ELECTROCHEMICAL CONTACT SEPARATION FOR PVD ALUMINUM BACK CONTACT SOLAR CELLS

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Fraunhofer Institute for Solar Energy Systems ISE

5th Metallization Workshop

Constance, October 20th 2014

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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

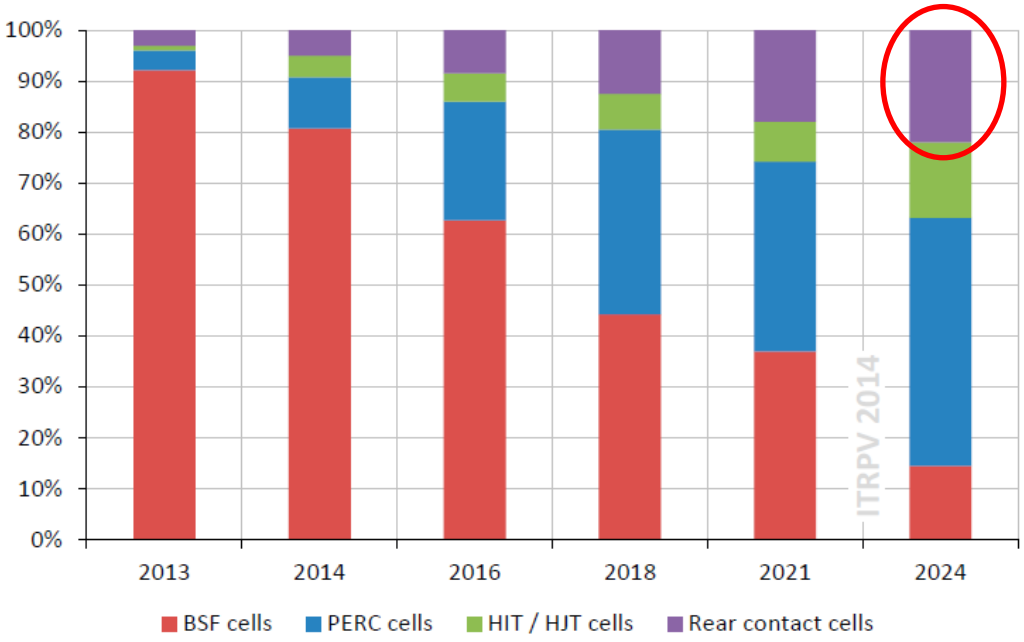
- Back contact solar cells
  - High efficiencies reached

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



[1] Panasonic HIT Solar Cell Achieves World`s Highest Energy Conversion Efficiency of 25,6% at Research Level, 04.2014
[2] D. D. Smith et. al. IEEE Journal of Photovoltaics, 2014.

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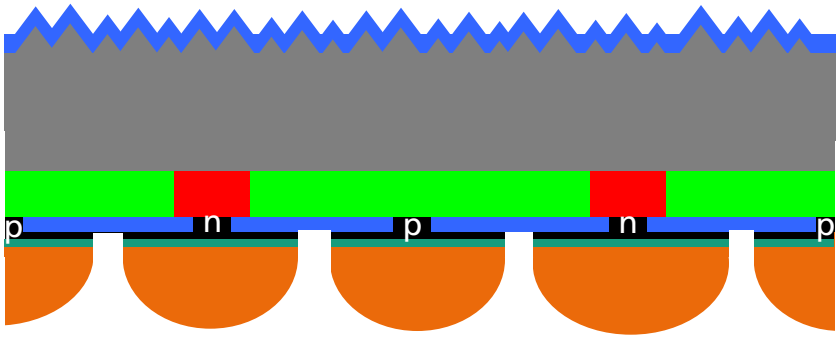
Metallization of IBC Solar Cells
Comparison of Process Steps

Established Process[3]

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



[3] W. P. Mulligan, Solar cell and method of manufacture, US 7897867 B1, 03.2011
[4] Kamp et al, Solar Energy Materials & Solar Cells, 2014

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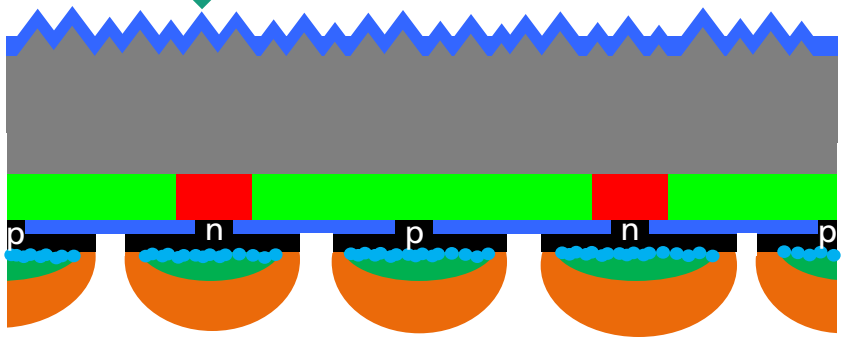
Alternative Maskless Process

1. PVD-Aluminum
2. Al structuring???
3. Zincate Process[4]
4. Plating



[3] W. P. Mulligan, Solar cell and method of manufacture, US 7897867 B1, 03.2011
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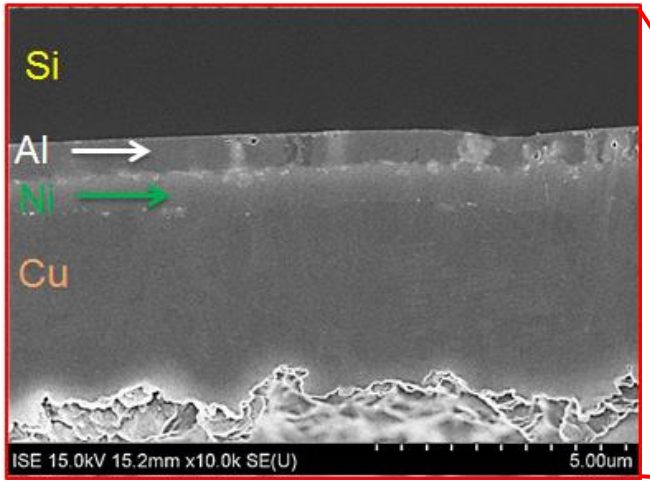

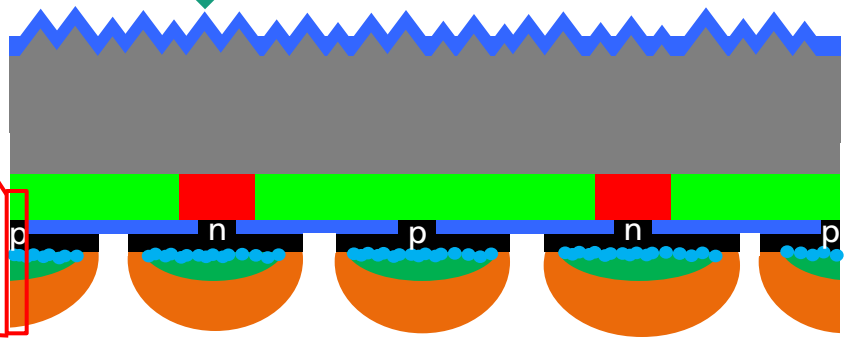

[3] W. P. Mulligan, Solar cell and method of manufacture, US 7897867 B1, 03.2011
[4] Kamp et al, Solar Energy Materials & Solar Cells, 2014

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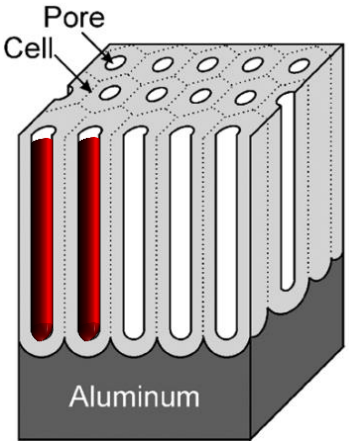
Aluminum Anodizing
Industrial Applications and Properties of AAO

- Aluminum can be converted into electrical isolating aluminum oxide by anodizing
- Structure of anodic aluminum oxide (AAO) first reported in 1953[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



Idealized structure of anodic porous alumina [6]


Anodized and dyed carabiners [7]

[5] F. Keller, M. S. Hunter, D. L. Robinson, J. Electrochem. Soc. 100, 411, 1953
[6] G. D. Sulka, Nanostructured Materials in Electrochemistry, 2008
[7] Anodizing, en.wikipedia.org/wiki/anodizing, 2014

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Aluminum Anodizing
Electrochemical Reaction

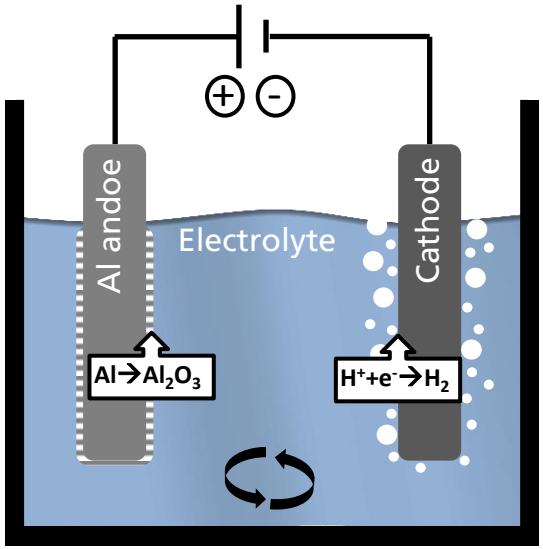
Main anodizing reaction

Cathode: $6\ H_3O^+ + 6e^- \rightarrow 3\ H_2 + 6\ H_2O$

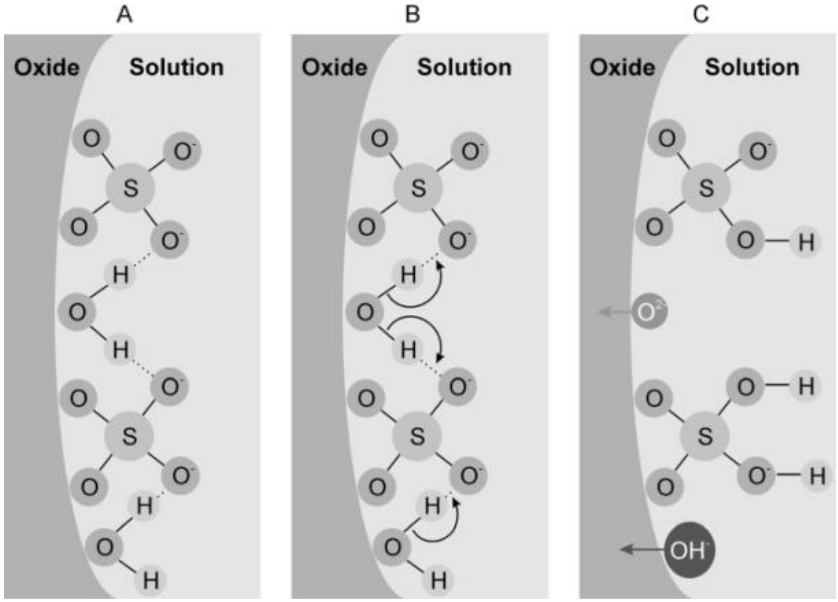
Anode: $2\ Al \rightarrow 2\ Al^{3+} + 6e^-$

$2\ Al^{3+} + 9\ H_2O \rightarrow Al_2O_3 + 6\ H_3O^+$

Overall: $2\ Al + 3\ H_2O \rightarrow Al_2O_3 + 3H_2$



Formation of Anions OH^- and O^{2-}



O^{2-} and OH^- ions formation at the oxide/elektrolyte interface from water interaction with absorbed SO_4^{2-} anions [6]

[6] G. D. Sulka, Nanostructured Materials in Electrochemistry, 2008

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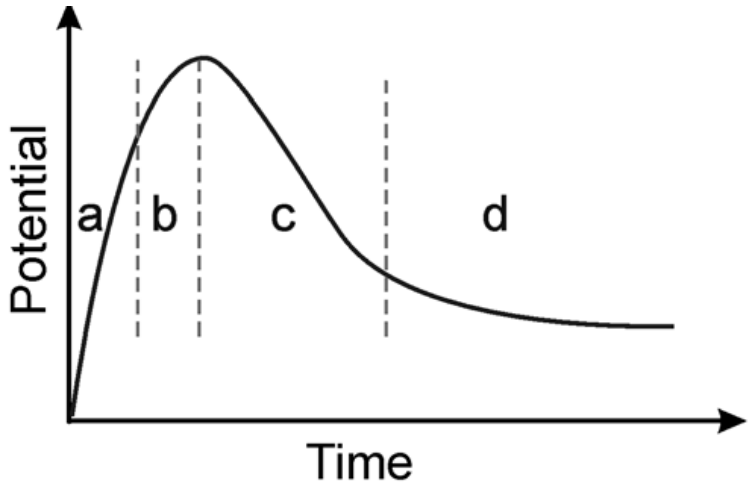
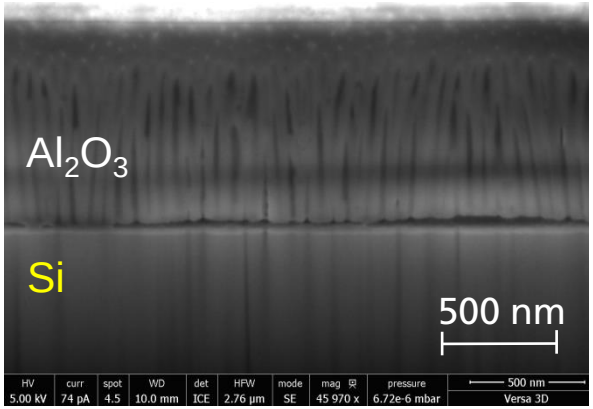
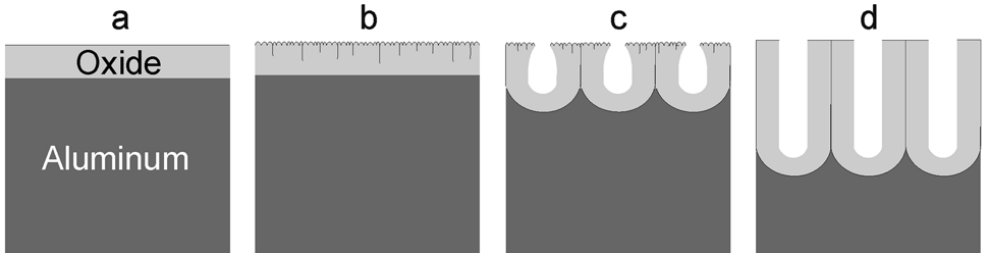
Aluminum Anodizing
Pore Formation

- 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







Top: Kinetics of porous oxide growth in galvanostatic regimes [6]

Bottom: Stages of anodic porous oxide development [6]

[6] G. D. Sulka, Nanostructured Materials in Electrochemistry, 2008

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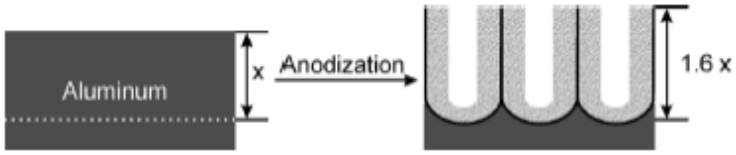
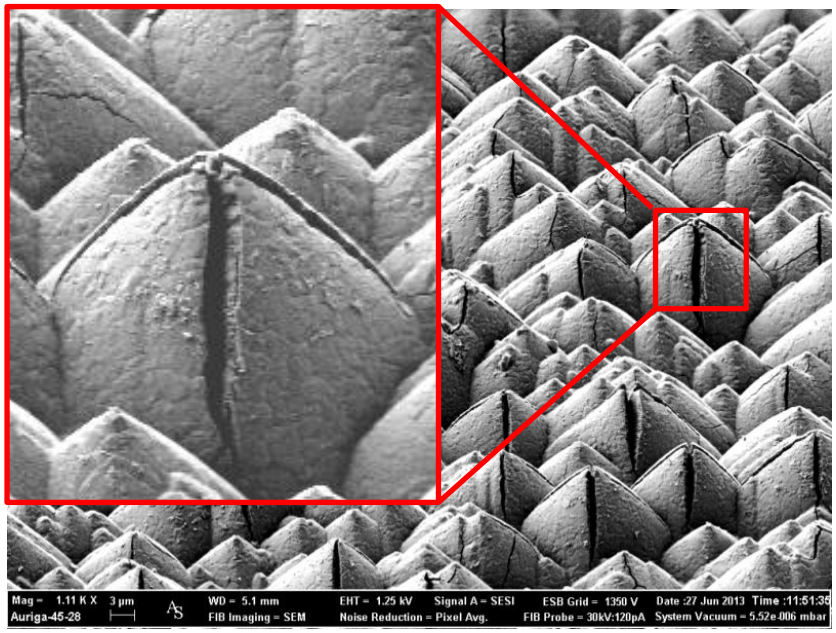
Aluminum Anodizing
Pore Formation

- 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 [6]



Anodized aluminum on textured silicon surface

[6] G. D. Sulka, Nanostructured Materials in Electrochemistry, 2008

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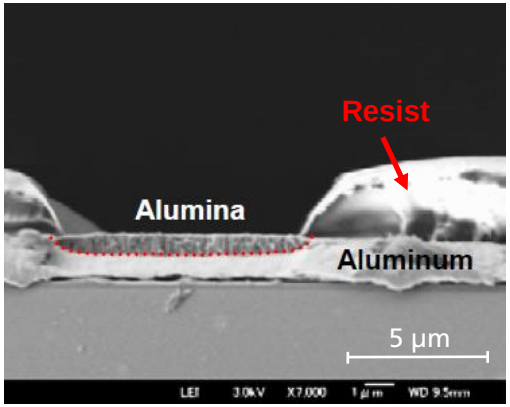
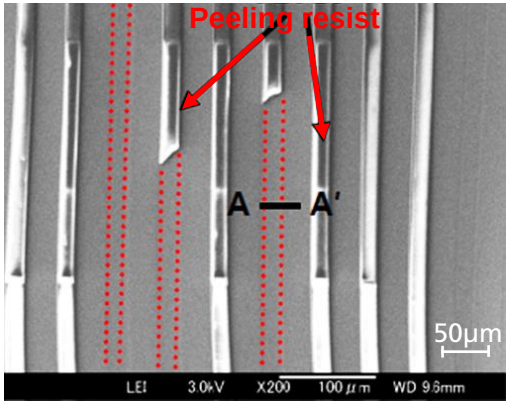
Local Anodizing
Previous Approaches for Contact Separation

- 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



Anodized masked sample after 20 min [9]



Printed resist after anodizing [9]

[8] P. Verlinden, Multilevel Metallization for Large Area Point-Contact Solar Cells, 1988
[9] J. Park, Fabrication of Aluminum/Alumina Patterns using Localized Anodization of Al., 2012
[10] P. H. Lu, Selective Anodization, 40th IEEE, 2014

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Local Anodizing

Previous Approaches for Contact Separation

1. PVD-Aluminum
2. PVD-TiW
3. PVD-Copper
4. Resist printing
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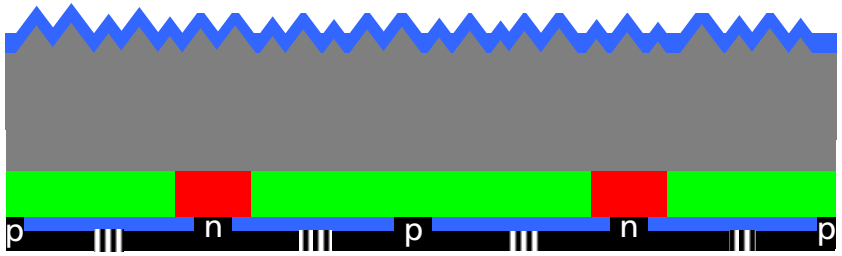

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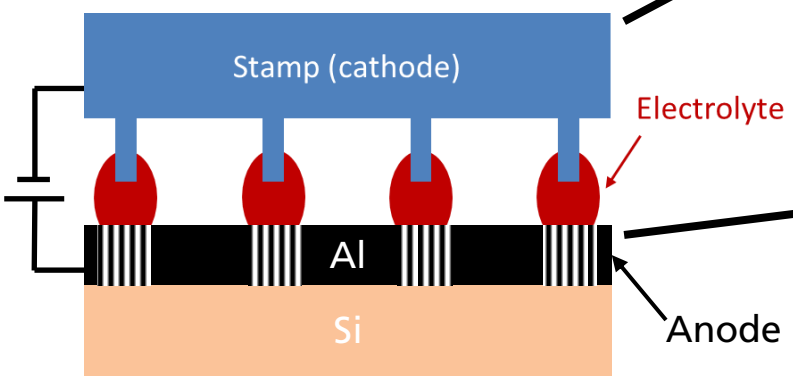
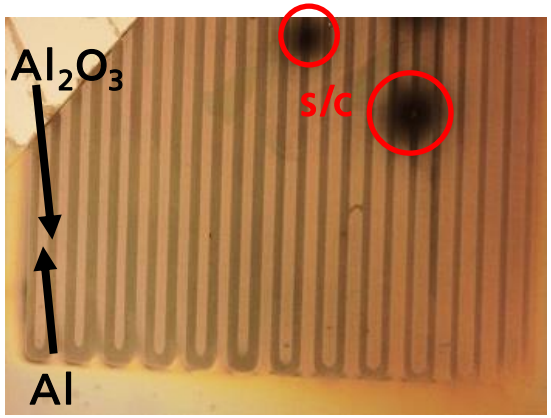
Novel Maskless Approaches
Metallic Elevations Stamp

- Wetting of elevations
  - Difficult process control
  - Expanded anodizing
  - Risk of short circuit
  - Short process duration (< 5 sec)





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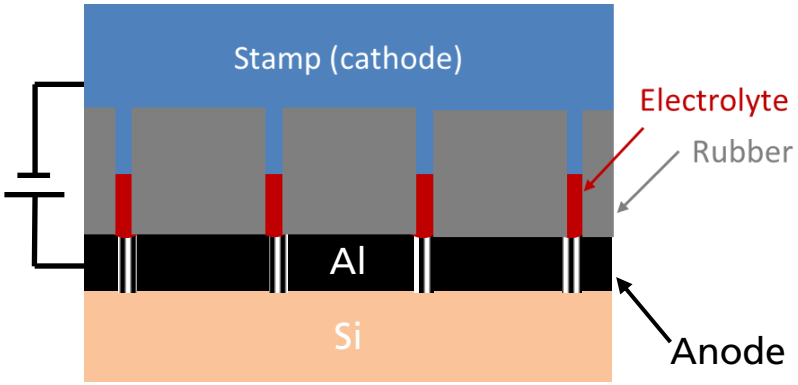
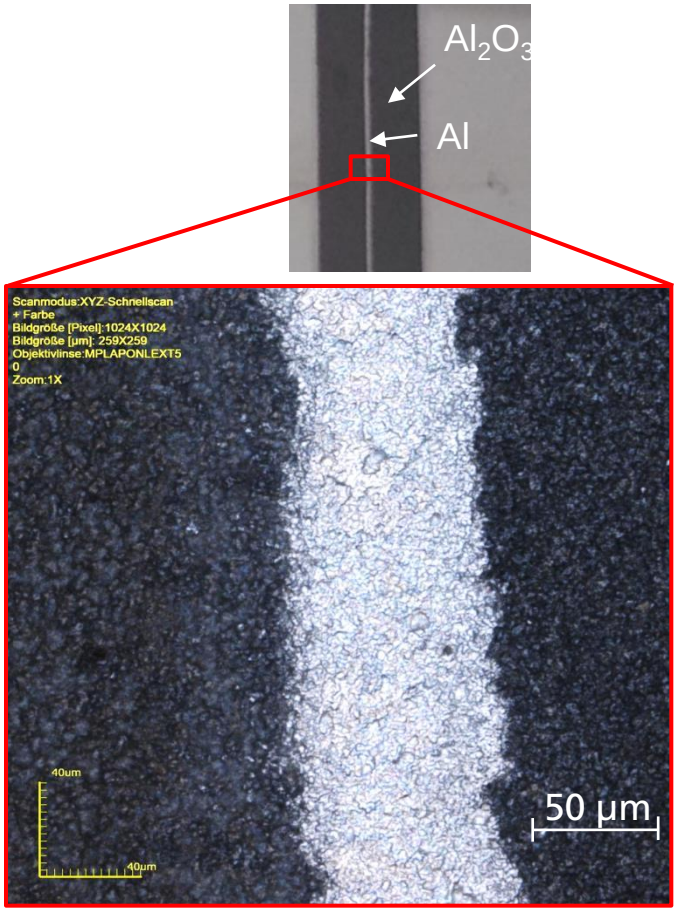
Novel Maskless Approaches
Local Sealing by Rubber

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





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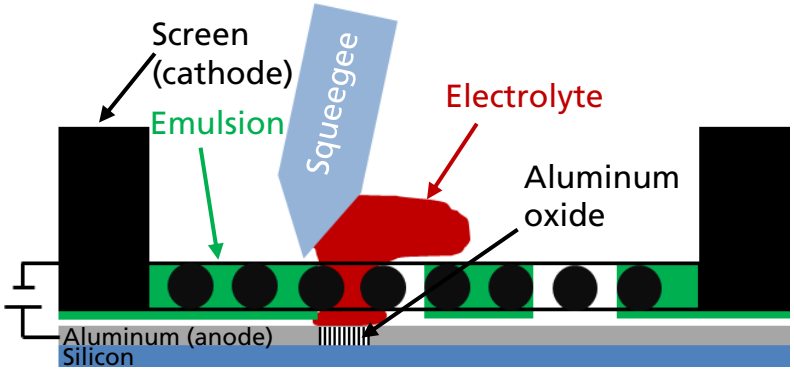
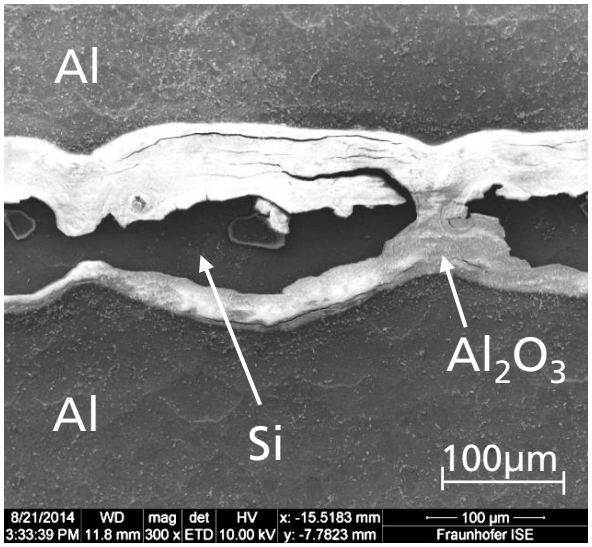
Novel Maskless Approaches
Electrochemical Screen Printing

- 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





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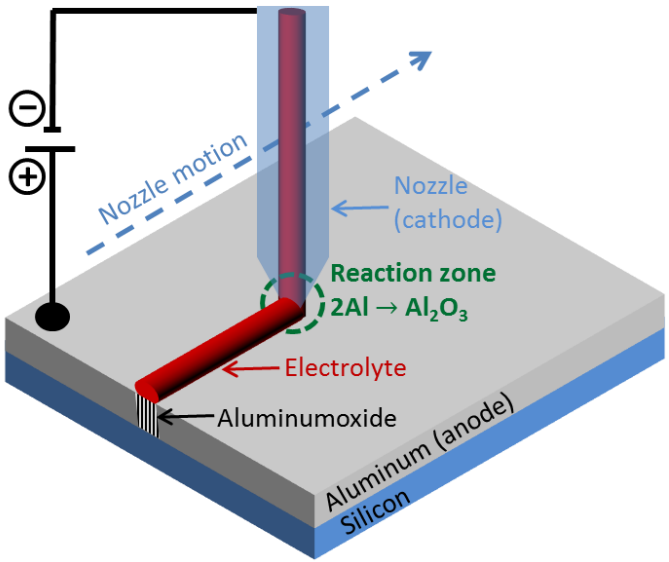
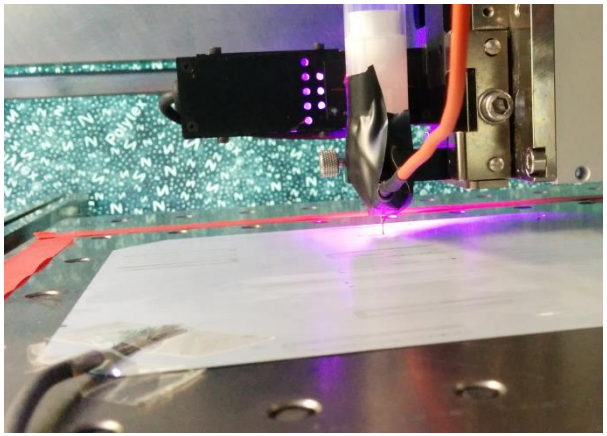
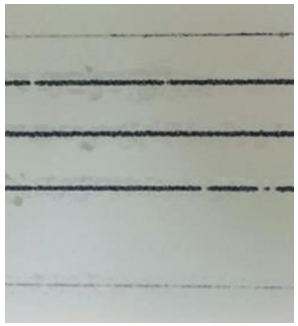
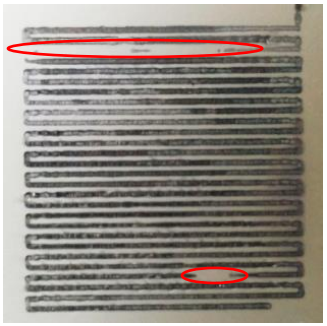
Novel Maskless Approaches
Electrochemical Dispensing

- Advantages
  - Small reaction zone
  - Excellent process control
- Challenges for further experiments
  - Line width > 200 µm
  - Line interuptions









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Local Anodizing
Previous Approaches for Contact Separation

Replacement of three process steps by maskless local anodizing

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

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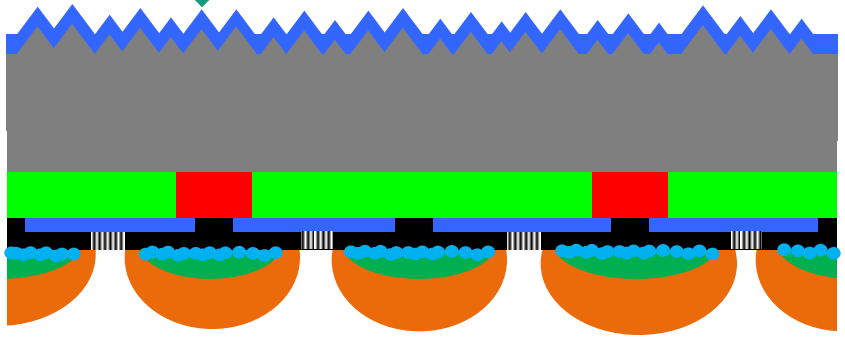
2. Local Anodizing
3. Zincate Process[4]
4. Plating



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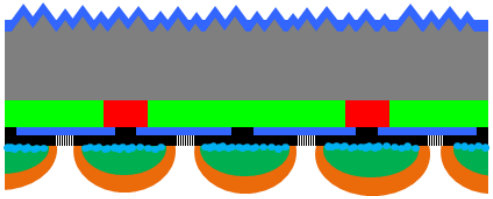
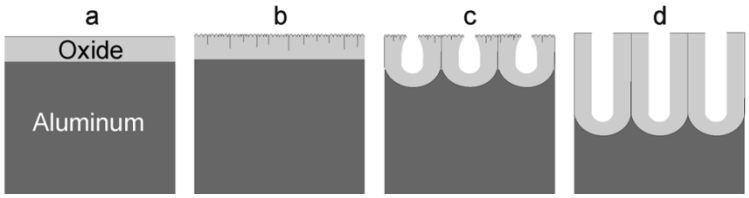
Summary

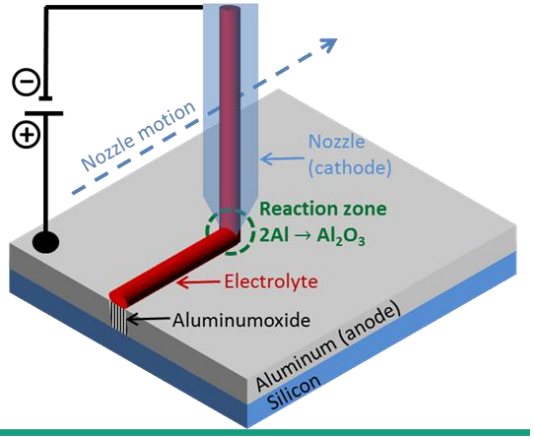
- **Alternative** efficient **metal patterning processes** for back-contact solar cells are **needed**, especially for aluminum

- **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**







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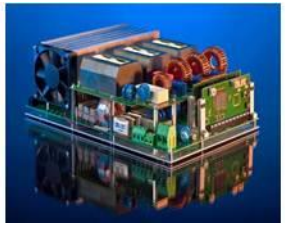
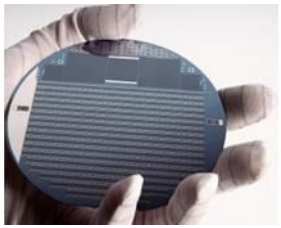
Thank you for your Attention!

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