

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

Zhang Lucheng(张陆成) and Shen Hui(沈辉)[†]

(Institute for Solar Energy Systems, Sun Yat-Sen University, Guangzhou 510006, China)

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

DOI: 10.1088/1674-4926/30/7/074007

PACC: 8630J; 7340L; 7340Q

EEACC: 8420; 2530

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

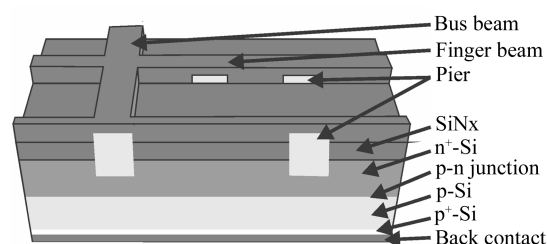


Fig. 1. Schematic structure of silicon solar cell with the front contact structure like beam bridge.

* Project supported by the National High Technology Research and Development Program of China (No. 2006AA05Z409) and the PhD Program Foundation of the Ministry of Education of China (No. 4111283).

[†] Corresponding author. Email: shenhui1956@163.com

Received 10 March 2009, revised manuscript received 8 May 2009

© 2009 Chinese Institute of Electronics

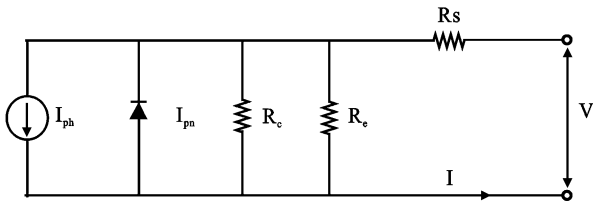


Fig. 2. Equivalent circuit for the new structure solar cell. R_c is the shunt resistance caused by the penetration of front contacts fingers through the p–n junction, and R_e is by the other shunting in the emitter except R_c .

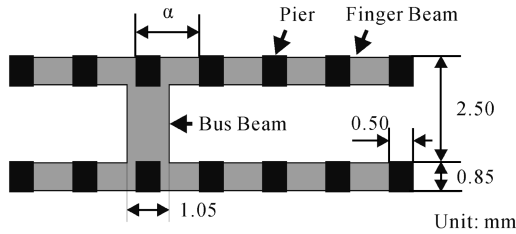


Fig. 3. Schematic layout for front beam bridge contacts (top view).

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).

$$\frac{1}{R_{sh}} = \frac{1}{R_c} + \frac{1}{R_e}, \quad (1)$$

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 $s_e = 9.00 \text{ cm}^2$ 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 $0.85 \times 0.50 \text{ mm}^2$, 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

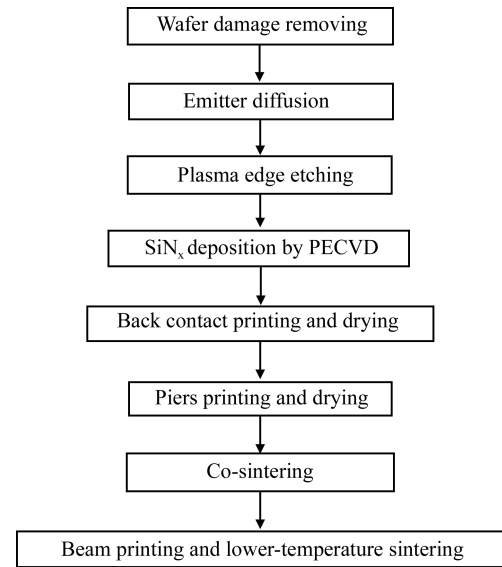


Fig. 4. Process sequence for the preparation of beam bridge contact solar cells.

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.

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 $r_c = 342 \Omega \cdot \text{cm}^2$ and $r_e = 536 \Omega \cdot \text{cm}^2$.

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

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

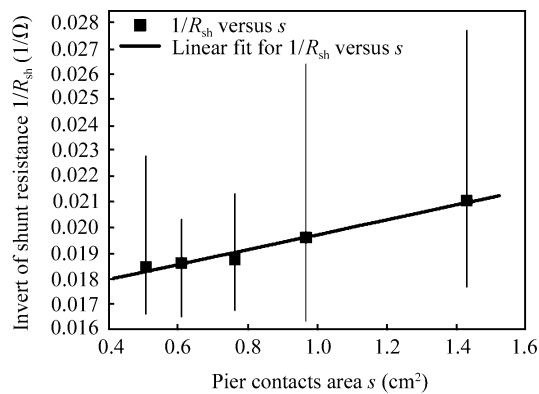


Fig. 5. Relation between the area of pier contacts s and the inverse of solar cell shunt resistances $1/R_{sh}$. The linear fitting for $1/R_{sh}$ versus s is also shown.

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 $400 \Omega\text{-cm}^2$. 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.

References

- [1] Green M A. Solar cells operating principles, technology and system applications. The University of New South Wales, 1986: 96
- [2] Correia S A, Lossen J, Bähr M. Eliminating shunts from industrial silicon solar cells by spatially resolved analysis. Proceedings of 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, 2006: 1297
- [3] Kirchartz T, Helbig A, Rau U. Note on the interpretation of electroluminescence images using their spectral information. Solar Energy Materials and Solar Cells, 2008, 92: 1621
- [4] Kasemann M, Grote D, Walter B, et al. Luminescence imaging for the detection of shunts on silicon solar cells. Progress in Photovoltaics: Research and Applications, 2008, 16(4): 297
- [5] Kaminski A, Jouglar J, Mergui M, et al. Infrared characterization of hot spots in solar cells with high precision due to signal treatment processing. Solar Energy Materials and Solar Cells, 1998, 51: 233
- [6] Breitenstein O, Langenkamp M, Lang O, et al. Shunts due to laser scribing of solar cells evaluated by highly sensitive lock-in thermography. Solar Energy Materials and Solar Cells, 2001, 65: 55
- [7] Breitenstein O, Rakotoniaina J P, Schmidt J. Comparison of shunt imaging by liquid crystal sheets and lock-in thermography. Proceedings of the 12th Workshop on Crystalline Solar Cell Materials and Processes, Breckenridge, Colorado, 2002, 12: 244
- [8] Van der Heide A S H, Bultman J H, Hoornstra J, et al. Locating losses due to contact resistance, shunts and recombination by potential mapping with the Corescan. 12th NREL Workshop on Crystalline Silicon Solar Cells, Materials and Processes, Breckenridge (CO), USA, 2002
- [9] Seidel H, Csepregi L, Heuberger A, et al. Anisotropic etching of crystalline silicon in alkaline solution. J Electrochem Soc, 1990, 137: 3612
- [10] Sopori B, Mehta V, Rupnowski P, et al. Studies on fundamental mechanisms in a fire-through contact metallization of Si solar cells. 22nd European Photovoltaic Solar Energy Conference, Milan, Italy, 2007: 841