CHARACTERIZATION OF COPPER DIFFUSION IN SILICON SOLAR CELLS

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Introduction

- Copper front-side metallization based on a fine line screen-printed silver seed-layer

+ Lower material costs (silver consumption < 16 mg/cell front-side\(^1\))
+ Inline capable (screen printing + light induced plating), little alterations to existing production lines
+ Comparable efficiency potential

- One of the open questions:
  - Long term stability

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Cu Migration through SiN\textsubscript{x} Layers\textsuperscript{2}
Experiment with Lifetime Samples

- Symmetric lifetime samples:
- Variated pre-treatment: HF-Dip (1\%, 30 sec.)
- Nitride variation: inline PECVD, sputtered, batch PECVD, Al\textsubscript{2}O\textsubscript{3} reference
- Copper evaporation (200-300 nm)
- Copper diffusion (Hotplate 300°C/500h)
- Characterization of copper diffusion using carrier lifetime (QSSPC) and photoluminescence imaging
Copper Migration through SiN$_x$ Layers
Photoluminescence Results

- PL-images at one sun
- samples without pre-treatment
- Al$_2$O$_3$ reference group show Cu influence on carrier life time
- All nitrides resist Cu diffusion without pre-treatment

<table>
<thead>
<tr>
<th></th>
<th>Al$_2$O$_3$</th>
<th>Inline PECVD</th>
<th>Sputtering</th>
<th>Batch PECVD</th>
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<tbody>
<tr>
<td>Initial state</td>
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<td>After Cu + thermal anneal</td>
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![Image showing PL images at one sun and after Cu + thermal anneal for different deposition methods](image-url)
Copper Migration through SiN$_x$ Layers
Lifetime Measurement (QSSPC)

- Al$_2$O$_3$ reference group show Cu influence on carrier lifetime
- Inline PECVD and sputtered nitride resist Cu diffusion even with HF-dip and screen printing
- Batch PECVD nitride allows Cu diffusion after HF-Dip and screen printing
Effectiveness of Nickel Diffusion Barrier\(^2\) Degradation of Cells

- Standard 156x156 mm\(^2\) cells with different nickel diffusion barrier masses (10-40 mg per wafer)
  - 10 mg \(\approx 0.1 \mu m\)
  - 20 mg \(\approx 0.2 \mu m\)
  - 30 mg \(\approx 0.4 \mu m\)
  - 40 mg \(\approx 0.6 \mu m\)

- Thermal stress at 200°C, 225°C, 250°C and 275°C on hotplates

- Characterization of the pFF\(^4\)


\(^3\) J. Bartsch et al., 21.8 % efficient n-type solar cells with industrially feasible plated metallization, 4th International Conference on Silicon Photovoltaics, ’s-Hertogenbosch, the Netherlands, 2014

Effectiveness of Nickel Diffusion Barrier Degradation of Cells – pFF Characterization

- More plated nickel leads to slower cell degradation
Effectiveness of Nickel Diffusion Barrier
Degradation of Cells – Arrhenius Plot

→ No long term stability issues due to Cu migration expected for a nickel diffusion barrier with > 20 mg plated nickel
Effectiveness of Nickel Diffusion Barrier Module Degradation

- Damp heat test 1500 h (85°C, 85% r. h.) according to IEC 61215
- Only the module without nickel diffusion barrier shows a degradation of 1.2%
- Electroluminescence measurements confirm these results

→ Even the module without diffusion barrier passes IEC criteria damp heat test

→ Copper not critical?

→ IEC procedure not suitable to show copper impact on module?
Effectiveness of Nickel Diffusion Barrier
Comparison Cell Degradation – Module Degradation

- Cell degradation at pFF loss of 0.25 % (black marks) compared to module degradation (red mark)
- First hint that degradation method on cell level is able to predict degradation on module level
- Result restricted by statistics → only one data point

→ Predicted long term stability on cell level shows good accordance with measured module degradation after 1500 h damp heat test.
Influencing Factors of Cell Degradation

- Degradation of cells with screen-printed Ag-seed-layers using different pastes
- Metallized area is varied
  - Degradation depends on the used seed-layer

### Paste 1
- 1 μm
- 47 μm

### Paste 2
- 9 μm
- 59 μm

### Paste 3
- 3 μm
- 100 μm

![Graph showing ln(t/s) vs. 1000/T]
Influencing Factors of Cell Degredation

Firing Temperature

- Degradation of cells with seed-layer firing temperatures of 860°C, 890°C, and 920°C
- Higher firing temperature leads to faster cell degradation

![Graph showing ln(t/s) vs. 1000/T for different firing temperatures and Ni contents.](image)
Summary

- Silicon nitride stops copper diffusion even after HF-Dip and screen printing
- 20 mg nickel effectively hinders Cu diffusion on the tested seed-layer
- Long term stability predicted by cell degradation shows accordance with module degradation
- Degradation behaviour of copper also depends on the seed-layer and the firing temperature
Thank you for your Attention!

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