Novel approach for characterizing the specific shunt resistance caused by the penetration of the front contact through the p–n junction in solar cell*

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Abstract: Shunt can drastically decrease the solar cell conversion efficiency and its current measurement result only reflects the overall shunting effect of all shunts in a whole cell. In order to accurately characterize local shunts caused by the penetration of front contacts through the emitter junction, silicon solar cells with a new structure named beam bridge contact were fabricated. The result showed that the region under the emitter was more badly shunted than the other emitter regions. The sample preparation process was completely compatible with the industrial silicon fabrication sequence, which was of great convenience. The measurement results give informations on the solar cell structure, material ingredients, and process parameters.

Key words: solar cell; shunt resistance; measurement
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1. Introduction

Current leakage is one of the main harmful effects in solar cells. Leakage is conventionally characterized by the shunt resistance R_{sh} of a resistor connected to a p–n junction in parallel[1]. A small R_{sh} decreases the open circuit voltage and reduces the fill factor, hence lowering the energy conversion efficiency E_{ff}. Moreover, if a large series resistance appears, the shunt resistance can further decrease the short circuit current leading to a more drastic decrease of E_{ff}. Leakage can be caused by the started wafer itself[2] or by the fabrication process during which inappropriate parameters or a wrong handling is used. Usually, leakage sites are distributed non-uniformly in the whole solar cell and can be detected with electroluminescence (EL)[3], photoluminescence (PL)[4] or thermograph (TG)[5] imaging techniques. Low cost liquid crystal sheet could also be used to detect shunts[6]. With lock-in techniques, high resolution thermo-images can be obtained[7].

Traditionally, the shunt resistance is only an overall value calculated from the I–V characteristic tested under the conditions of the AM 1.5 G at a temperature of 25 °C. Spatially resolved shunts measurements are done by many research groups[3–8], and those results are qualitative or quasi-quantitative.

In this article, we propose a new method to quantitatively measure the shunt resistance R_c caused by the penetration of the front contact fingers through the p–n junction under the emitter of conventional crystalline silicon solar cells. After R_c is determined, the shunt resistance R_e caused by the other facts can be also identified.

2. Model

To measure the shunt resistance under the front contacts, a new structure solar cell is designed. Its structure is illustrated in Fig. 1. The front contact has the structure of a beam bridge and is made up of two components, piers and beams. The pier bottom penetrates through the antireflection layer and has an ohmic contact with the solar cell emitter. The beam is exactly above the reflection layer and has an electric connection with the pier heads. Apart from the piers, the beam only has contact with the antireflection layer without penetrating the layer. So the photo-generated currents are all connected by the beam levers through the piers. Except for the front contact, the other parts of the novel structure are the same as for the conventional silicon solar cell, i.e., involving a front junction and a back surface field (FJ & BSF): Ag/ n^+-Si/ p-Si/ p^+-Si/Al. The equivalent circuit of the new solar cell is shown in Fig. 2. R_c is the shunt resistance coming from the penetration of front contacts fingers through the emitter junction (the p–n junction in Fig. 1) of conventional crystalline silicon solar cells, and R_e is the shunt resistance caused by other shunting in the emitter in

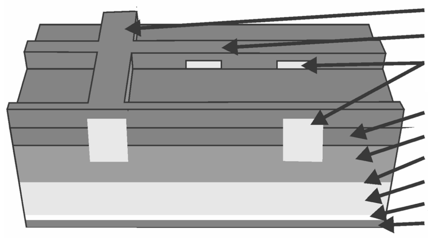

Fig. 1. Schematic structure of silicon solar cell with the front contact structure like beam bridge.

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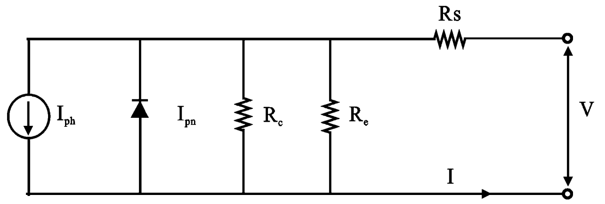

Fig. 2. Equivalent circuit for the new structure solar cell. R_c is the shunt resistance caused by the penetration of front contacts fingers through the p–n junction, and R_e is by the other shunting in the emitter except R_c.

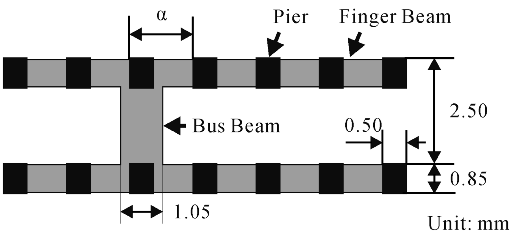

Fig. 3. Schematic layout for front beam bridge contacts (top view).

addition to R_c. R_e is mainly caused by the leakage in the non-ideal p–n junction, defects through the p–n junction, etc. The overall shunt value R_{sh} is the effect of R_c in parallel to R_e and their relation is shown in Eq. (1).

$$\frac{1}{R_{sh}} = \frac{1}{R_c} + \frac{1}{R_e}, \tag{1}$$

where $R_c = r_c/s$ and $R_e = r_e/s_e$. Here, s is the sum area of the contact between the piers and the emitter, and s_e is the total area of the emitter in the solar cell with $s_e = 9.00$ cm^2 in this article. r_c and r_e are their corresponding specific shunt resistances. By varying s, different R_{sh} can be obtained. So, from the relation between s and R_{sh}, r_c and r_e can be extracted. To be noted, the samples in this article are textured and the actual areas of emitter and contact are $\sqrt{3}$ times of S_e and S_c[9], which does not affect the conclusions.

3. Experiment

The dimension of the pier was 0.85×0.50 mm^2, as illustrated in Fig. 3. By varying the pier pitch α on the front surface, the area of the contact between the piers and the emitter was changed. For a more precise resistance determination with the least square method, five groups of silicon solar cells were prepared with different α values. The other parameters for the five groups of cells were the same.

The solar cell samples were prepared completely in our pilot production line and they were all started from p-type crystalline silicon wafers with the dimension of 9.00 cm^2. After saw damage been removed and wafer been polished in an alkaline solution, the emitter was formed by $POCl_3$ diffusion followed by plasma etching to remove the heavily diffused edge shunts. Then an antireflection SiN_x layer was formed by plasma enhanced chemical vapor deposition (PECVD). Subsequently, Al-rich paste was screen printed and dried on the back surface for the back surface field and the back contact. After this, Ag-rich paste was screen-printed as piers on the front surface, which was followed by co-sintering in a furnace. During the co-sintering process, front ohmic contacts between the piers and the emitter were formed by firing the metal paste through the SiN_x layer on the front emitter surface; at the same time, front ohmic contacts between the back Al and the base region were also achieved. At last, the bridge beam for the front contact was formed by the other Ag-rich paste printing and sintering processes, during which the paste was different from that used for piers and the sintering temperature was lower than that of the previous co-sintering step. The process sequence is shown in Fig. 4.

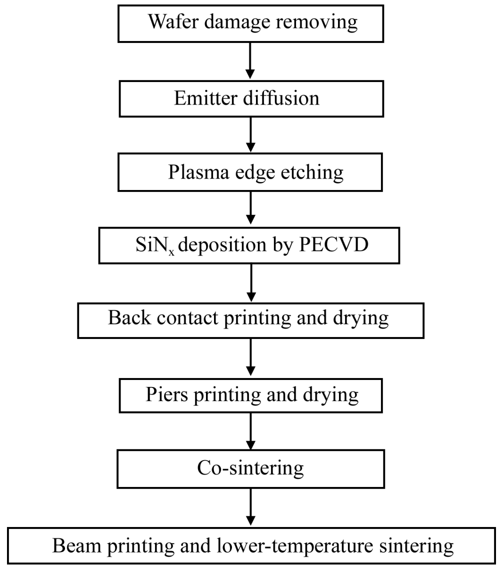

Fig. 4. Process sequence for the preparation of beam bridge contact solar cells.

4. Results and discussion

Five groups of samples, i.e., 1#, 2#, 3#, 4#, and 5#, were prepared with their pier areas s being 1.43, 0.969, 0.765, 0.612, and 0.51 cm^2, respectively, and their average shunt resistances R_{sh} being 47.5, 51.0, 53.3, 53.7, and 54.2 Ω, respectively. R_{sh} was extracted from the I–V curve tested under the condition of illumination of AM 1.5G and 25 °C. The curve of R_{sh} versus s is illustrated in Fig. 5. By using linear fitting and Eq. (2), we could get $r_c = 342$ Ω·cm^2 and $r_e = 536$ Ω·cm^2.

$$\frac{1}{r_c} s + 9.00 \times \frac{1}{r_c} = \frac{1}{R_{sh}}. \tag{2}$$

The test results showed that r_c was much smaller than r_e, which shows that the p–n junction under the front contacts could be more easily shunted than that away from the front contacts. Because the p–n junction under the front contacts was closer to the front metal-rich contact paste, the former was more easily penetrated by the paste impurity atoms than the latter. It was pointed out that front metallization shunts became difficult to avoid when low contact resistance values needed to

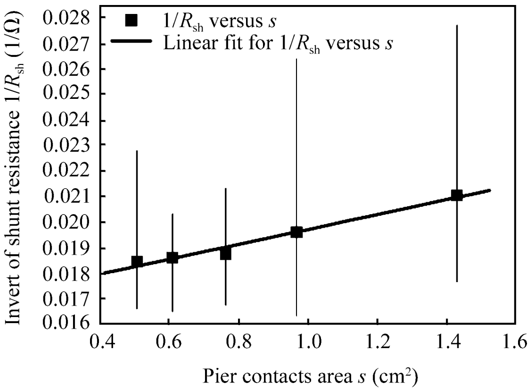

Fig. 5. Relation between the area of pier contacts s and the inverse of solar cell shunt resistances $1/R_{sh}$. The linear fitting for $1/R_{sh}$ versus s is also shown.

be achieved for the whole solar cell[2]; but to the best of our knowledge, it is the first time that the accurate numerical proof was given in this work.

For normal industrial crystalline solar cells, the specific shunt resistance is greater than 400 $\Omega\cdot cm^2$. So, in the above experiment, the shunts were mainly caused by the front contacts penetration through the p–n junction underneath. The penetration through the p–n junction under the front contact also depends on the junction depth, the defects and impurities in the emitter. Furthermore, the solar cell processes—especially the sintering step when using inappropriate parameters—can lead to the bad shunts in cells[10]. By measuring the shunt caused by the penetration of the front contact through the p-n junction of a solar cell, the optimization can be achieved for junction depth, contact chemical components, and process parameters. If the optimization is achieved, an maximal shunt resistance and a good ohmic contact can be simultaneously obtained, leading to the highest cell fill factor and, hence, the highest energy conversion efficiency.

5. Conclusion

A novel structure of beam bridge contacts is proposed for precisely measuring the specific resistance caused by the penetration of front contacts through the p–n junction under the emitter. The sample preparation process is completely compatible with the industrial silicon fabrication sequence, which is very convenient. The measuring approach is useful for the optimization of the junction depth, contact chemical components, and solar cell processes to achieve the highest cell fill factor and conversion efficiency.

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