An Evaluation of Constituents in Paste for Silicon Solar Cells with Floating Contact Method: A Case Study of Tellurium Oxide

Takayuki Aoyama\textsuperscript{1, 2}, Mari Aoki\textsuperscript{3, 4}, Isao Sumita\textsuperscript{3, 4}, Yasushi Yoshino\textsuperscript{1}, Atsushi Ogura\textsuperscript{2}

\textsuperscript{1}Noritake Co., Limited
\textsuperscript{2}Meiji University
\textsuperscript{3}Asada Mesh Co., Ltd.
\textsuperscript{4}Toyota technological Institute

Corresponding author: takayuki_aoyama@n.noritake.co.jp
Outline

- **Motivation**
  - Problems in contacts

- **Evaluation method**
  - Floating contact method

- **Case study 1**
  - Effects of paste constituents on n-type solar cells

- **Case study 2**
  - Impacts of TeO$_2$ on Ag paste in conventional p-type solar cells

- **Conclusion**
Problems in contacts

Severe limit of cell efficiency!

High $V_{oc}$…

- Smaller contact area (e.g., PERC, PERL)
  

- Lower shunting and recombination

Paste contacts

- Ag metal
- Glass frit
- Additives

Effects of each constituent on cell performance should be clarified.

$\square$ Shunting

$\checkmark$ Recombination

Cell $V_{oc}$ – implied $V_{oc}$

Metallization area fraction
“Floating contact method”

Standard H-pattern “grid-contact”
- An electrode to measure cell parameters
- Ag Paste used is fixed through experiments.

“Floating contacts (F.C.)” interpose between adjacent fingers.*
- Electrically and geometrically isolated from grid-contact
  - Less influences on measuring cell parameters
- Affecting on carrier behavior: shunting or recombination
- Test pastes used
  - Conductive ✓
  - Nonconductive ✓
  - Non-contact ✓

This method can clearly show paste effects on shunting and recombination.

"Floating contact method"

Floating contact area "fraction"

<table>
<thead>
<tr>
<th>Number of F.C.</th>
<th>Contact Area Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>4%</td>
</tr>
<tr>
<td>Two</td>
<td>8%</td>
</tr>
<tr>
<td>Three</td>
<td>12%</td>
</tr>
</tbody>
</table>

Contact area fraction depending on the number of F.C.
Case study 1

Effects of paste constituents on n-type solar cells
**Experimental setup**

**Floating contacts: homemade test pastes**

- **Ag-only paste**
  - No glass frit

- **Ag/glass paste**
  - Glass frit: PbO-SiO$_2$-B$_2$O$_3$-ZnO
  - Effects of Al

- **Ag/glass/Al paste**
Glass frit in the Ag paste significantly increases the hump current due to shunt and/or recombination current.
The hump current decreases by adding Al to the Ag/glass paste.

This method demonstrates ‘mitigation effect’ of Al in the Ag/Al paste.
Experimental setup

This method can even evaluate insulating materials like glass frit.

Floating contacts: homemade test pastes

- Glass frit paste
- Glass/Al paste

Effects of glass frit itself *
Effects of Al on glass frit

Glass frit: PbO-SiO$_2$-B$_2$O$_3$-ZnO

Dark $I$-$V$ curves

Glass frit itself drastically increases the hump current.
Dark $I$-$V$ curves

The hump current also reduces by adding Al to the glass frit paste, as in the case of the Ag/glass paste.
Analysis results of dark I-V curves; $R_{sh}, J_{02}$

Numerical Fitting with the two-diode model

The Floating contact method clearly shows the dependence of $R_{sh}$ and $J_{02}$ on the fraction every paste.

Simplifying these results...
Analysis results of dark I-V curves; $R_{sh}$, $J_{02}$

- Aluminum addition to glass frit paste reduces the $J_{02}$ increase.
- Aluminum addition to Ag/glass paste reduces both of the $R_{sh}$ decrease and the $J_{02}$ increase.
Summary

✓ Aluminum can mitigate the recombination current increase not only in the silver/aluminum paste, but also in the glass frit paste.

✓ The floating contact method can demonstrate the effects of the paste constituents on shunting and recombination in the n-type solar cells.
Case study 2

Impact of TeO$_2$ addition on Ag paste in conventional p-type solar cells

Background

- TeO$_2$ is used as a constituent of glass frit in almost commercially available Ag paste to achieve high-efficiency of silicon solar cells.
- Detail effects of the TeO$_2$ on the Ag paste has not been clarified yet.
Experimental setup

Floating contacts: homemade test pastes

- Ag-only paste
- Ag/glass paste
- Ag/glass/TeO₂ paste

Experimental setup:

SiNₓ

n⁺ emitter (80Ω/sq.)

Al BSF

p-type Si (156 x156 mm²)

Al paste

Grid contact: Ag paste

Effects of TeO₂

Glass frit: PbO-SiO₂-B₂O₃-ZnO

No glass frit
Glass frit in the Ag/glass paste significantly increases the hump current due to shunt and/or recombination current.
Effects of TeO\textsubscript{2} on dark I-V curves

Increasing rate of the hump current on the Ag/glass paste is reduced by the TeO\textsubscript{2} addition to the paste.
The $R_{sh}$ decreasing rate of Ag/glass paste reduces by adding TeO$_2$ to Ag/glass paste.
Effects of TeO$_2$ on recombination current

The $J_{02}$ increasing rate of Ag/glass paste drastically reduces by adding TeO$_2$ to Ag/glass paste.
Summary

✓ TeO$_2$ in Ag paste reduces $R_{sh}$ decreasing rate and $J_{02}$ increasing rate in conventional p-type solar cells.

✓ The floating contact method can clarify effects of paste constituents on shunting and recombination not only in n-type solar cells, but also in conventional p-type solar cells.
Conclusion

The effects of paste constituents on shunting and recombination were clarified in the following case studies:

- Al effects on Ag paste in n-type solar cells
- Effects of glass frit itself in n-type solar cells
- Al effects on glass frit itself in n-type solar cells
- TeO$_2$ effects on Ag paste in conventional p-type solar cells

The floating contact method is a very effective and powerful tool to evaluate paste and/or paste constituents for development of high efficiency solar cells.
We are looking forward to understanding the mechanism of the effects of paste on shunting and recombination underneath the metallization contacts, and to innovate a new composition of paste for high efficiency cells by using the floating contact method.

Thank you for your kind attention!