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고효율 실리콘태양전지의 최근개발동향
Recent development in high efficiency silicon solar cell

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Abstract: This paper summarizes recent development in the silicon cell area : PERL (passivated emitter, rear locally diffused cells), BCSC (buried contact solar cells) and Hybrid buried contact/ PERL cells.

1. Introduction

There have been further improvements in silicon solar cell design during recent years.
Solar cells of high efficiency can make an essential contribution to the cost reduction of photovotaic arrays. A considerable portion of this cost depends inversely on the efficiency of the cell. The key factor for high efficiency is a long diffusion length of the charge carriers in the base of the cell. It should exceed the cell thickness, by at least a factor of two; High diffusion lengths require monocrystalline silicon of high quality, selected chemicals of high purity, and sopisticated wafer cleaning process.

2. PERL

The solar cell producing the highest efficiency in Fig. 1 is the PERL(Passivated Emitter, Rear Locally-Diffused Cell) developed at the University of New South Wales, Australia and shown in Fig.2. The highest performance cell to date has an efficiency of 24.0% with an open circuit voltage 709 mV, a short circuit current density of 40.9 mA/cm, and a fill factor of 82.7 % [1].

The processing sequence for PERL can be divided into five major steps:
1. Formation of a local diffusion with BBr_3
2. Inverted pyramids of the front side
3. Double emitter diffusion
4. Surface passivation with SiO_2 on front and rear side
5. Metallisation of front and rear side

All the masking and passivation oxides of the cells were grown in a TCA ambient because TCA oxidation is important for reducing surface defects and maintaining the furnaces free from contamination. Trichloroethane is widely used in the photovoltaic community in order to ensure a high degree of cleanliness in the furnaces. The oxidation time is very often chosen in order to produce about 105 nm thick oxides, so that the

SiO_2 film also acts as a rudimentory antireflection coating on textured surfaces. The given oxidation times do not include ramp up and ramp down times.

The local diffusion of boron in rear contact areas reduces the effective recombination rate at the rear contacts by suppressing minority-carrier concentrations in the regions. Hence,it is possible to reduce the spacing of the rear contact points to decrease the cell lateral series resistance, giving much higher fill factors. The reduced recombination rates at the rear contact also improve both Voc and Jsc as well as allowing substrates of resistivity above 0.5 ohm cm to be used. The boron dopant sheet resistivity for PERL cells was relatively low at around 20 ohm.square to passivate the rear metal-silicon contact. Boron was deposited at 900℃ for 15 min followed by drive-in at 1070℃ for 2 hour.

The front surface structure of the inverted pyramids was fabricated using lithography and etching in KOH. These inverted pyramids combined with the rear aluminium mirror form an excellent light -trapping scheme. Slightly offsetting the inverted pyramids, as shown in Fig.3, increases prospects for light reflected from the rear being internally incident on pyramide faces conducive to trapping into the cell by total internal reflection. The most fundamental disadvantage of silicon as a photovoltaic material is that it is an indirect band gap semiconductor. The long wave length part of the solar spectrum is therefore only weakly absorbed. Unless light trapping techniques are employed, a silicon device must be more than a hundred micrometers thick in order to absorb a sufficient proportion of the available solar radiation[2].

The front metallization was formed by vacuum evaporated thin Ti-Pd layers followed by a lift-off process. The rear metallization was made by vacuum evaporated aluminium. A thick layer of silver is then plated onto the front grids to increase the grid conductivity.

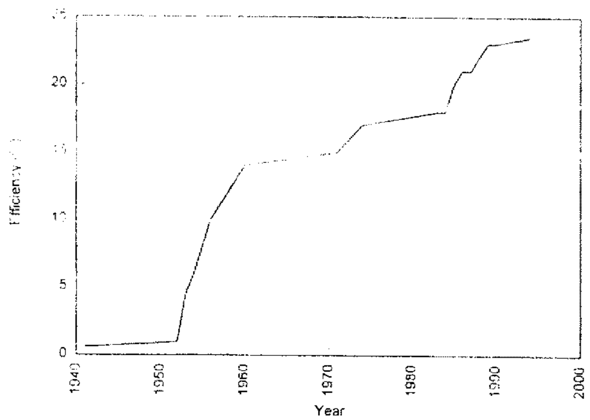

Fig.1 Evolution of silicon laboratory cell efficiency

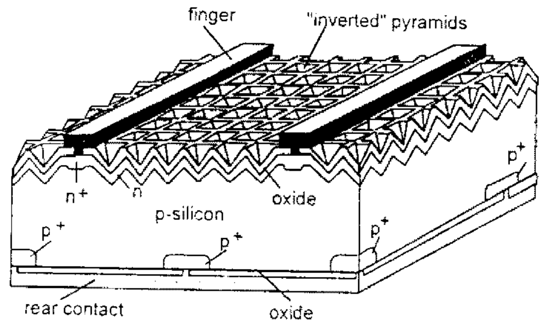

Fig.2 Passivated emitter, rear locally-diffused cell(PERL cell)

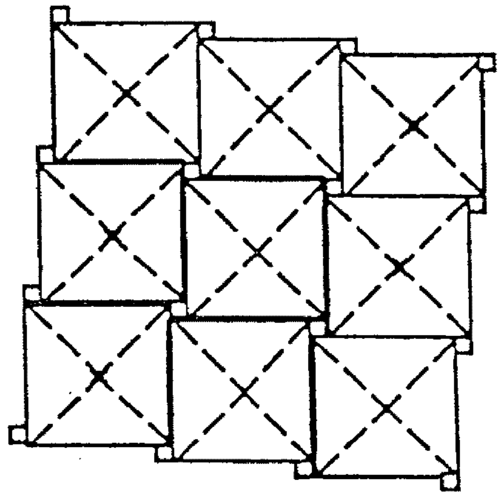

Fig.3 " Tiler's pattern" to improve light trapping ability of inverted pyramids

3. BCSC

The buried contact solar cell (BCSC) shown in Fig.4 is designed to minimize surface shading and resistive losses, and utilizes lighter emitter doping junction recombination. The fabrication of BCSC involves the following processing steps:

1. Saw damage removal and texturing
2. Pre-diffusion cleaning
3. Top surface phosphorus diffusion
4. Thermal oxidation
5. Groove formation by laser scribing
6. Chemical cleaning
7. Groove diffusion
8. Al deposition and sintering
9. Plating for front contact
10. Edge isolation

To minimise reflection losses from the surface of the solar cell, the silicon wafers of <100> surface orientation are first etched in a texturing solution so that pyramids are formed on the surface by exposing the intersecting <11 1>planes. It is necessary to ensure complete and uniform texturing of the whole surface for minimum reflection loss. Pyramid size plays an important part in determining the efficiency of the completed solar cell[3].

The initial phosphorous diffusion forms a p-n junction across the entire top surface of the wafer. Following the phosphorous diffusion over the top surface, the wafer is oxidised. This thermally grown oxide will later serve as a mask for the heavy groove diffusion and for the metal deposition. Upon completion of the sequence, the oxide will also act as a rudimentary anti-reflection coating for the solar cell.

To reduce shading losses from the top surface, it is necessary to have the width of the grooves as narrow as possible. It is necessary to heavily dope the silicon beneath the metal contact so as to obtain high open circuit voltages. Firstly, the diffusion serves to isolate the metal/silicon interface from the active regions of the solar cell. This significantly reduces the overall recombination current for the cell and would result in an increase in the open circuit voltages. Secondly, the high phosphorus surface concentration over the large surface area of the groove serves to form a low resistance ohmic contact between the nickel and the silicon. This is essential for the solar cell to have good electrical performance.

Aluminium facilitates the formation of an ohmic contact to the rear of the cell through the thick oxide layer without requiring any form of rear surface preparation. The aluminium is seen to possess extremely good gettering capabilities and it also minimises the effects of any phosphorus which may have diffused into the rear of the wafer during previous processing steps. Furthermore, alloying and diffusion of the aluminium into the rear of the wafer will form a reasonable back surface field (BSF) region.

The metallisation system on a solar cell normally serves two major functions. Firstly it forms a low resistance, highly adherent contact to the silicon. Secondly, it provides a high conductivity path to the cell outputs for current generated by the cell. The nickel plating step followed immediately at 90-97℃ for 5-8 minutes and the subsubsequent copper plating for 7-12 hours at 42℃. Copper, because of its very high diffusivity in silicon must be separated from the silicon by a barrier layer to ensure cell reliability. Nickel is used as the first metal because nickel silicide acts as a barrier layer to the diffusion of copper. Nickel provides a good mechanical ohmic contact to the silicon interface.

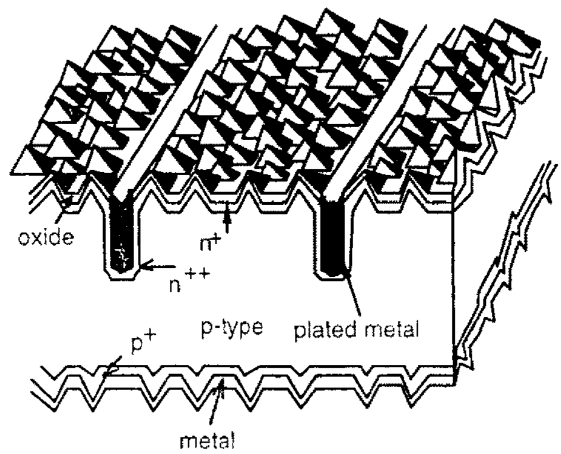

Fig.4 Single sided buried contact solar cell

4. Hybrid BCSC

A hybrid cell structure as shown in Fig.5 using the standard BCSC front surface and metallization, but improved rear surface passivation by incoporating the PERL sequence[4].

A Magnesium fluoride antireflection coating was subsequently applied to the glass surface to reduce reflection. Module effieciency of 20% is believed to be the first of any non-concentrating solar cell technology. This particular approach, though it gave the best results is not commercially viable for mass production because of the associated photolithography which is labour intensive, and requires expensive equipment and consumables.

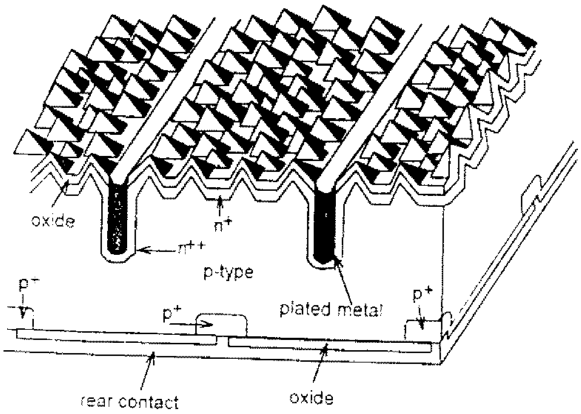

Fig.5 Hybrid BCSC/ PERL structure

5. Conclusion

A number of PV manufactures have adopted the BCSC structure. The mean conversion efficiencies are in the 18-20% range. Progress continues to be made in the high efficiency silicon cell area with scope remaining for further incremental improvements. New concepts, such as devices relying on impurity photovoltaic effects or germanium alloying,are probably necesssary to allow further extension of such results beyond about 25 % energy conversion efficiency.

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