This paper first appeared in the fourteenth print edition of the *Photovoltaics International* journal, published in November 2011.

A novel technological process for p-type back-contact solar cells

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ABSTRACT

A new production process for crystalline silicon (c-Si) solar cells, specifically p-type back-contact solar cells, is proposed. In contrast to the conventional c-Si solar cell manufacturing method, this new technology eliminates the etching process and reduces the industrial three-step electrode printing to only one step, greatly improving the technological process. Furthermore, the proposed process is also largely compatible with a traditional c-Si solar cell production line. Oxidation technology for producing the SiO_2 film on a c-Si wafer, together with corrosive window technology, such as through HF corrosive paste screen printing, for creating the patterning on the wafer covered with SiO_2 film, are used in the fabrication of the p-type back-contact solar cells.

Introduction

In recent years, many solar cell technologies have been developed, such as dye-sensitized solar cells [1,2], film solar cells [3,4] and crystalline silicon (c-Si) solar cells [5–8]. The photovoltaic (PV) industry has experienced a rapid rate of development, particularly in the number and scale of enterprises producing c-Si solar cells. However, conventional c-Si solar cells [9] have two sides with electrode grid lines, and the electrode grid lines on the side facing the sunlight can create a shadow, thus reducing the effective area that receives sunlight. It is therefore clear that back-contact solar cells [10–12] can increase solar efficiency compared to conventional c-Si solar cells. In back-contact solar cell technology the positive and negative electrodes are both formed on one side of the p-type silicon wafer doped with boron, enhancing the effective surface for receiving sunlight and avoiding any shielding by the electrodes. To increase efficiency in capturing electrons and holes, there are many p-n junctions on the reverse of the back-contact solar cell.

This paper presents a new technology for manufacturing p-type back-contact solar cells, in which the costly etching step is eliminated and the electrode printing is carried out in one step rather than three. This new manufacturing technology therefore greatly simplifies the process steps and minimizes the production costs, making it extremely attractive to conventional c-Si solar cell manufacturers all over the world. Moreover, this new process is largely compatible with traditional c-Si solar cell production lines, which means that it can be adopted with only minor modifications of the current manufacturing process.

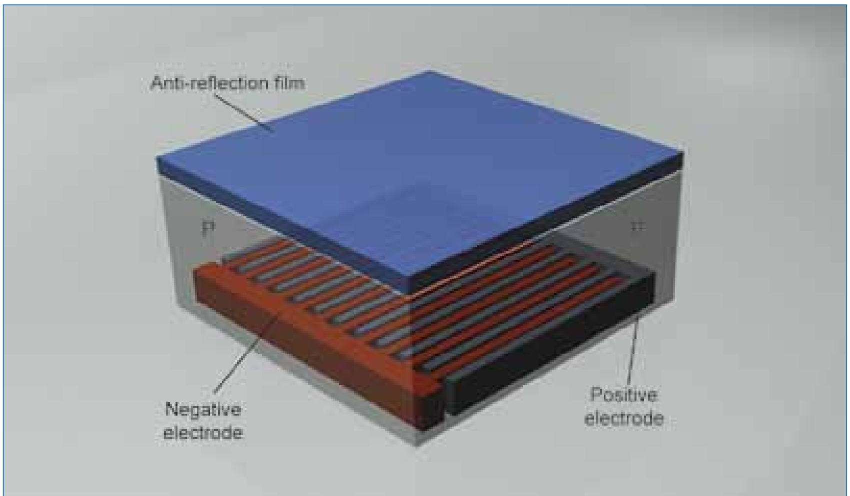

Figure 1. The p-type back-contact solar cell.

Principle

The p-type back-contact solar cell is composed of an anti-reflection film, a pyramid layer, a p-type boron-doped wafer, several p-n junctions, and positive and negative electrodes (Fig. 1). An anti-reflection film made up of Si_3N_4 can reduce the reflection of the incident sunlight and improve the sunlight absorption for this particular type of solar cell. Without electrode shading on the sunlight-facing surface, the p-type back-contact solar cell is able receive more sunlight than a traditional c-Si solar cell. Under and adjacent to the Si_3N_4 film lies the pyramid layer, which increases the probability of incident sunlight because of the particular pyramid structure. This structure can change the transmission direction of the sun's rays and double the probability of incidence.

The c-Si wafer is doped with boron and referred to as a ***p-wafer***, which is currently used universally for making solar cells in the field of photovoltaics. In order to maintain compatibility with industrial p-wafer supplies and conventional solar cell production lines, a p-wafer has been chosen and used for the p-type back-contact solar cell.

On the reverse of the p-type back-contact solar cell, there are many p-n junctions with electrodes to obtain high efficiency in capturing electrons and holes. The number of p-n junctions and electrodes can be optimized without the need to consider sunlight shading. These p-n junctions can reduce the combination of electrons and holes and improve the collection of these. By using a silver electrode material, the electrode resistance can be reduced because of the high number of finger electrodes. All these factors have the potential to improve the efficiency of the p-type back-contact solar cell.

Technological process

The process for manufacturing conventional c-Si solar cells with two-side electrodes, from the texture-making stage to testing, is illustrated in Fig. 2(a). For comparison, the p-type back-contact solar cell technological process is shown in Fig. 2(b). Although the new process has the additional steps of oxidation and corrosive window, there is no costly etching step; moreover, the conventional three-step electrode printing has been reduced to a single step. The new production process is therefore simplified but still compatible with a conventional c-Si solar cell production process.

> “Although the new process has the additional steps of oxidation and corrosive window, there is no costly etching step; moreover, the conventional three-step electrode printing has been reduced to a single step.”

P-type c-Si wafer

P-type c-Si wafers of conventional dimensions, doped with boron, can be purchased on the market (commercially produced by, for example, LDK or Motech); these include polycrystalline, quasi-monocrystalline and monocrystalline silicon wafers as illustrated in Fig. 3.

Texture making

The pyramid-like texture of a monocrystalline silicon wafer can be created using an alkali method; the texture of a polycrystalline silicon wafer, by an acid method. The texture structures can change the sunlight transmission direction and increase the probability of incident sunlight falling on the solar cells by a factor of two or more. These texture structures can reduce the sunlight reflection and improve the spectrum response and short-circuit current.

Alkali method

Using a low concentration of NaOH aqueous solution, the production of monocrystalline silicon wafers and quasi-monocrystalline wafers starts with anisotropic corrosion that produces an intensive pyramid structure. The chemical reaction [9] is:

$$Si + 2NaOH + H_2O = Na_2SiO_3 + 2H_2$$

and the resulting pyramid structure is shown in Fig. 4.

Acid method

At a certain concentration of nitric acid and hydrofluoric acid in aqueous solution, the production of polycrystalline silicon wafers begins with a chemical reaction that produces the texture of a wormhole structure (for example, using a device such as RENA). The chemical reaction is:

$$3Si + 4HNO_3 + 18HF \rightarrow 3H_2[SiF_6] + 8H_2O + 4NO\uparrow$$

and the texture of the polycrystalline silicon wafer [13] is shown in Fig. 5.

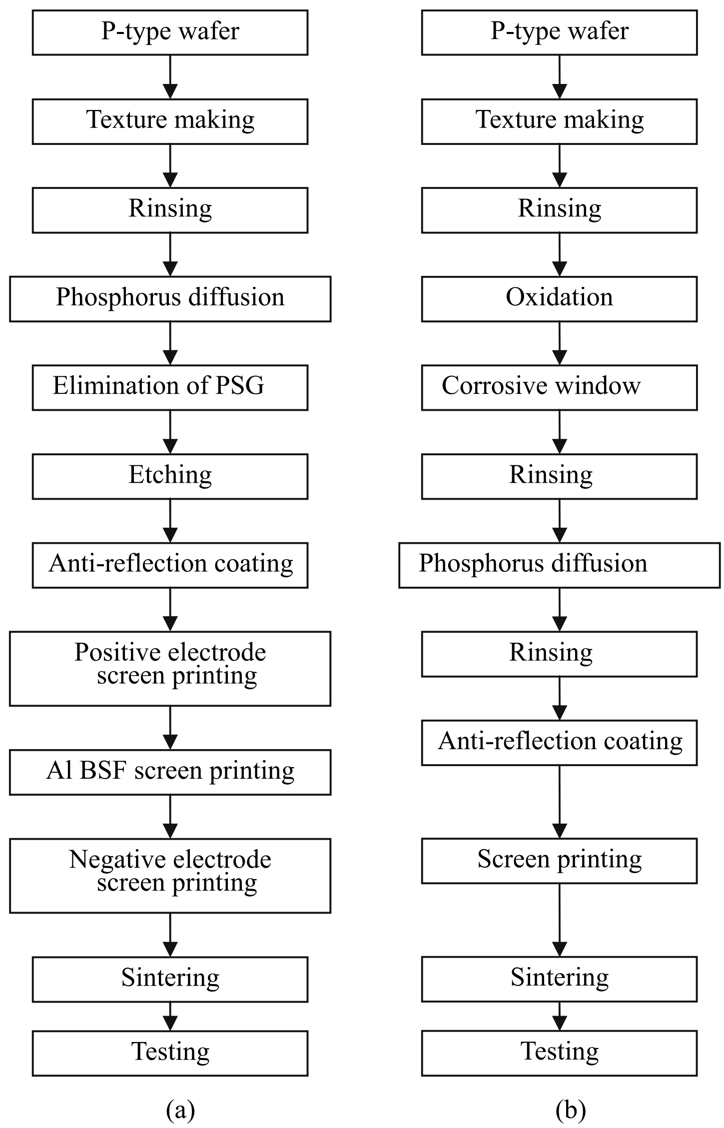

Figure 2. Production processes for (a) conventional c-Si solar cells, and (b) new p-type back-contact solar cells.

Oxidation

In forming the SiO_2 film, the chemical reactions are as follows:

$$Si + O_2 \rightarrow SiO_2$$
$$Si + 2H_2O \rightarrow SiO_2 + 2H_2.$$

The chemical reactions take place industrially at a high temperature of approximately 950°C in an oxidation furnace such as a Seven Star or a CECT. The oxidation film of SiO_2, having a reddish-purple appearance and a thickness of around 50nm, can effectively prevent phosphorus from diffusing into the silicon.

Figure 3. The appearance of p-type c-Si wafers: polycrystalline (left), quasi-monocrystalline (centre) and monocrystalline (right).

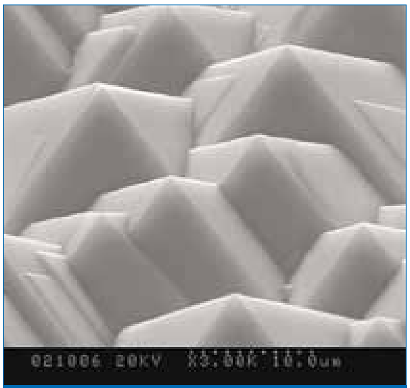

Figure 4. Pyramid texture of a monocrystalline silicon wafer, created by the alkali method.

> "The oxidation film of SiO_2, having a reddish-purple appearance and a thickness of around 50nm, can effectively prevent phosphorus from diffusing into the silicon."

Corrosive window

The SiO_2 oxidation film can be corroded by using a paste containing HF. The reaction is:

$$SiO_2 + 6HF \rightarrow H_2[SiF_6] + 2H_2O.$$

The corrosive patterning (window) is formed by screen printing. Fig. 6 shows the oxidized wafer with patterning, where the red grid lines comprise the corrosive window and the grey area is covered with SiO_2 film. In Fig. 6 the number of grid lines needs to be optimized with the patterning. The negative electrode should be aligned within the grid line during the screen printing of the metal electrode.

Phosphorus diffusion

The p-n junctions are made using hot phosphorus diffusion on the corrosive window, referred to as *patterning* where the silicon wafer area is exposed. The reaction [14, pp. 94–95] is:

$$5POCl_3 \rightarrow P_2O_5 + 3PCl_5$$
$$4PCl_5 + 5O_2 \rightarrow P_2O_5 + 10Cl_2$$
$$2P_2O_5 + 5Si \rightarrow SiO_2 + 4P.$$

At around 850°C, liquid $POCl_3$ decomposes and reacts with oxygen and silicon, thus generating phosphorus. The phosphorus can diffuse into the silicon wafer through the patterning not covered by the SiO_2 oxidation film and can form many p-n junctions of the design shown in Fig. 7. On the other hand, the phosphorus does not diffuse into the area covered by the SiO_2 film, since the film obstructs the diffusion. A diffusion furnace (such as the CECT, Tempress Systems or Seven Star brand) is normally used for this process.

Rinsing

After phosphorus diffusion, the wafer needs to be cleaned to eliminate phosphorus silicon glass (PSG), the SiO_2 oxidation film and metal ions. Removal of PSG and the SiO_2 oxidation film can be done simultaneously [14, p. 100]:

$$SiO_2 + 6HF \rightarrow H_2[SiF_6] + 2H_2O.$$

Metal ions can be removed using hydrochloric acid (HCl) and a metal ion complexation reaction.

In a solar cell production line, a washing machine with many tanks is normally used for rinsing. After reactions have taken place in one tank, the wafers are washed and cleaned by spraying them with deionized water in other tanks.

Anti-reflection coating

A Si_3N_4 anti-reflection film is coated on the sunlight-facing top surface without electrodes by plasma-enhanced chemical vapour deposition (PECVD) or physical vapour deposition (PVD). PECVD and PVD are the most common processes used in the photovoltaic industry (Centrotherm and Applied Materials are two examples of suppliers).

In the case of PECVD, the reaction is:

$$3SiH_4 + 4NH_3 \rightarrow Si_3N_4 + 12H_2.$$

Taking into account the glow discharge, gas flow, reaction time, temperature and electric field, a Si_3N_4 film is formed. The detailed parameters should be optimized according to the on-site production.

For PVD, the reaction is:

$$4NH_3 + 3Si \rightarrow Si_3N_4 + 6H_2.$$

A silicon (Si) bar, NH_3, Ar (argon) and

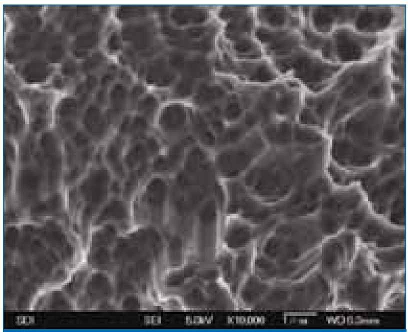

Figure 5. SEM image of a polycrystalline silicon surface, textured using the acid method.

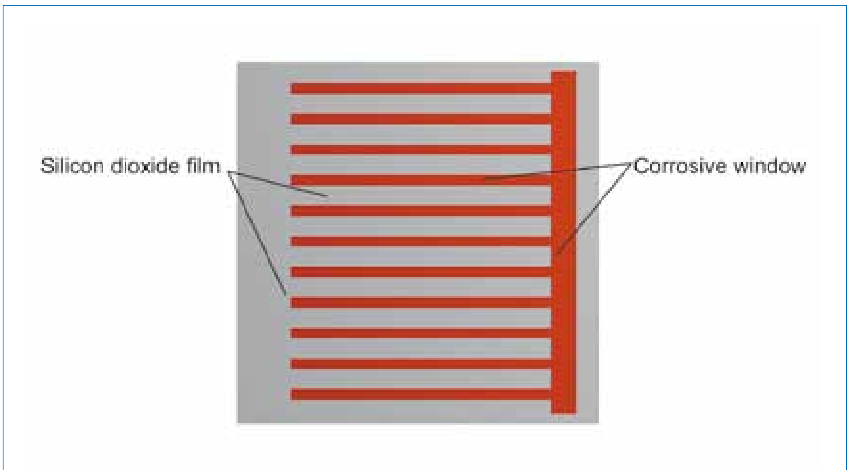

Figure 6. Corrosive patterning (window) on the oxidized wafer.

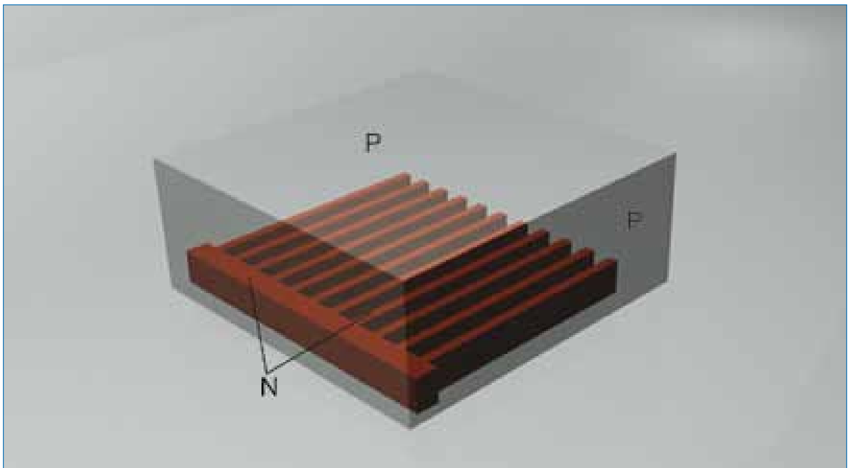

Figure 7. Phosphorus diffusion on patterning.

N_2 are used in the PVD process. Under the conditions of a strong electric field and magnetic field, at a temperature of around 500°C, the gases ionize, whereby highly dynamic Ar ions hit the Si bar and sputter Si ions. The Si ions then react with N (nitrogen) ions to generate Si_3N_4, which is deposited on the wafers. The thickness of the anti-reflective coating film is usually measured by ellipsometry.

Screen printing

In accordance with the design of the p-type back-contact solar cell, a special screen needs to be made for the metal electrode printing. The negative electrode pattern should align with the previous pattern for phosphorus diffusion. An example of screen-printed electrodes is shown in Fig. 8. The electrode paste (such as silver paste) can be purchased on the market and is available from, for instance, DuPont and Ferro; common suppliers of screen printers are ASYS GmbH, Baccini and Manz Automation.

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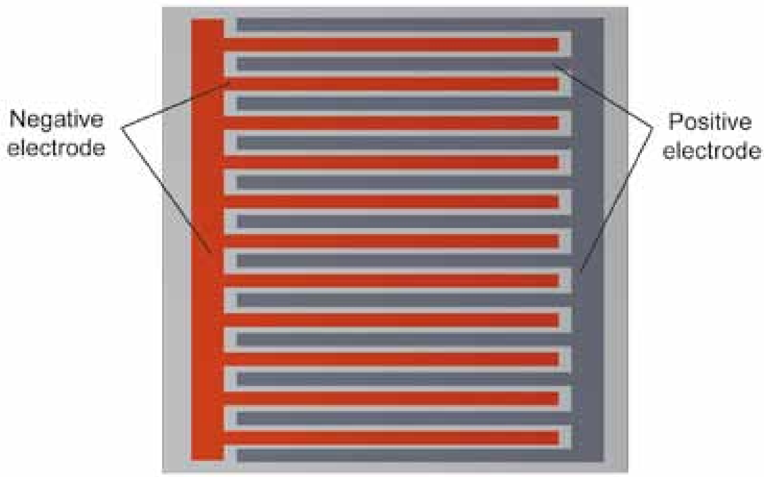

Figure 8. Screen-printed back-contact positive and negative electrodes.

Sintering

After the electrode paste screen print, the paste needs to be sintered to get rid of the impure ingredients, such as organic material, as well as to form metal electrodes on the p-type back-contact solar cell. Generally, a welding furnace is used for sintering in the photovoltaic industry, taking nitrogen as the protective gas at around 950°C. (Some commercial welding furnace suppliers are BTU, Despatch Industries and Roth & Rau.)

Testing and sorting

In conformity to the solar cell test standard IEC60904, the p-type back-contact solar cells are tested for their electrical characteristics. The cells are then classified and sorted according to the test results and ratings. For classification, it is better to take into account the efficiency and short-circuit current simultaneously. Using solar cells of the same or similar current values can minimise potential problems of mismatch and power loss when they are used together in PV modules. Well-known suppliers of cell testers and sorters are Berger Lichttechnik, ASYS GmbH and Applied Materials.

Conclusions

A new process of manufacturing p-type back-contact solar cells has been described, which, compared to the traditional solar cell production process, has the advantages of eliminating the etching process and reducing the number of steps in the electrode printing process from generally three to just one. Oxidation technology for the creation of the SiO_2 film on the c-Si wafer, and corrosive window technology in the HF corrosive paste screen printing, are both used in the new process. Not only is this method compatible with the conventional solar cell production process, but also the p-type back-contact solar cell with many p-n junctions is expected to increase efficiency in capturing electrons and holes.

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