ELECTROCHEMICAL CONTACT SEPARATION FOR PVD ALUMINUM BACK CONTACT SOLAR CELLS

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AGENDA

- Metallization of back contact solar cells
- Aluminum anodizing
  - Industrial applications
  - Electrochemical reaction
- Local anodizing of aluminum
  - Mask based approaches
  - Novel maskless approaches
- Summary
Metallization of IBC Solar Cells

Motivation

- Back contact solar cells
  - High efficiencies reached
    - Panasonic 25.6%¹
    - SunPower 25.0%²
  - Proprietary process from SunPower
  - Aluminum as contacting material
  - Metal contact separation challenging
→ Alternative contact separation process necessary

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¹ Panasonic HIT Solar Cell Achieves World’s Highest Energy Conversion Efficiency of 25.6% at Research Level, 04.2014
Metallization of IBC Solar Cells
Comparison of Process Steps

Established Process\(^3\)

1. PVD-Aluminum
2. PVD-TiW
3. PVD-Copper
4. Resist printing
5. Plating
6. Resist removal
7. Metal etching

Metallization of IBC Solar Cells
Comparison of Process Steps

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Alternative Maskless Process

1. PVD-Aluminum
2. Al structuring???
3. Zincate Process\(^4\)
4. Plating

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Aluminum Anodizing
Industrial Applications and Properties of AAO

- Aluminum can be converted into electrical isolating aluminum oxide by anodizing
- Structure of anodic aluminum oxide (AAO) first reported in 1953\textsuperscript{5}
- Industrially transferred a few years later

Today’s main applications
- Anti corrosion treatment of Al alloys (aircraft and automotive)
- Decorative surfaces (color coating)
- Electronics industry
- Template for nanowire fabrication

\begin{itemize}
\item \cite{5} F. Keller, M. S. Hunter, D. L. Robinson, J. Electrochem. Soc. 100, 411, 1953
\item \cite{6} G. D. Sulka, Nanostructured Materials in Electrochemistry, 2008
\item \cite{7} Anodizing, en.wikipedia.org/wiki/anodizing, 2014
\end{itemize}
Aluminum Anodizing
Electrochemical Reaction

Main anodizing reaction

Cathode: \(6 \text{H}_3\text{O}^+ + 6\text{e}^- \rightarrow 3 \text{H}_2 + 6 \text{H}_2\text{O}\)

Anode: \(2\text{Al} \rightarrow 2\text{Al}^{3+} + 6\text{e}^-\)
\(2\text{Al}^{3+} + 9\text{H}_2\text{O} \rightarrow \text{Al}_2\text{O}_3 + 6 \text{H}_3\text{O}^+\)

Overall: \(2\text{Al} + 3\text{H}_2\text{O} \rightarrow \text{Al}_2\text{O}_3 + 3\text{H}_2\)

Formation of Anions \(\text{OH}^-\) and \(\text{O}^{2-}\)

\(\text{O}^{2-}\) and \(\text{OH}^-\) ions formation at the oxide/electrolyte interface from water interaction with absorbed \(\text{SO}_4^{2-}\) anions \(^6\)

Aluminum Anodizing

Pore Formation

- Stages of pore formation
- Potential developing depends on the formation stages
- Crack initiation in the oxide barrier layer
- Local increase of current density results in pore formation

Top: Kinetics of porous oxide growth in galvanostatic regimes
Bottom: Stages of anodic porous oxide development

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Aluminum Anodizing
Pore Formation

- Stages of pore formation
- Potential developing depends on the formation stages
- Crack initiation in the oxide barrier layer
- Local increase of current density results in pore formation
- Volume expansion

Volume expansion observed during anodization of aluminum

Anodized aluminum on textured silicon surface

Local Anodizing
Previous Approaches for Contact Separation

- Well known local anodizing processes by masking (SiO$_2$ as mask$^{8,9}$, PL organic resists$^{9,10}$)

- Disadvantages
  - SiO$_2$ has to be structured expensively before anodizing
  - Patterned printed resists has to be removed in an extra step
  - Adhesion of printed resist could fail by volume expansion
  - Process speed is limited

- Local and fast anodizing process is desired to establish AAO in PV
Local Anodizing

Previous Approaches for Contact Separation

<table>
<thead>
<tr>
<th>Step</th>
<th>Process</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>PVD-Aluminum</td>
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<tr>
<td>2</td>
<td>PVD-TiW</td>
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<td>6</td>
<td>Resist removal</td>
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<td>7</td>
<td>Metal etching</td>
</tr>
</tbody>
</table>

1. • PVD-Aluminum
2. • Local Anodizing??
Novel Maskless Approaches
Metallic Elevations Stamp

- Wetting of elevations
  - Difficult process control
  - Expanded anodizing
  - Risk of short circuit
  - Short process duration (< 5 sec)
Novel Maskless Approaches
Local Sealing by Rubber

- Aluminum is locally shielded by a rubber seal
- Narrow lines are reached (< 70 µm)
- Short process duration (< 5 sec)
- Force application to wafer necessary
Novel Maskless Approaches

Electrochemical Screen Printing

- Advantages
  - Screen printing established in PV
  - Fast process (< 5 sec)
  - Narrow anodized line widths are realized (100-150 µm)

- Challenges
  - Special screen to provide current transport
  - Special emulsion (chemically resistive against acid pastes)
  - Acidic pastes still have to be optimized for printing
Novel Maskless Approaches
Electrochemical Dispensing

- Advantages
  - Small reaction zone
  - Excellent process control

- Challenges for further experiments
  - Line width > 200 µm
  - Line interruptions
Local Anodizing

Previous Approaches for Contact Separation

Replacement of three process steps by maskless local anodizing

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1. PVD-Aluminum
2. Local Anodizing
3. Zincate Process
4. Plating
Summary

- **Alternative efficient metal patterning processes** for back-contact solar cells are needed, especially for aluminum.

- **Anodizing of Aluminum introduced** in general, full layer localized anodizing suitable for PV application.

- **In-situ anodizing** via screen-printing or dispensing prove to be promising methods for high through-put industrial application.
Thank you for your Attention!

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