between the center of the first stepper motor and the axis of driven pulley is 58.32 cm. The diameters of the driving pulley and driven pulley are 8.913 cm. The thickness of the belt is 0.50 cm.

By the constant rotation of the belt the error is accumulated. After a period of time the pulley must be re-positioned. After the laser perforation is performed on eight silicon wafers and the opening of the belt is over the photoelectric sensor the stepper motor stops for 1 s by a predetermined program.

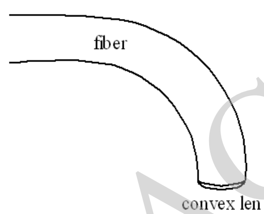

Fig. (4). Fiber.

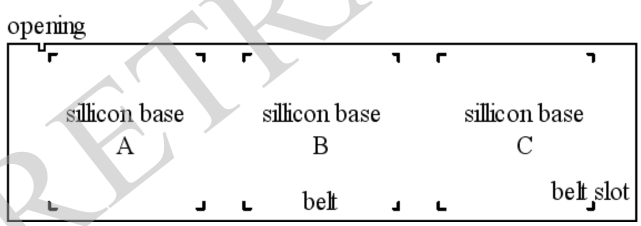

Fig. (5). Belt.

CONCLUSION

Solar energy is one of the cleanest forms of energy and its application is becoming an important research topic. At present the solar cell that based on silicon has the main grid lines and the fine grid lines on the front surface for collecting the charge. But the main grid lines and the fine grid lines on the front surface of solar cell reduce the effective lighting area and at the same time promotes the recombination of minority carrier, thus it reduces the efficiency of solar cells. Based on MWT technology, the main grid lines are moved onto the back surface from the front surface of solar cell, which effectively decreases the shading area and the conversion efficiency of solar cell is improved.

The most important process of MWT technology in solar cell is laser perforation. The open patent that is proposed by author is one-time two-dimensional array laser perforation device. The important points include the high power laser has been divided into a number of lights and the lights are distributed by optical fiber templates, there are two light barriers that control the laser perforation, the stepper motor moves the belt and the silicon wafer is placed on the silicon wafer base. The open patent is scheme is designed for the quick one-time two-dimensional laser perforation.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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