RESISTANCE ANALYSIS OF WRAPPED THROUGH EMITTERS

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ABSTRACT

To analyze the via-hole emitter resistance two different test devices were designed consisting of symmetric n⁺p⁻n⁺-structures whereas the emitter via-holes are ideally the only connection between the two emitter layers. The first device allows measuring the resistance of a single via hole. The second device features a plurality of via holes, in order to determine the resistance of 25…100 via-holes in parallel. Subtracting spreading resistance and geometry contributions with an analytical approach the via-hole resistance can be deduced from both methods. The presented approach reveals the series resistance contribution of the emitter via-hole independently of the complete solar cell device. Further it permits to test a variety of emitter formation processes, metallization schemes and damage etching or texturization steps regarding their specific series resistance contribution or the general feasibility of a process sequence respectively.

INTRODUCTION

The Emitter-Wrap-Through-Concept (EWT) enables a high efficiency potential using relatively low material quality (i.e. low diffusion length) and a reduction of module assembly costs due to easier cell interconnection of back-contacted solar cells [1]. One of the key features of the EWT cell concept is an emitter via-hole that connects the front side emitter with the back side emitter, where the contact metal is deposited. Depending on the conductivity of the via-hole emitter and / or its metallization, a potential drop from front to back side will be present reducing the maximum power point voltage. Since via-holes are commonly drilled with laser light, the laser induced damage must be removed in a subsequent etching step prior to emitter diffusion. Different laser processes and accompanying etching steps lead to a different via-hole geometry concerning radius, shape and surface structure, and are thus expected to lead to differing values for the via resistance. Independently of the via-hole geometry the emitter formation in the via hole may differ from the formation on plane wafer surfaces due to the particular set-up additionally depending on the dopant deposition technique used. Further different process sequences for producing EWT-cells may lead to insufficient via-hole diffusion, or even to a missing connection of front and back side emitter.

MEASUREMENT PRINCIPLES

In the following the measurement principles and sample designs used are described. Generally n⁺p⁻n⁺ -structures connected by a certain number of via-holes with emitter are applied.
As mentioned above an analytical approximation is calculated potential difference between the via-hole and y-direction. As a result the new element is arranged about twenty times in x contact. In order to calculate the potential distribution opposite sign) to account for the presence of the metal direction, with a current carrying tip (current with element is complemented by a mirrored element in x-carrying tip at the center of the via-hole. The symmetry and length is represented by a two dimensional element of width resistance for a symmetry element with one via is metal contact 1 and the via-hole (for two via-holes the calculated for the section of the samples between the with finite dimensions \[2\]. The potential distribution is used to determine the contribution of the resistance of metalized emitter via-holes.

CALCULATION OF \( R_{1,\text{Via}} \) AND \( R_{M,\text{Via}} \)

As mentioned above an analytical approximation is used to determine the contribution of the resistance between the last contact and the via-hole. The calculation of \( R_{1,\text{Via}} \) is based on the method of images, and has been used for the evaluation of four-point-probe measurements of the sheet resistance on samples with finite dimensions \[2\]. The potential distribution is calculated for the section of the samples between the metal contact 1 and the via-hole (for two via-holes the resistance for a symmetry element with one via is calculated and connected in parallel with the second). It is represented by a two dimensional element of width \( w \) and length \( a_0 \) as pictured in Fig. 3 with a current carrying tip at the center of the via-hole. The symmetry element is complemented by a mirrored element in x-direction, with a current carrying tip (current with opposite sign) to account for the presence of the metal contact. In order to calculate the potential distribution the new element is arranged about twenty times in x and y-direction. As a result \( R_{1,\text{Via}} \) is the ratio of the calculated potential difference between the via-hole

\[
R = \frac{1}{k} (R_{m} + 2R_{M,\text{Via}}) \tag{4}
\]

whereas \( R_{M,\text{Via}} \) is the contribution of the path from metal contact to via-hole edge. The notches are necessary to establish a well defined contact-area avoiding current paths via metal inside the hole. In a second step, a back side contact design without notches can provide information about the resistance of metalized emitter via-holes.

SAMPLE PREPARATION AND MEASUREMENT

Both sample types described above were realized several times on 4'' Float Zone silicon wafers of 250 \mu m thickness. For via-drilling a pulsed laser source of the wavelength \( \lambda = 1064 \text{ nm} \) was used. The samples were etched for 12 min in 30\% KOH at a temperature of 80°C. This resulted in an average via-hole radius of \( r_{fs} \approx 40 \mu \text{m} \) on the laser incident side and \( r_{fs} \approx 30 \mu \text{m} \) on the other side. After emitter diffusions of \( \sim 35 \Omega/\text{sq.} \text{ and } \sim 120 \Omega/\text{sq.} \text{ and phosphorus glass removal the samples were coated with a photo resist resin subsequently structured photo-lithographically. Finally a Ti/Pd/Ag-stack was deposited by physical vapor deposition and after a lift-off process an annealing step under forming gas was applied. On each wafer both samples for method 1 with different widths (0.5 cm and 1.0 cm) and one or two vias and samples for method 2 with three different numbers of via holes are present. To separate the samples a laser groove was applied on one side with a depth of about 100 \mu m. Subsequently the samples were broken along the groove. For each sample the characteristic curve between n and \( n' \text{ was measured in the dark with a four-point set-up to extract the resistance value. The resulting dataset resistance vs. path length through emitter (sample length without metal pads) was linearly fitted. The sheet resistance extracted from the slope was used to calculate } R_{1,\text{Via}}. \)

Some care has to be taken about edge isolation for the single via measurement since the measured resistance takes values of several 100 \Omega. Any kind of shunt can lead to a considerable error.
calculation of $R_{\text{via}}$ gives value for the sheet resistance used in the calculation of $R_{\text{via}}$. $R_{\text{via}}$ can be deduced from the latter along with the ordinate intercept.

The edge isolation quality was verified by a reference sample without via-holes. Further only samples with via-holes that satisfied the following criteria were taken into account:

- the characteristic curve between $n$ and $n'$ is ohmic for at least one current direction
- a linear fit of the resulting data set resistance vs. path length through emitter is reasonable

The second sample type was measured with a four point set up as well. A resistance contribution due to metal sheet resistance was neglected. For the multi-via measurement the edge isolation is less critical, due to the lower absolute value. Finally for both methods a measurement the edge isolation is less critical, due to the lower absolute value. Finally for both methods a

RESULTS

Fig. 4 displays a fit of a typical data set $R_{n,n'}$ vs. path length through emitter extracted from resistance measurement of a sample with a single via-hole and a 35 $\Omega$ sq. emitter diffusion. The slope of the linear fit gives value for the sheet resistance used in the calculation of $R_{\text{via}}$. $R_{\text{via}}$ can be deduced from the latter along with the ordinate intercept.

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Table 1: Results of the evaluation of samples of method 1 for different diffusions and sample widths. The values of $R_{\text{via}}$ exhibit the expected behavior for both parameters.

<table>
<thead>
<tr>
<th>$w$ [cm]</th>
<th>$R_{\text{sh}}$ [Ω/sq.]</th>
<th>$R_{\text{via}}$ [Ω] (1 via / 2 vias)</th>
<th>$R_{\text{via}}$ [Ω] (ave. / no. samples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>35.7±0.6</td>
<td>78.9±1.2 / 60±0.9</td>
<td>37.8±1.8 / 8</td>
</tr>
<tr>
<td>1.0</td>
<td>35.7±0.6</td>
<td>66.6±1.4 / 47.4±1</td>
<td>37.4±1.8 / 4</td>
</tr>
<tr>
<td></td>
<td>114±6</td>
<td>208±4 / 154±3</td>
<td>133±5 / 4</td>
</tr>
</tbody>
</table>

Table 2: Results of the evaluation of samples of method 2 for different diffusions and via-hole numbers. The average values of $R_{\text{via}}$ are very similar for 25 and 49 vias, and slightly increased for 100 vias-holes and high doping.

<table>
<thead>
<tr>
<th>No. via-holes</th>
<th>$R_{\text{sh}}$ [Ω/sq.]</th>
<th>$R_{\text{via}}$ [Ω] (ave. / no. samples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>35.7±0.6</td>
<td>16.3±1.2 / 12.2 ± 0.5 / 5</td>
</tr>
<tr>
<td></td>
<td>114±6</td>
<td>51±4</td>
</tr>
<tr>
<td>49</td>
<td>35.7±0.6</td>
<td>16.3±1.2 / 12.2 ± 0.7 / 3</td>
</tr>
<tr>
<td></td>
<td>114±6</td>
<td>51±4</td>
</tr>
<tr>
<td>100</td>
<td>35.7±0.6</td>
<td>16.3±1.2 / 12.4 ± 0.7 / 3</td>
</tr>
<tr>
<td></td>
<td>114±6</td>
<td>51±4</td>
</tr>
</tbody>
</table>

Further the value of $R_{\text{via}}$ is consistent with the sheet resistances of the diffusions. The error for $R_{\text{via}}$ subsumes the standard deviation of averaging the measured resistance and the error of $R_{\text{via}}$.

A typical result for method 2 is shown in Fig. 5 for a sample with a 35 $\Omega$ sq. diffusion. The surface fraction calculated according to equation 5 has already been subtracted. It can be observed that the sample with 100 via-holes shows a slightly increased value, which is also true for the average of the 35 $\Omega$ sq. diffusion whereas for the low doping samples this cannot be observed. A possible interpretation is that the differences are caused by neglecting metal sheet and contact resistances, whose contributions are multiplied by the number of via-holes. Table 2 subsumes the average values for two different diffusions for the samples of method 2.

Fig. 5 Examples for $R_{\text{via}}$ vs. voltage for measurement of samples with 25, 49 and 100 via-holes with method 2. The sample with 100 via-holes shows a slightly increased value.

Further the value of $R_{\text{via}}$ is consistent with the sheet resistances of the diffusions. The error for $R_{\text{via}}$ subsumes the standard deviation of averaging the measured resistance and the error of $R_{\text{via}}$.
Fig. 6 Sketch of cross section of via-hole as assumed for the calculation of the ideal via-hole resistance.

The value for $R_{M,\text{via}}$ is much lower than $R_{1,\text{via}}$ since the path through emitter is about 0.1 mm compared with about 3 mm for sample type 1. The error for $R_{M,\text{via}}$ is calculated considering a radius measurement error. The average values of $R_{\text{via}}$ are very similar for the different numbers of via-holes. The error given is again due to averaging and the error of $R_{M,\text{via}}$.

The values deduced from both methods are in good agreement. Method 1 has the advantage that single via-holes can be investigated, but it is more sensitive to shunting since high absolute values in the range of several 100 Ω are measured compared to 0.5...2 Ω for method 2.

At this point it can already be stated that the diffusion in the tube furnace allows the formation of wrapped-through emitters. For a more quantitative evaluation it is important to define what value would be expected if the emitter at the via-hole wall forms in the same manner as on plane wafer surfaces. In this work we calculate the expected value by assuming the via-hole to be of conical shape with a crater at the entrance and at the exit, formed due to the anisotropy of the alkaline etch (sketch of cross section in Fig. 6). Since the crater at the edge has a negligible influence on the ideal via-hole resistance we calculate the ideal via-hole resistance with entrance and exit radius $r_{fs}$ and $r_{rs}$ and the full sample width according to

$$R_{\text{exp}} = \frac{R_s}{2\pi} \int_0^d \frac{dz}{r(z)} \tag{6}$$

The resulting values are 36.4±5 Ω for the 35 Ω/sq. emitter and 115±13 Ω for the 114 Ω/sq. emitter. These values are in good agreement with the values deduced from the resistance measurement. Fig. 7 displays a graphical comparison of the results for the resistance values obtained with the two methods as well as the calculated expected values.

Fig. 7 Graphical comparison of results for $R_{\text{via}}$ obtained with the two methods and the expected values. For the 35Ω/sq. diffusion the agreement is excellent. For 115Ω/sq. diffusion the results of the two methods are similar and slightly higher than the expected value.

**SUMMARY**

Two methods to determine the via-hole resistance were evaluated. Both methods show consistent results and are in good agreement. Further, assuming the sheet resistance at the via-hole wall to be the same as on plane wafer surfaces an expected value for the resistance of a via-hole was calculated. This value and the measured values are in good agreement. It can be concluded that the process sequence consisting of laser drilling, alkaline damage etching and tube furnace diffusion is appropriate for the formation of wrapped through emitters.

**ACKNOWLEDGEMENTS**

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**REFERENCES**
