THE PRODUCTION OF SOLAR CELLS FROM MONOCRYSTALLINE SILICON BY PHOSPHORUS DIFFUSION

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Abstract- *This article outlines the materials and methods used to fabricate monocrystalline silicon solar cells. The purpose of this research is to study solar cell production technology and solar cell monocrystalline silicon production technology locally. We use several processing steps to obtain the final result of the solar cell. First, a square single crystal silicon wafer with a size of 150×150 mm 2 and a thickness of 200 μm is prepared. m, it is a oriented Cheklaussky (100) silicon wafer. The cleaning and texturing of the wafer are performed using various chemical solutions, and the edge of the wafer is isolated with an edge release paste. The phosphor is diffused in a diffusion furnace, a pn junction is formed with phosphorous oxychloride (POCl 3) liquid, and the front and back sides are respectively metalized by screen printing with silver and aluminum pastes. The plate is then subjected to rapid thermal annealing at the high temperature of the contact hardening zone. Finally, the LIV tester was used to characterize the solar cells produced. The data shows that the maximum power is 10.3369 W, and the maximum voltage power is 027504 V, full power current -37.5833 mA, open circuit voltage -0.555462 V, short-circuit current -56.5867 mA, fill factor -32.8868, battery efficiency-about 7%. Since Monocisralin solar cells are manufactured in India for the first time, the output of solar cells we produce is very low. The India Atomic Energy Commission (BAEC) has established a laboratory for the local production of solar cells. The processing technology, equipment temperature and the quality of air, water and other chemicals need to be optimized. To improve the efficiency of solar cells.*

***Key Words*:** LIV tester, phosphorus oxychloride, rapid thermal annealing, screen printing, Texturing.

1. INTRODUCTION

Electricity is a prerequisite for economic growth and social development. However, India is one of the countries with the most power outages in the world [1], [2]. India has faced an energy crisis for about ten years, mainly due to insufficient power generation. The capacity and demand of many existing power generation facilities and the comparison of old infrastructure [3]. Despite the huge potential of renewable energy in India, their contribution to power supply has so far been negligible. They play an important role in meeting the electricity demand in rural and remote areas of the country, as approximately 70% of people do not have access to electricity, and most of them live in rural areas. India is an ideal choice for efficient use of solar energy. In India, sunshine has dropped by about 70% [4]. The solar radiation intensity during the day ranges from 3 to 6.5 kW/m2, the maximum is from March to April, and the minimum is from December to January [5] [6] [7]. Crystalline silicon solar cells are the most used of all types of solar cells in the market, accounting for about 90% of the total global solar cell production in 2008 [8].The monocrystalline silicon process is used as a very promising process for the production of solar cells. For the production of monocrystalline silicon solar cells, the phosphor diffusion method is the most widely used method in the photovoltaic industry [10]. The India Atomic Energy Commission (BAEC) established a laboratory for the first time to produce monocrystalline silicon solar cells to partly meet the country's electricity demand. We conducted experiments in this solar cell laboratory. Current research will focus on the use of phosphorus diffusion methods to manufacture monocrystalline silicon solar cells and their characteristics. It is expected that the development of solar cells at the local level will play an important role in the field of renewable energy. in India.

2. PHOSPHORUS DIFFUSION THEORY

At present, the diffusion of phosphorus (P) is the main method for generating emitters in the processing of silicon (Si) solar cells [11]. The thermal diffusion of the phosphorus is required to create an n-type emitter on a p-type wafer [12]. Diffusion depends on several factors, the most important of which are temperature and gas environment [13]. P-type silicon wafers are widely used in the solar industry, so diffusion techniques have been developed to deposit n-type alloying elements and create pn junctions. Under the action of nitrogen (N 2) and oxygen (O 2), liquid phosphorus source phosphorus oxychloride (POCl3) is also often used in the standard diffusion process of solar cells [14] [15]. Due to its low boiling point (105.8°C) in the 850-900 itC diffusion chamber [16], it will decompose into simple phosphorus compounds, such as P4, P8, P2O5, etc. The diffusion coefficient (D) at 850°C can be close to D~0.0013μm2/h. Phosphorus diffusion of POCl.The manufacture of crystalline silicon solar cells with emitter diffusion, surface passivation and electrode screen printing results in the formation of n+ type emitters on top of the wafer. Phosphorus oxychloride (POCl3) is the initial liquid that evaporates at room temperature. Therefore, it must be retained. For the diffusion process, the vapor is removed from the carrier gas nitrogen, while the oxygen passes through another valve. When the reaction occurs, phosphorus oxychloride reacts with oxygen to form phosphorus pentoxide, and then the oxide of the phosphorus plume reacts with silicon. Produce silica and phosphorus. Generally, the diffusion process of phosphorus is carried out in two stages. The first step is called pre-deposition, in which a phosphorus-rich oxide film is formed on the silicon substrate. The second stage is called introduction [17], [18], [19], in which the phosphorus-rich oxide film serves as an infinite source of phosphorus diffusion in the Si substrate.

In the pre-separation process, the reaction of phosphorus and oxygen forms phosphorus pentoxide (P2O5) on the surface of the panel. P2O5 immediately reacts with silicon, causing phosphorus to diffuse and form a layer of phosphosilicate glass (PSG) [SiO2: (P2O5) x] [20] on the surface of Si. The phosphorus atoms formed at the PSG-Si interface penetrate the silicon wafer [21], which can be simplified by the following reaction equation:

POCl3 (liquid) + N2 (bubble) → POCl3 (vapor) (pre-deposition)

4 POCl3 + 3O2 →2 P2O55 + 6Cl2

2 P2O5 + 5Si →4P + SiO2 (drive-in)

P + 3Si → n-type doped Si

3. MANUFACTURING MONOCRYSTALLINE SILICON SOLAR CELLS

The manufacture of monocrystalline silicon solar cells includes basic materials, chemical composition, equipment and machinery. The properties of the main materials are shown in Table 1. The main material used to manufacture solar cells [22] is a single crystal silicon wafer initially doped with P-type. The production of our c-Si solar cells starts with square wafers (100) of oriented Czochralski-Si (or Cz-Si) plates with a size of 150×150 mm2 and a thickness of 200μm

Raw Wafer	Cell type	Doping	Shape and size	Thickness
Silicon wafer	Monocrystalline	p-type	150×150 mm2	200μm

Table 1: Basic Materials Involved in Solar Cell

4. Fabrication

The production of monocrystalline silicon solar cells from p-silicon wafers requires several process steps to obtain the final result of the solar cell. Figure 1 shows the sequence of steps in the solar cell manufacturing process.

FABRICATION PROCESS STEPS

Cleaning & Texturing
Edge Isolation (Screen Printing)
POCl3 diffusion
Back metallization (Screen Printing)
Front metallization (Screen Printing)
Drying
Rapid Thermal Annealing
LIV Testing

The initial p-type monocrystalline silicon wafer used to manufacture solar cells in our experiment is shown in Figure 2. The description of the solar cell production process in our experiment is given below.

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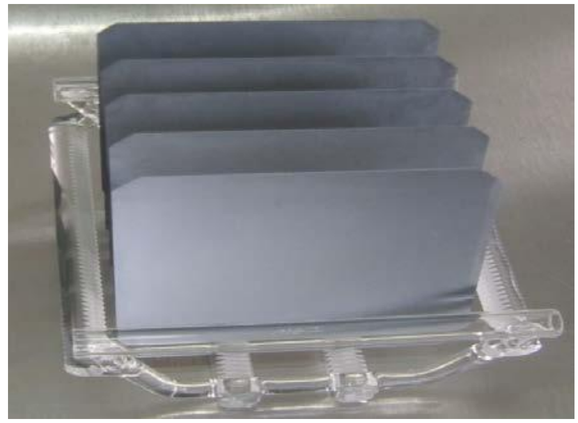

Figure 2: Starting p-type monocrystalline silicon wafer A. Cleaning and Texturing

The manufacture of solar panels requires cleaning and texturing of wafers. Cleaning is performed to remove organic debris, thin oxide layers and metal particles, and texturing is performed to create random sub-wavelength cone properties on the surface of the panel to reduce reflection and improve light reflection. Absorb [12], [23]. This type of treatment needs to go through a wet chemical treatment station, exhaust system and water treatment before being discharged into wastewater. Use the following three methods to clean and texture the panel.

5. SAW DAMAGE REMOVAL PROCESS

First rinse the tray containing the wafers with deionized (deionized) water. Remove the jar and wash it thoroughly with detergent and deionized waffles. Then transfer 4 liters of deionized water to this clean beaker, put it in the heating system, and heat the water to 70°C. Then weigh 400 g of sodium hydroxide (NaOH) pellets on an electronic balance and transfer them to a beaker with DI wafers. Prepare for the above. This is done to make a 10% NaOH solution. It should be prepared according to the ratio of NaOH (sodium hydroxide): H 2 O (deionized water) = 1 g: 10 ml. Once the temperature of the NaOH solution measured with the thermometer reached 70°C, the plate with the plate was transferred to the glass and immersed in the solution for 10 minutes. After 10 minutes, take the waffle bowl out of the glass and immerse it in deionized water several times before the waffle is ready for the next step.

6. Hydrophobic process

The hydrophobic method needs to prepare a solution according to the ratio of HF (hydrofluoric acid): H 2 O (deionized water) = 1ml: 50ml, and mix the two liquids in the above ratio. The wafer that has gone through the saw removal process was immersed in the HF solution for 3 minutes, and then it was taken out of the HF solution and immersed in the DI wafer several times. After the wafer is dried with compressed air, it can proceed to the next step.

7. Texturing Process

The deformation process requires the use of KOH (potassium hydroxide): IPA (isopropanol): H 2 O (deionized water) = 1 g: 5 ml: 125 ml to prepare the solution. First we rinse the glass with deionized water, and then use it for 4 times. Add a few liters of deionized water and place the beaker in the electric heater. Then measure 32 grams of potassium hydroxide particles on an electronic balance and transfer them to a beaker with DI wafers when the beaker reaches 70°C. A container with a plate according to the HF method was put into a beaker, and then 160 ml of ISO 2 solution was added to the propanol in the beaker, and the wafer was kept in the solution for 10 minutes. Remove the wafer from the beaker, then immerse it in the DI wafer several times, then repeat the hydrophobic process, and finally dry the wafer with compressed air and complete the texturing process. If the orientation of the wafer changes after texturing, the wafer can be viewed under a scanning electron microscope. FIG. 3 shows a structured silicon wafer, and FIG. 4 shows an SEM image of the structured surface of a p-type silicon wafer obtained by an electron microscope.

8. Edge Isolation

The key step in solar cell manufacturing is the electrical isolation of the n-type and p-type regions. Edge padding is used to separate the front and back sides. In the next step, after cleaning and texturing the carrier, cover the back of the panel edge with a stencil. Use a printer and anti-diffusion paste to seal the edges. The wafers were dried in an oven preheated to 200°C for 10 minutes. Figure 5 shows a picture of the printer screen used to seal the edges, and Figure 6 shows the screen design used in our experiment.

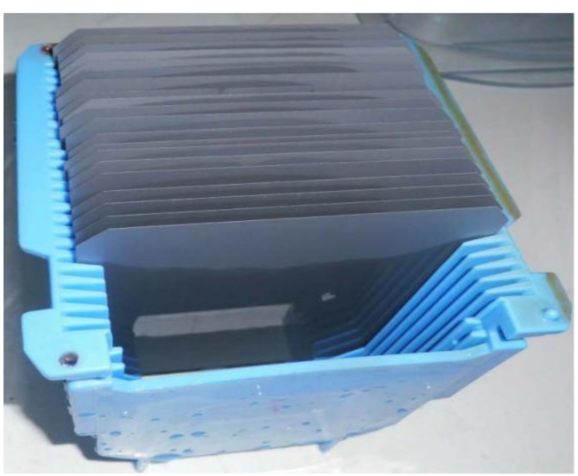

Figure 3: Textured silicon wafer

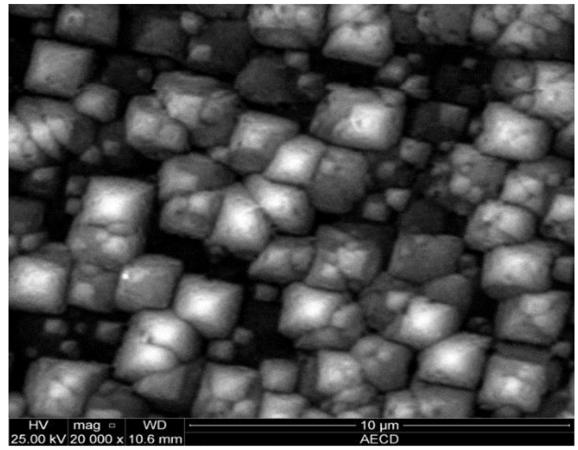

Figure 4: SEM pictures of textured silicon Wafer

Figure 5: Screen printer for edge isolation

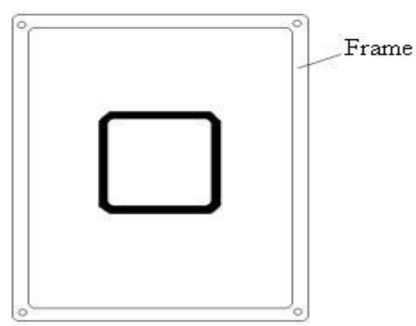

Figure 6: Designed screen used for edge isolation *C. $POCl_3$ Diffusion*

After texturing and cleaning, the solar cell is subjected to phosphorous diffusion and forms an np junction. After isolating the edges, the plate is stored in a glass dish for the diffusion process. Before use, clean the petri dish with isopropyl alcohol (IPA) solution. First, turn on the diffuser and set the temperature in the central area to 600°C. When the temperature reaches 600°C, the tray containing the plate is transferred to the diffusion chamber. During the delivery process, to ensure that the waffle does not break. After putting the waffle inside, the neck of the container will close properly, and it is necessary to ensure that the gas is properly discharged through the exhaust system. We have to wait 10 minutes and then raise the temperature to 875°C without turning off the nitrogen. After reaching 875°C, turn off the nitrogen, and oxygen and POCl3 (phosphorus oxychloride) become the same gas. Then, we must wait for 10 minutes in this state. After the diffusion time of 10 minutes, the oxygen and POCl3 gas are turned off at the same time, and the nitrogen is turned on. We must let the nitrogen flow for 10 minutes.After 10 minutes, turn off the nitrogen, and then turn on only the oxygen for the next 10 minutes. Turn off the oxygen and let the nitrogen flow for 10 minutes. Finally, the chamber temperature dropped from 875°C to 600°C after 10 minutes, while the nitrogen remained open. After the temperature in the box drops to 600°C, turn off the nitrogen gas, and then pull the board out. All operations must be performed at high temperatures, so safety must be ensured. After the plate is naturally cooled, it is subjected to the next stage of processing. Figure 7 shows a silicon wafer doped with phosphors.

Figure 7: Phosphorous doped on P type Si wafer from diffusion chamber.

9. Back and front surface metallization (Screen Printing)

Screen printing measure is most regularly used to shape metal contacts on back and front surfaces of sun powered cells. Following dissemination, screen printed metallic contacts are shaped to frame electrical contacts to n and p doped areas. A thick, gooey metal arrangement or glue is constrained through impeccable screen network onto the wafer in chose lithographically characterized open areas in the screen. The metal lines on the front surface (n-type) are made of silver and on the back surface (p-type) are made of aluminum. Aluminum contact on the wafer posterior likewise serves to frame an intensely diffused p++ layer that decreases contact opposition and improves back surface reflectance. Properly planned screens are utilized for this interaction, and screen printers are utilized to shape Ag and Al contacts to front and back sun oriented cell surfaces. The printing interaction starts as a silicon wafer is put onto the printing table. A fine-network print screen mount inside a casing, is set over the wader; the screen closes off specific territories and leaves different regions open, where the glue can go through. The distance among wafer and screen is painstakingly controlled (canceled the 'snap' distance). Screens utilized for front side printing regularly have a lot better cross section size than do posterior screens, because of the better metal lines needed on the front side. After a deliberate measure of glue is apportioned onto the screen, a wiper circulates the glue over the screen to consistently fill the screen openings. As the wiper gets across the screen, it pushes the glue through the screen openings and onto the wafer surface. Rear screen printing done by utilizing aluminum glue. This interaction should be firmly controlled for temperature, pressing factor, speed, and numerous different factors. After each printing step the wafer goes to a drying heater

Make the paste hard. Transfer the board to another printer to print other lines on the front or back of the board. Each solar cell has conductive lines on both sides of the front and back. These conductive lines are printed with screen masks and have different functions. The silver wire on the front is much narrower than the silver wire on the back. Some manufacturers first perform a reverse printing step and then reverse the surface contact printing plate to minimize the possibility of damage during processing. Seal the edges, back and front prints in an oven preheated to 120°C for 10 minutes to make the paste adhere well to the surface of the printing plate.After screen printing, the silicon wafer must be dried for a period of time at a relatively low temperature (about 120°C). In our experiment, we placed it behind each plate

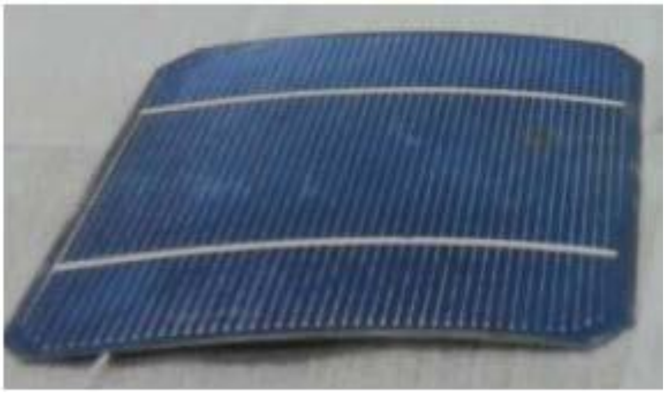

Figure 8: Complete screen printed solar cell E. Drying

10. Rapid Thermal Annealing (RTA)

After screen printing, a high temperature process will be used to harden the contacts into ohmic contacts. The rapid thermal annealing furnace is used to harden or bake the shield contacts on the silicon solar cell. In order to establish ohmic contact (low resistance contact), it is recommended to ignite the silicon solar cell when processing it. Generally, any RTA process can run this process. In this case, the integrated RTA processing unit of the conveyor system can be used for continuous contact cooking. The maximum temperature used in this step is 1000°C. In our experiments, the RTA of the screen-printed battery was performed at temperatures of 500, 600, and 800°C, respectively. •Rapid thermal annealing is important because it ensures proper contact between the conductor and the semiconductor. Figure 9 shows the contact ignition process of a silicon wire mesh solar cell.After the assembly of the solar cell module is completed, LIV (Photo Current Voltage) test will be performed to evaluate the battery performance and mainly calculate the efficiency of the solar cell. First, the records are stored in gold-plated compartments, and then on the bus. The cell field is aligned with the pin. Then turn on the vacuum. Then connect the power supply and control unit to the portable computer. Use a low-flash xenon light source for IV measurement. In the customer-specific electronic interface integrated into the high-resolution programmable voltage source, the lighting cost data is collected IV. A voltage across the solar cell is applied to measure the photocurrent. User-friendly LabVIEW interface. The use of ASCII data logging function is the basis of data collection. The spectral distribution of high-intensity xenon. The plasma discharge lamp is the light closest to the solar spectrum and is the industry standard.The LIV flash can measure both small (about 10 cm2) and large (about 15x15 cm2) solar cells. Using a simple absorbent metal filter, the intensity change can be controlled between ~10 mW/cm² and 100 mW/cm². The LIV measurement system is shown.

Figure 9: Contact firing at RTC furnace

Figure 10: LIV measurement system

11. RESULTS AND DISCUSSION

Solar cells are characterized by their ability to convert sunlight into electricity. The light intensity (L)-current (I)-voltage (V) test is a series of measurements performed on complete solar cells to measure their operating characteristics. The LIV test identifies characteristics such as short circuit current (Isc), open circuit voltage (Voc), fill factor (FF) and power maximum (Pmax). These results can be used to determine the efficiency of solar cell. Solar cells are tested under one-sun conditions using Xenon-arc lamps; a xenon spectrum is closest to sunlight. Data acquisition based on programmable current-voltage source power supplies capable of handling current up to ~ 8 A is used in conjunction with a proprietary data acquisition system. Calibration of this LIV measurements system is based on independently measured c-Si solar cells at Sandia National Laboratories. The measured LIV data are shown in Figure 11.

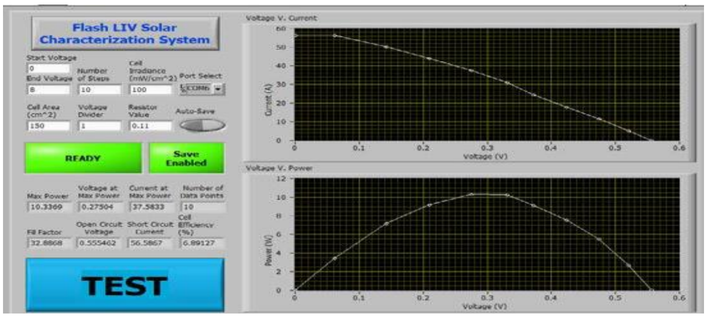

Figure 11: Measured LIV data

Shows the VI curve of the solar cell we made. According to the LIV data, we obtained the following results of the monocrystalline silicon solar cell: maximum power 10.3369 W, maximum power 0.27504 V voltage, maximum power 37.5833 mA current, open circuit voltage 0.555462 V., short circuit current 56.5867 mA, duty cycle It is 32.8868, and the efficiency is 6.89%. Our solar cell efficiency is very low because it is the first locally produced solar cell in India. Processing technology as well as air quality, water quality and other chemicals are needed to improve the efficiency of solar cells.

12. CONCLUSION

BAEC established a local production laboratory for monocrystalline silicon solar cells for the first time. In this laboratory, we manufacture our solar cells. The efficiency of our solar cells is about 7%, which is quite low compared to commercial cells. Affordable solar panels on the market. Our main goal is to research solar cell technology and local production of monocrystalline silicon solar cells. There are many problems related to improving the efficiency of solar cells. Formulas and techniques require an iterative approach. A specific formula and technology takes 3-4 days and requires a lot of consumables (raw materials, chemicals, gases, etc.). As a result, significant progress has been made in broad understanding and manufacturing. The maximum device conversion efficiency of silicon solar cells is 7%. For example, the cleaning and texturing process has been achieved, the optimal flow rate of POCl3 and the correction of the difference, the temperature zone rented by the RTA process, which can significantly improve the efficiency of solar cells. In addition, the doping concentration must be further optimized and its characteristics must be carefully characterized for further improvement.In the near future, by optimizing all tasks, the laboratory will play a leading role in the development and promotion of solar cell production technology in the country..

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