Bifacial Silicon Solar Cells with Spin-on Doping and Electroless Plating

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(Received July 18 2003, Accepted October 13 2003)

A new method for fabrication of transistor like structure of the bifacial solar cell using spin-on doping and electroless plating has been proposed and the basic characteristics of the bifacial cell have been investigated. It is found that 9% increase in short circuit current is achieved with bifacial connection than the unifacial connection. Some unwanted effect of the series resistance on collection efficiency under different mode of illumination has been pointed out. Loss mechanisms inherent in the transistor like bifacial structure have also been discussed.

Keywords : Bifacial, Silicon, Solar cell, SOD

1. INTRODUCTION

Crystalline silicon solar cells presently dominate the majority of the commercial applications of photovoltaic (PV) power generation[1]. This is due to the combination of comparatively high conversion efficiency, long term stability and optimized manufacturing techniques. The major limitations are related to the areas of cost and performance[2]. Two main directions of PV cost reduction are innovative solutions in the field of low-cost solar grade silicon technology and solar concentrator technology. Both directions are of a substantial value for the future of photovoltaic industry and for the solution of the problems of scalability of PV manufacturing capacity. The cost of material for the fabrication of mono-silicon solar cell is approximately known to be about 50% of the total cost of the cell. A unique approach to reduce the cost of mono-crystalline silicon solar cell through better utilization of silicon material is bifacial solar cells[3-6]. Since the first proposal of a double sided bifacial structure, a great deal of research has been carried out[7-9]. A significant progress has recently been made in the area of bifacial Si-solar cells as demonstrated by energy conversion efficiencies above 18% under front and rear illuminations[12]. Bifacial silicon solar cell enables us to get electrically illuminated light from both sides of the cell. It also enables us to collect additional photo-generated electrons near the rear surface, which has not been utilized so far in the materials with short diffusion length[10,11]. Moreover, one way to achieve a higher PV power station efficiency is to apply bifacial PV module. Use of bifacial solar arrays is possible because the efficiency of the backside is approaching to that of front side by the new thin bifacial solar cells. Bifacial module cost will be even more reducing if we use electroless nickel metallization instead of conventional Ag/Ag-Al metal paste.

In present work, attempts have been made to fabricate a bifacial mono-silicon solar cell of transistor like structure employing the major steps of spin-on source diffusion and autocatalytic nickel metallization[12,13].

2. EXPERIMENTAL

Monocrystalline p-type <100> silicon wafers of 5 cm × 5 cm in size, 250 μm thickness and resistivity of 1-5 Ω-cm are used for fabrication of bifacial solar cells. The wafers are cleaned by conventional cleaning technique followed by alkali etching and texturing. Just before diffusion, an additional surface treatment for alkali textured wafers has been carried out by dipping the wafers in a bath consisting of a solution of H_2O_2 and H_2SO_4 for 3 min followed by several times D.I. water rinsing. Then silicon wafer surfaces are thermally oxidized in an open tube furnace. The transistor like bifacial solar cell has n^+ diffused region on both front and back face of a silicon wafer [14]. The schematic diagram of transistor like bifacial silicon solar cell is shown in Fig. 1.

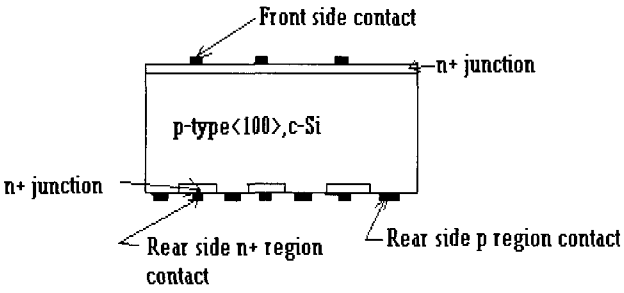

Fig. 1. Schematic cross-sectional view of the investigated bifacial silicon solar cell.

Diffusion mask pattern of the backside of the bifacial solar cell is formed on one surface of the oxide coated wafer with the help of screen printing technique. The oxide coating of the other surface (considered to be front surface of the cell) is removed by Buffer HF. Emitter N-250 (Emulsitone company, USA) is used as the spin-on diffusion source. After diffusion, the residual silica film is removed by dilute HF solution.

The metallization mask patterns are formed on both surfaces of the bifacial cell. Front and back surface metallization has been carried out by dipping the patterned wafer in an auto catalytic nickel bath[14] at temperature 75 °C for 20 minutes. Figure 2 shows the metal grid pattern of the front and backside of our proposed bifacial structure.

The front surface metal grid pattern is the same as the conventional solar cell but the back surface has two metal grid structures, one for base connection and the other for back n^+ emitter contact. Both the n^+ layer metal contacts are inter-connected to form the common n^+ contacts. The finger width of both surfaces is 100 micron and busbar width is 0.5 mm. The width of each n^+ diffused region and p-region of backside is 3mm each. So, the overall shading loss of the front and back surface of the proposed bifacial are 6.4% and 9.5% respectively have been taken in our proposed bifacial structure.

All other dimensions are given in mm unit in Fig. 2. The I-V characteristics of bifacial silicon solar cell, under illumination of two tungsten halogen lamps with computer controlled system, have been plotted. The I-V characteristics have been measured under different conditions of the cell as shown in Table 1. A standard cell has been used to monitor the intensity of the incident light. The study of spectral response of the bifacial cell under different illumination and current collection configuration has been made with the help of monochromator (Oriel Corporation, UK) in the range of 400 nm to 900 nm wavelength regions.

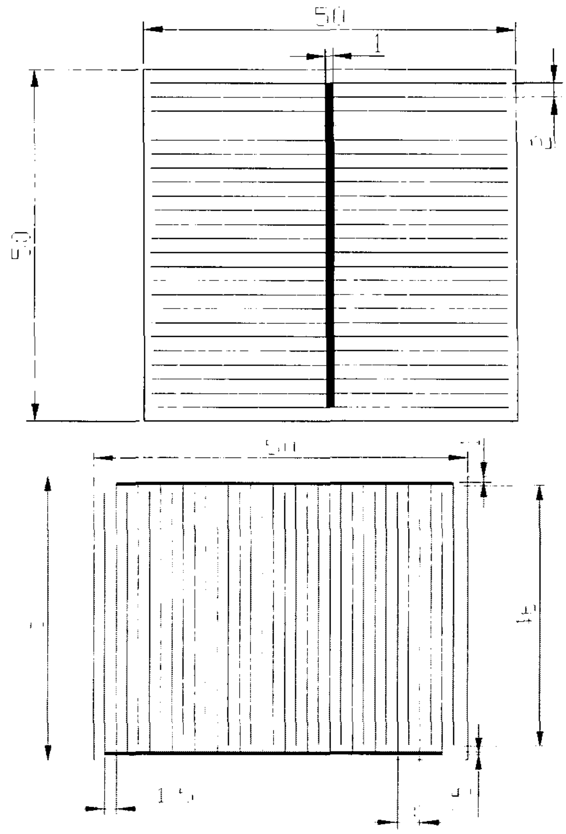

Fig. 2. Grid design of proposed bifacial solar cell: (a) front (b) back.

3. RESULTS AND DISCUSSION

Table 1. shows the list of normalized open circuit voltage and normalized short circuit current density of the back wall solar cell under different surface illumination and collection conditions using 1 sun ($100mW/cm^2$) illumination. The normalization is with reference to the light on the front surface and collection from the front surface.

Table 1. List of normalized V_{OC} and normalized J_{SC} of different modes of illumination on surface and collection of carriers of bifacial solar cells.

Illumination on surface, collection of carrier	Normalized V_{OC}	Normalized J_{SC}
CF, LF	1	1
CBa, LF	0.727	0.468
CBa, LBa	0.954	0.638
CBo, LF	0.878	1.085
CBo, LBo	0.954	1.319

(CF = Collection Front, LF = Light on Front, CBa = Collection Back, LBa = Light on Back, CBo = Collection Both, LBo = Light on Both)

It should be noted that the integrated collection exceeds (by about 9%) the front surface collection even when light is incident only on the front surface indicating the beneficial effect of bifacial cell. However, the sum of the collection from the front and the back surface is much more than the integrated collection under front surface illuminated condition implying a loss mechanism operating within the cell.

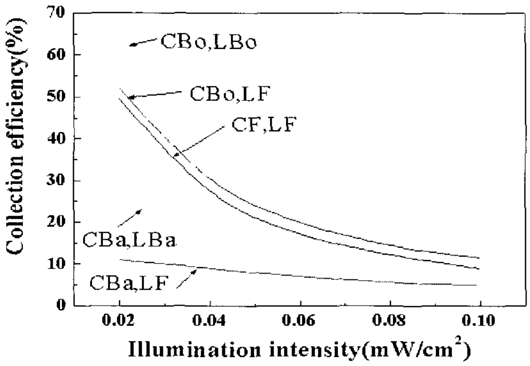

Fig. 3. Variation of collection efficiency with illumination intensity illumination intensity.

The loss mechanism in this type of cell is further shown in Fig. 3 where the variation of collection efficiency measured by the short circuit current per unit intensity is plotted with the intensity of illumination. For a normal unifacial (one side n^+ of p-base silicon) cell, short circuit current is proportional to the light intensity up to one sun so that the collection efficiency should be independent of intensity up to one sun.

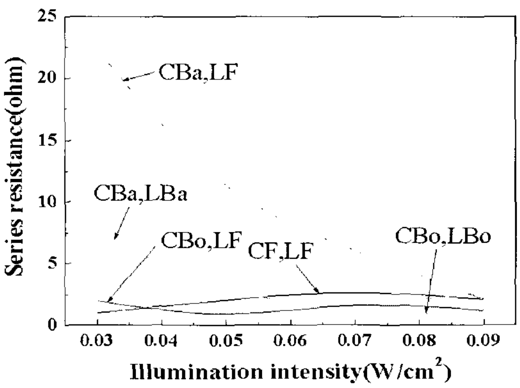

Fig. 4. Variation of series resistance with illumination intensity.

However, in case of bifacial cells, a strong non-linearity is observed particularly when the front surface is illuminated, strong non-linearity of these curves can not be explained by the presence of the high series resistance of the cell which has been measured from the I-V characteristics of the cell at different intensity corresponding to different modes of collection and illumination and displayed in Fig. 4. For example, Fig. 3 indicates that the collection efficiency improves almost exponentially with the reduction of intensity while Fig. 4 indicates the increase in series resistance values when the intensity is lowered below 0.05 W/cm^2. A further insight in the mechanism of operation of the bifacial cell is obtained through the measurement of its spectral response under varied modes of collection and illumination (Fig. 5).

From Fig. 5, it has been noted that the increase in short circuit current for CBa, LF mode which is perhaps due to decrease in surface recombination velocity of the back surface of the bifacial solar cell.

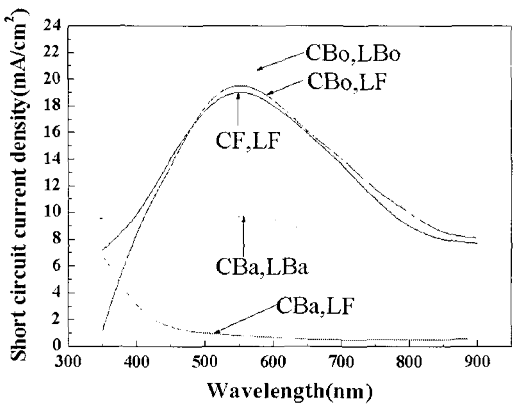

Fig. 5. Spectral response of bifacial silicon solar cell under different modes.

The bifacial cell has a grid contact at the back in place of being totally covered by metal and the residual oxide layer at the back. For the wavelength greater than 500 nm, however, the current collection shows low values. This may be the repelling effect of light generated minority carriers from the opposite field generated at the back by n^+ junctions.

This may be the cause of structural defects of our proposed bifacial cells. The exact physics behind this nature of response of the bifacial cells is not known.

However, it can be represented under short circuit condition by a circuit model consisting of a number of shunted diodes originating from the back surface in parallel with a diode originating from the front surface as shown in Fig. 6.

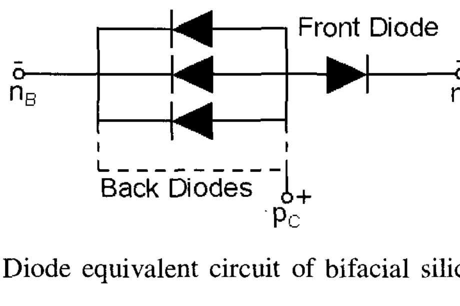

Fig. 6. Diode equivalent circuit of bifacial silicon solar cell.

The low voltage across the back surface may be due to the non-uniformity of the parallel diodes representing the back surface. Moreover, in the case of collection from both surfaces, both the diodes need to be forward biased simultaneously and which is rather difficult. This may explain the observed loss of J_{sc} in this case. This is a very interesting phenomenon and appears to be similar to the case with integral bypass diode.

4. CONCLUSION

Transistor like structure of the bi-facial solar cell has been fabricated and the characteristics of the bifacial cell have been investigated. It is found that 9% increase in short circuit current is achieved with bifacial connection than the unifacial connection. One important behavior of our fabricated bifacial is that a strong non-linearity of collection efficiency at different intensities is observed particularly when the front surface is illuminated. The strong non-linearity of the curves can not be explained by the presence of high value of series resistance of our proposed bifacial structure. Moreover, it has been noticed that the design of back surface of a bifacial silicon solar cells is very important, otherwise some series resistance affects and some anomalous behavior gets incorporated into bifacial characteristics. The aforesaid effects may be hampering the overall efficiency gain of bifacial solar cells. The loss mechanisms, which are inherent in the transistor like bifacial structures are difficult to eliminate. However, if it could be done, the promise of the bifacial solar cell would be greatly increased.

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