CONTACT RESISTANCE SCANNING FOR PROCESS OPTIMIZATION: THE CORESCANNER METHOD

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ABSTRACT

It is difficult to obtain screen printed grid lines on solar cells with a low contact resistance, since the contact formation is very sensitive to many parameters. To optimize the process, it is necessary to be able to measure the contact resistance for each grid line. Recently, we have introduced an instrument that can do this, called the Corescanner.

In this paper, the relation between process parameters and contact resistance is investigated using this instrument. The most important finding is that poor contacting results in large inhomogeneities in contact resistance. Even for cells with very low fill factors, regions of low contact resistance can be found. Low firing temperature settings lead to a large region of high contact resistance, and an uneven printing pressure results in large contact resistance differences across the cell, although no problems were visible by microscope. In this way, we will build a problem solving library of process issues and related contact resistance scans.

To conclude, the Corescanner provides us with a technique to monitor contact resistance. This instrument is a valuable tool for fault detection, error diagnosis and process optimisation.

INTRODUCTION

One of the key issues in industrial crystalline solar cell processing is to obtain a good contact below the screen printed metallisation. The print quality and the sintering determine the quality of the formed contact. For instance, cleaning of screens, screen quality, paste rheology and print pressure influence the print quality. The sintering of the metal paste can be influenced by emitter homogeneity and sheet resistance, coating homogeneity and thickness, temperature homogeneity and stability of the furnace. Although it is possible to achieve fill factors of 78% for screen printed cells in the laboratory, in industry 5-10% lower fill factors are common due to the sensitivity of contact formation.

Of course, it is important to determine which process parameter is responsible for the high contact resistances on the low fill factor cells. Recently, we have introduced a new patented technique [1,2,3] to scan the COntact REsistance over the entire surface of a solar cell, which is used by the Corescanner. With this instrument, a start is made to relate process problems and contact resistance scans.

THE CORESCANNER

The Corescanner can scan the contact resistance or locate shunts. The method for locating shunts is explained in [1,2], a comparison with lock-in thermography is presented at this workshop [4]. The Corescanner method for measuring contact resistance is shown in Figure 1. The principle is to measure the potential jump between a grid line and neighbouring silicon, which occurs due to a light beam induced current that flows through the metal-silicon interface. A potential probe is used for the measurement of the potential jump between grid line and neighbouring silicon. The probe is centred in the beam, moving together with it across the cell, while being in continuous contact with the surface.

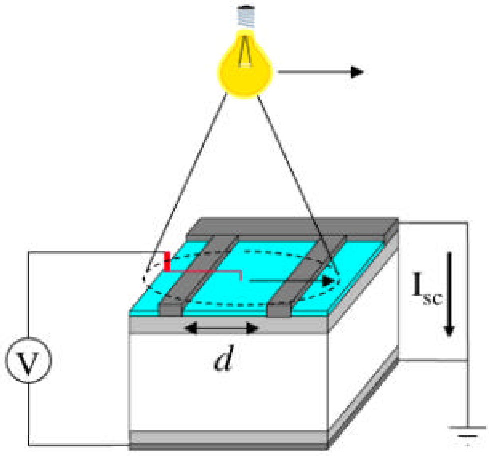


Figure 1: Working principle of the Corescanner

The contact resistance of the lines can now be determined from the measured potentials. The contacting properties of grid lines are traditionally characterized by the specific contact resistance r_c; however, this approach has several disadvantages. In the first place, the local specific contact resistance below a screen printed line is not constant over the width of the line. Secondly, for low to medium r_c values it is necessary to know the sheet resistance below the line $r_{s,bl}$ for an accurate r_c calculation. Finally, for the performance of a region between grid lines it is only the combined influence of r_c and $r_{s,bl}$ that is important for the fill factor. Therefore, it is best to include the influence of $r_{s,bl}$ and inhomogeneous contacting in a useful definition of the contact resistance for grid lines, called the line contact resistance R_{cl}. In the following definition this is the case, since the potential difference V_{ce} between the edge of the contact (grid line) and the neighbouring silicon is determined by the combination of all resistance sources below the line:

$$R_{cl} = \frac{V_{ce}}{i_c} = \frac{V_{ce}}{J_{sc} d},$$

where i_c is the current entering the contact per unit length of contact, J_{sc} is the local short circuit current density generated in the illuminated area and d is the distance between the fingers. J_{sc} needs to be measured only once per cell: J_{sc} variations from point to point are typically less than 10%. J_{sc} should be kept at approximately 30 mA/cm^2, to minimize errors due to possible non-ohmic behaviour of the finger contact which occurs at high current densities. An example of a typical Corescanner line scan perpendicular to the fingers and performed at J_{sc} = 30 mA/cm^2 is shown in Figure 2:

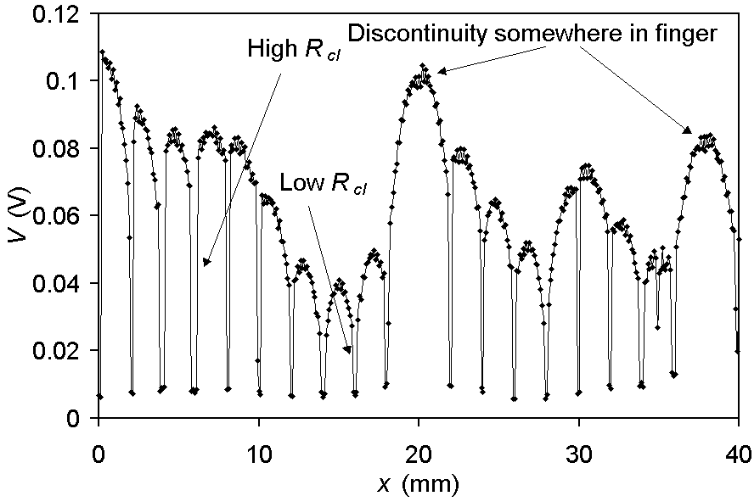


Figure 2: Corescanner line scan perpendicular to fingers

This line scan shows typical features of a Corescanner measurement:

1. Fingers are at the lowest potential because they are in contact with the grounded busbar,
2. Between the fingers the potential has a parabolic shape due to emitter sheet resistance,
3. Potential jumps are present at the fingers due to contact resistance,
4. Finger interruptions cause high parabolas due to a doubled finger spacing.

Cells can be studied best by scanning the entire surface in about 20 min time, and plotting potentials in 2D or 3D graphs, as shown for a typical example given in Figure 3:

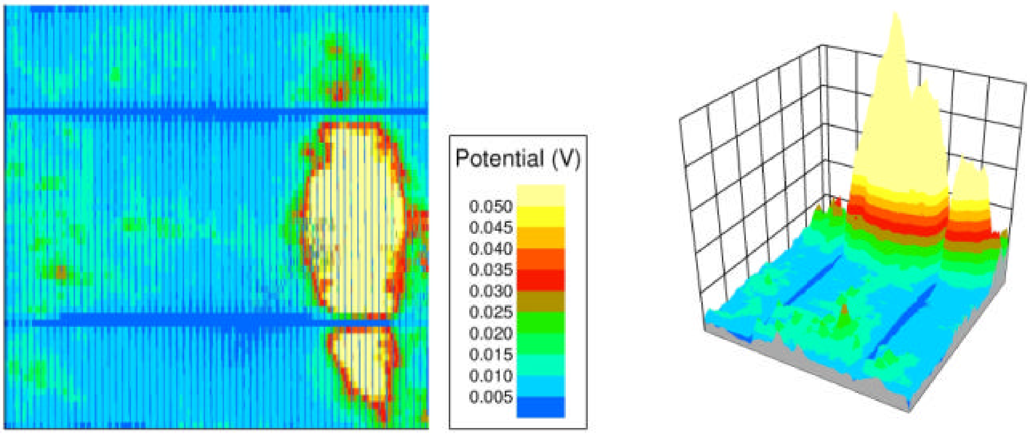


Figure 3: 2D and 3D representation of contact resistance measurement with the CoreScanner

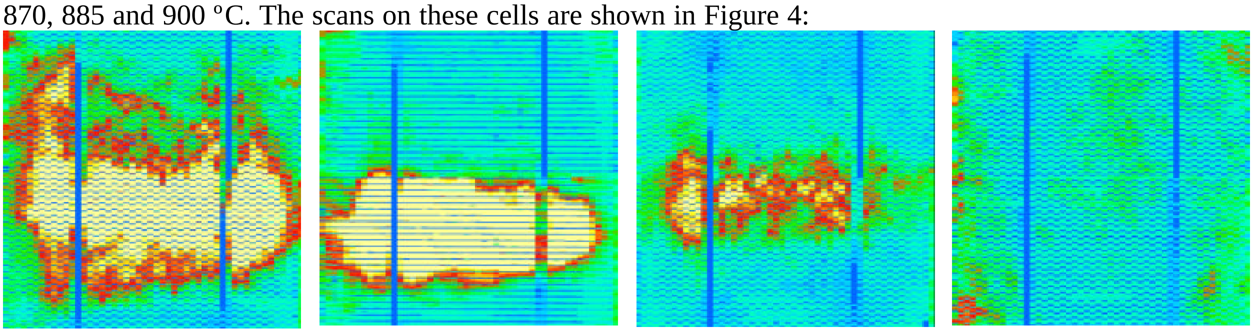
In a 2D graph, large colour differences between finger and silicon indicate a high contact resistance. The cell was measured at a J_{sc} of about 30 mA/cm^2, as for all the cells presented in this paper. Also the colour encoding of the above 2D picture is used throughout the paper. Potentials between fingers above 0.015 V indicate locations where the contact resistance is too high.

ANALYSING PROCESSING PROBLEMS

With the Corescanner, we now have an instrument to monitor the contact resistance over the complete solar cell surface. In this section, some process parameters are changed and contact resistance scans measured. These results will be used to set up a library of process problems and related scans. When low fill factors occur, this library can be used to determine the cause.

Influence of firing temperature

To investigate the influence of peak firing temperature on contact formation, multicrystalline silicon solar cells coated with SiN_x were fired in a belt furnace at different peak temperatures. The peak temperatures used were 855, 870, 885 and 900 °C. The scans on these cells are shown in Figure 4:



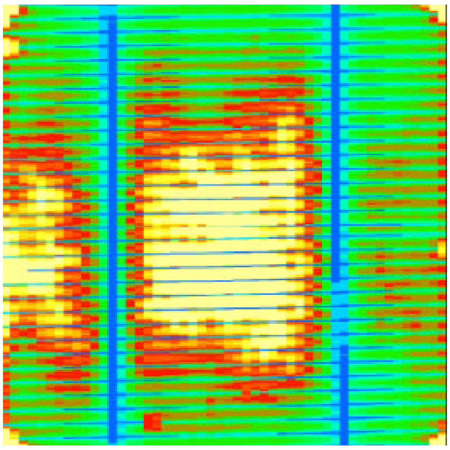
T_{peak}	855 °C	870 °C	885 °C	900 °C
FF	61%	62%	72%	77%

Figure 4: Contact resistance scans as a function of peak firing temperature

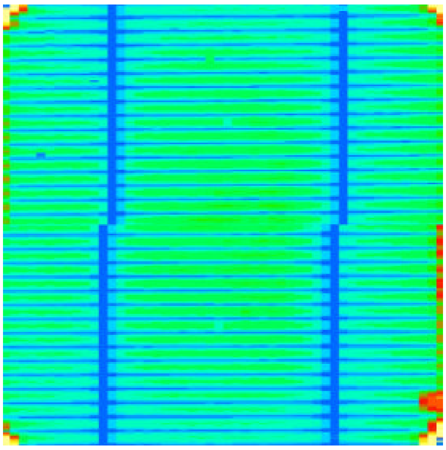
These pictures show for the first time the influence of firing temperature. Surprisingly, it is the homogeneity of the contact resistance that is influenced the most. Even for the cell with a very low fill factor, regions can be found where the contact resistance is as good as for the high fill factor cells. Currently, we are investigating the cause of these inhomogeneities to increase the process window for firing.

Influence print pressure

A second factor influencing the contact formation is the print quality. Normally, this is monitored with a microscope. However, not all effects are visible by detecting the shape of the printed lines. For instance, when the print pressure is varied, the visible print quality stays the same. However, the contact resistance is strongly influenced, as can be seen in Figure 5:



Low print pressure



High print pressure

Figure 5: Influence of print pressure on contact resistance scan

Contact resistance is highest at the centre of the cell. It was determined that the vacuum chuck of the printer was not flat due to wear of placing cells. The non-flatness of the chuck becomes strongly visible for lower pressures.

CONCLUSIONS

In this paper, contact resistance is measured over the entire cell surface using the newly developed Corescanner in contact resistance mode. For the first time, it has been possible to investigate the relationship between processing parameters and the distribution of contact resistance over the solar cell. Peak firing temperature for example, is found to influence the contact resistance homogeneity drastically. This provides a means for diagnosing temperature settings during production. The method also forms a powerful aid in troubleshooting of other processing problems. For example, low fill factors during production could be allocated to the non-flatness of a worn vacuum chuck of a screen printer, whereby printing at a low squeegee pressure leads to high contact resistance at the centre of the cell.

Most importantly, poor contacting results in large inhomogeneities in contact resistance. However, even when low fill factors are obtained, areas of low contact resistance may still be present for a large region of the cell. This surprising result is a strong encouragement to improve the contacting process window by diagnosis with the Corescanner.

REFERENCES

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[3] A.S.H. van der Heide, J.H. Bultman, J. Hoornstra and A. Schönecker, Proceedings 12th Photovoltaic Science and Engineering Conference, Jeju (Korea), 591 (2001).

[4] O. Breitenstein, J.P. Rakotoniaina and A.S.H. van der Heide, this workshop.