CHARACTERIZATION OF COPPER DIFFUSION IN SILICON SOLAR CELLS

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5th Metallization Workshop

Constance, October 21st 2014

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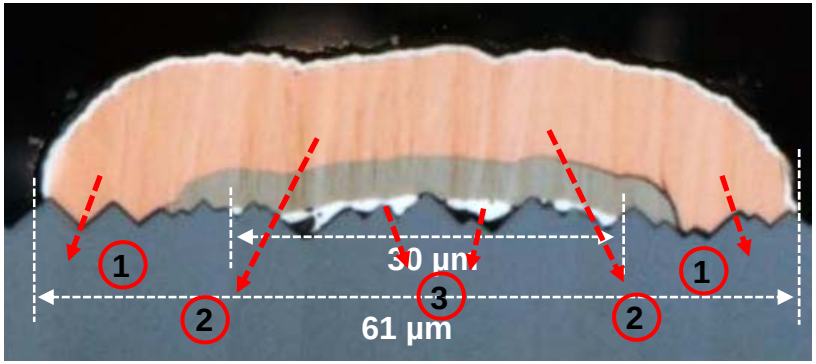
Introduction

- 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

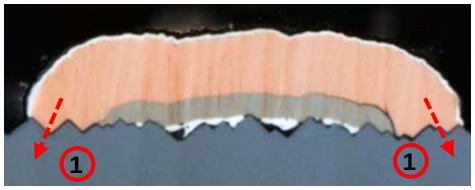
+ Comparable efficiency potential

- One of the open questions:
  - **Long term stability**

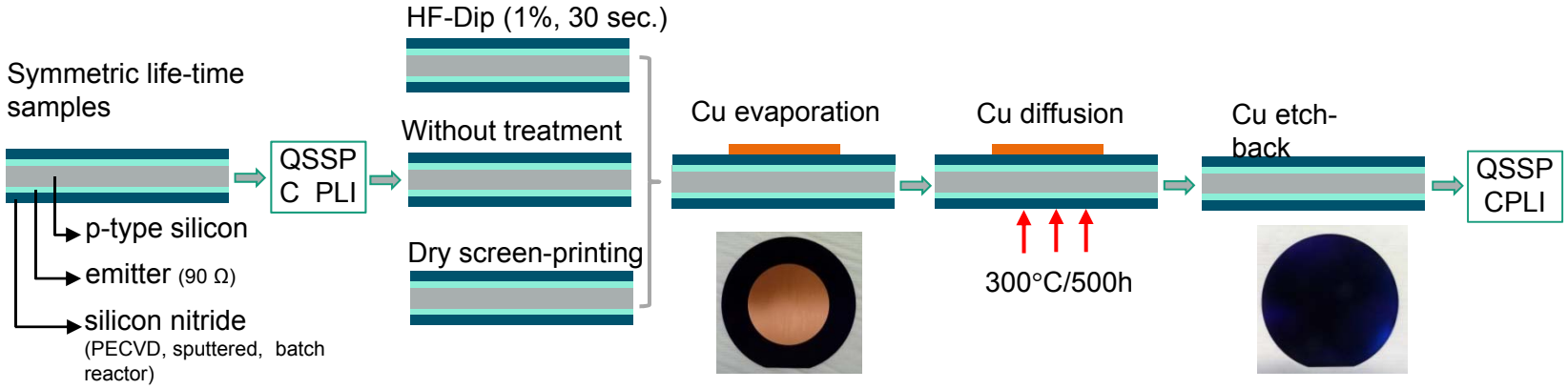
[1] A. Kraft et. al. *Long Term Stability Analysis of Copper Front Side Metallization for Silicon Solar Cells, 4th* International Conference on Silicon Photovoltaics, ´s-Herzogenbosch, Netherlands, 2014

Cu Migration through SiN_x Layers[2]

Experiment with Lifetime Samples



- Symmetric lifetime samples:
  - FZ, p-type wafers; emitter (90 Ω); random pyramid texture
- Varied pre-treatment: - HF-Dip (1%, 30 sec.)
  - dry screen-printing (100 N squeegee pressure)
  - Nitride variation: inline PECVD, sputtered, batch PECVD, Al_2O_3 reference
- Copper evaporation (200-300 nm)
  - Firing (900°C; inline furnace)
- Copper diffusion (Hotplate 300°C/500h)
- Characterization of copper diffusion using carrier lifetime (QSSPC) and photoluminescence imaging
- Copper etch back (Piranha etch)



[2] A. Kraft et. al. *Long Term Stability of Copper Front Side Contacts for Crystalline Silicon Solar Cells,* submitted to the Journal of Solar Energy Materials & Solar Cells

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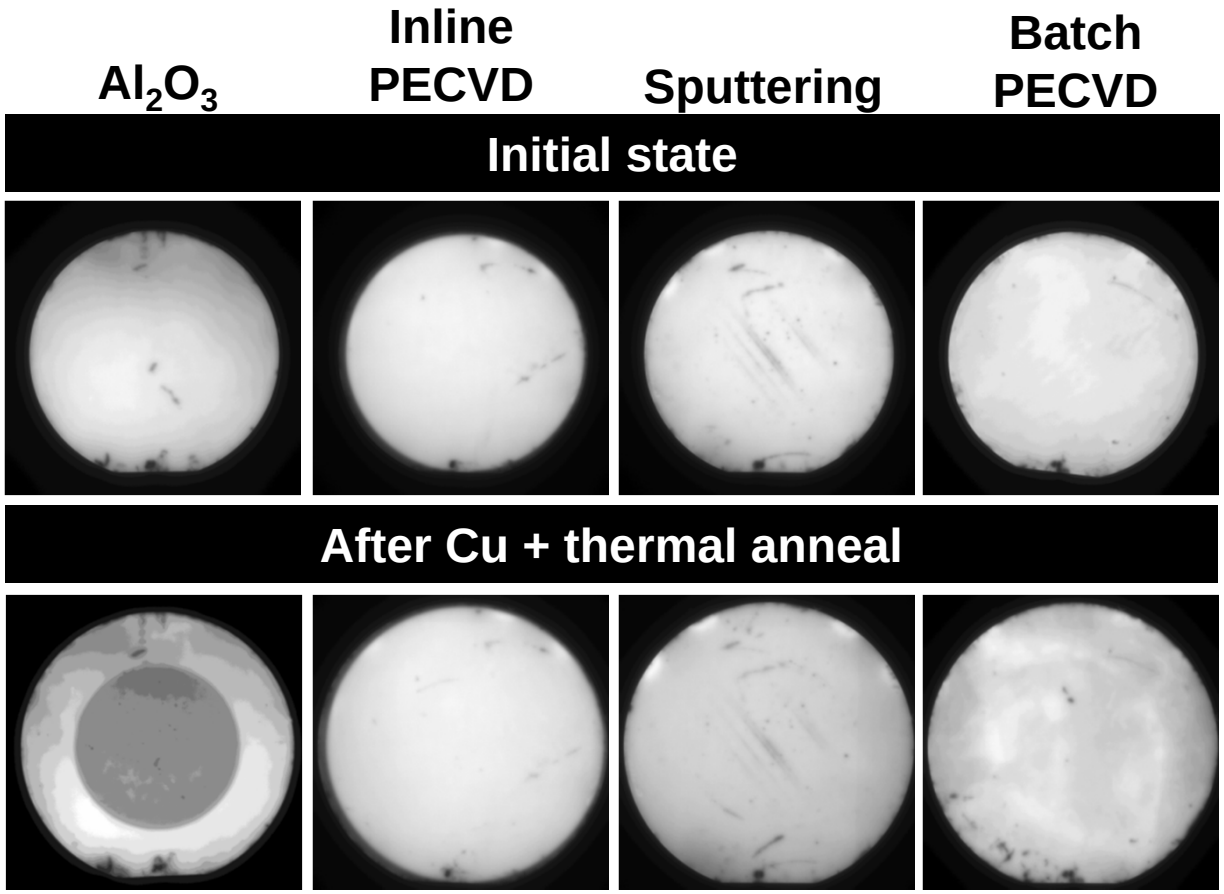
Copper Migration through SiN_x Layers
Photoluminescence Results

- PL-images at one sun
- samples without pre-treatment
- Al_2O_3 reference group show Cu influence on carrier life time
- All nitrides resist Cu diffusion without pre-treatment



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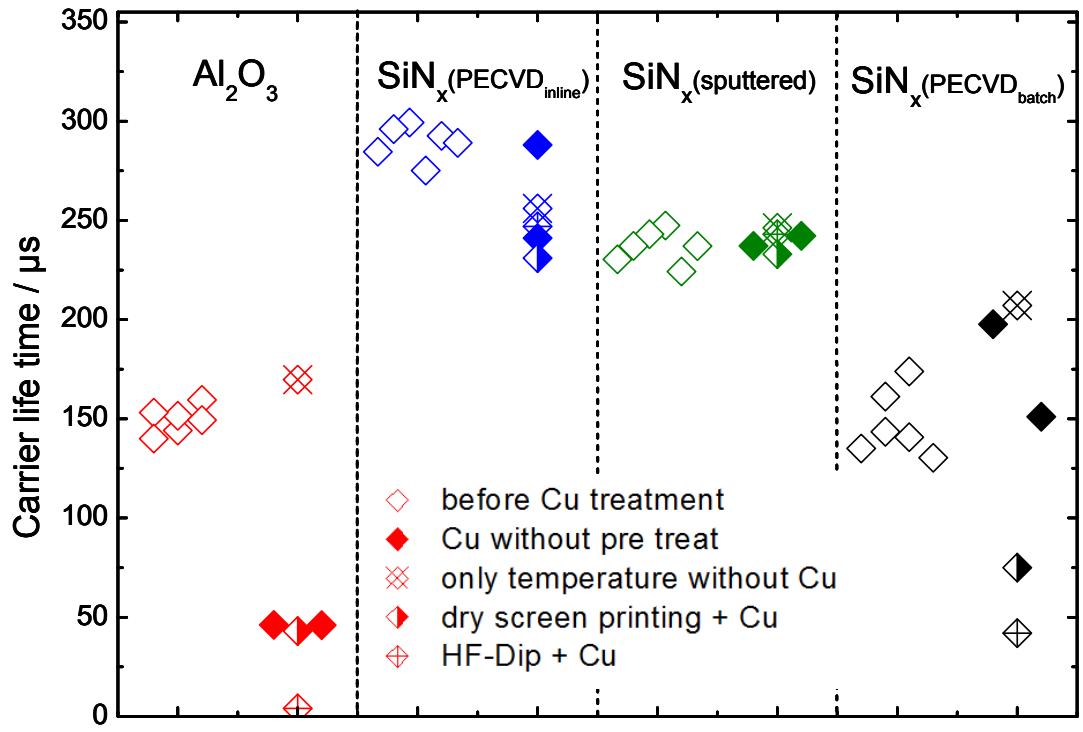
Copper Migration through SiN_x Layers
Lifetime Measurement (QSSPC)

- Al_2O_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



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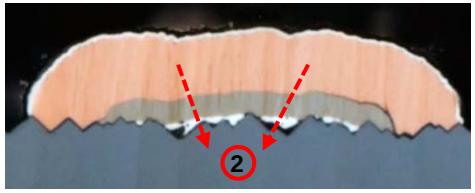
Effectiveness of Nickel Diffusion Barrier[2]
Degradation of Cells



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

  measured in the middle of the cell at the busbar
  → area with the lowest thickness[3]
- Thermal stress at 200°C, 225°C, 250°C and 275°C on hotplates
- Characterization of the pFF[4]

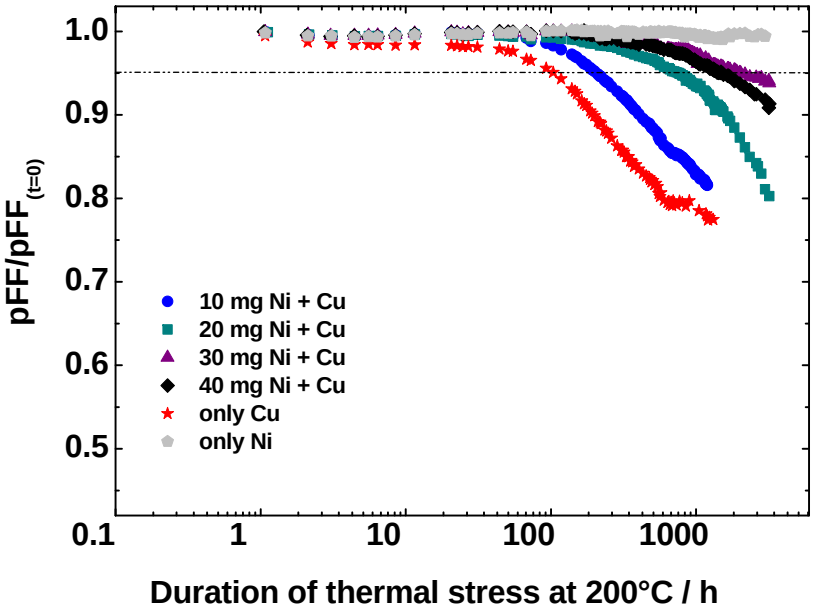
[2] A. Kraft et. al. *Long Term Stability of Copper Front Side Contacts for Crystalline Silicon Solar Cells,* submitted to the Journal of Solar Energy Materials & Solar Cells

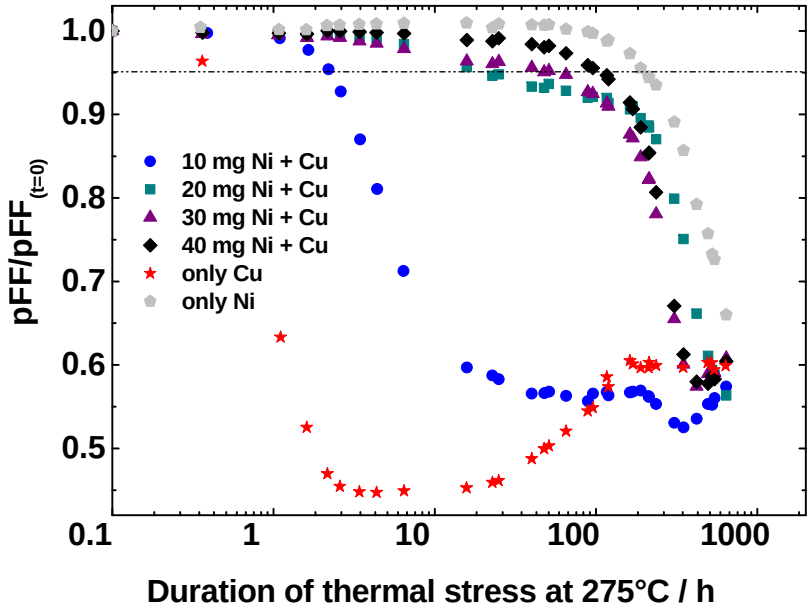
[3] J. Bartsch et.al., *21.8 % efficient n-type solar cells with industrially feasible plated metallization, 4th* International Conference on Silicon Photovoltaics, ´s-Hertogenbosch, the Netherlands, 2014

[4] J. Bartsch et.al., *Quick determination of copper-metallization long term impact on silicon solar cells*, J. Electrochem. Soc., volume 157(10): pp. H942-946 (2010)

Effectiveness of Nickel Diffusion Barrier

Degradation of Cells – pFF Characterization





- More plated nickel leads to slower cell degradation

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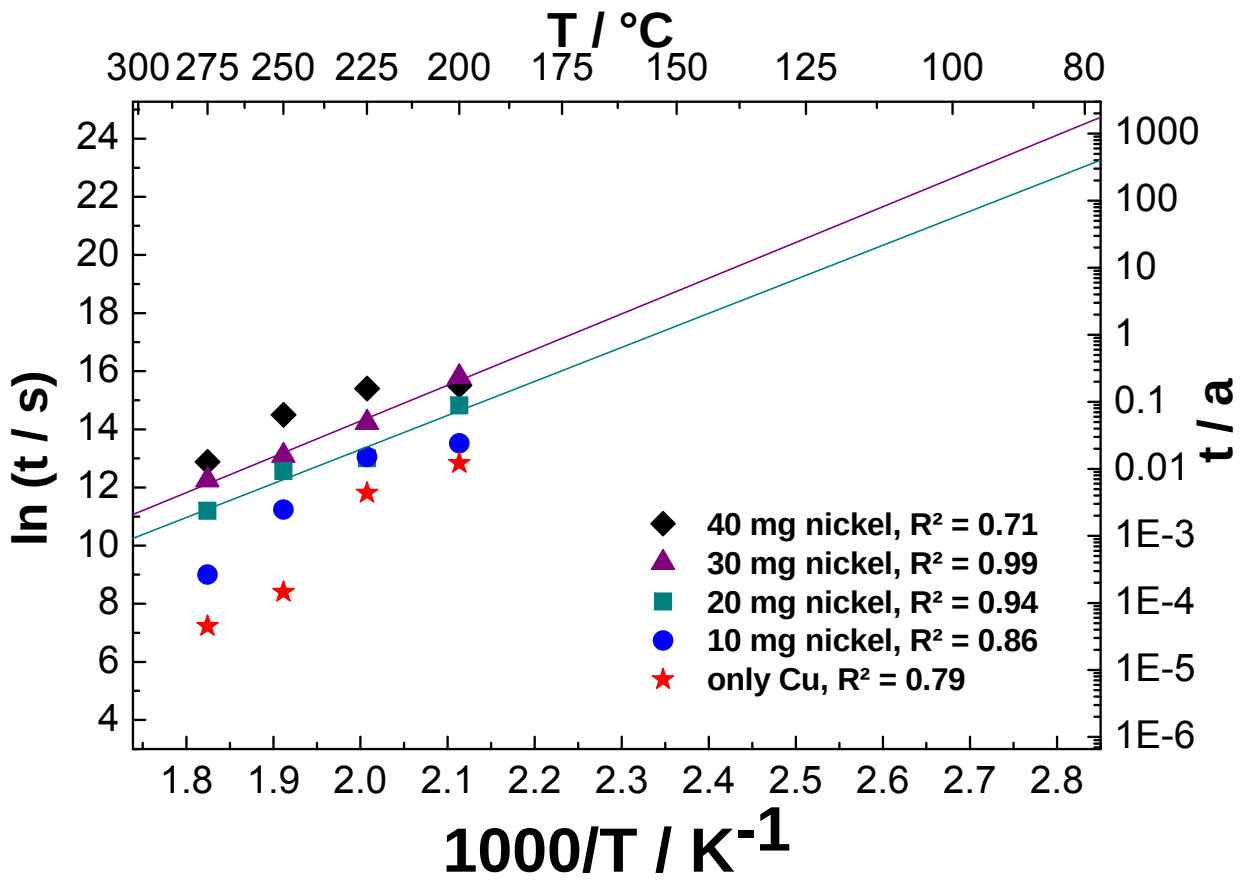
Effectiveness of Nickel Diffusion Barrier

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



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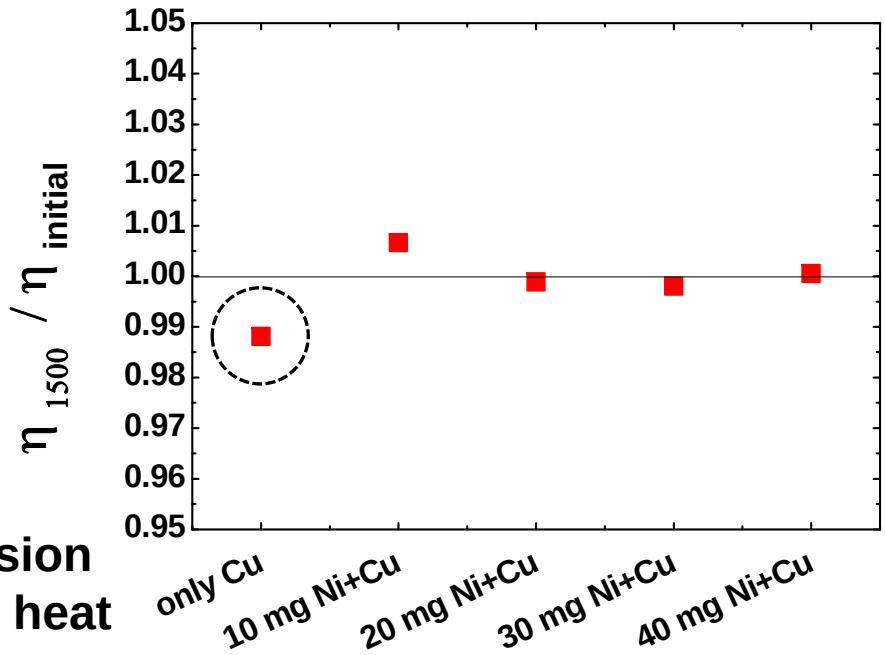
Effectiveness of Nickel Diffusion Barrier
Module Degradation

- 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?*

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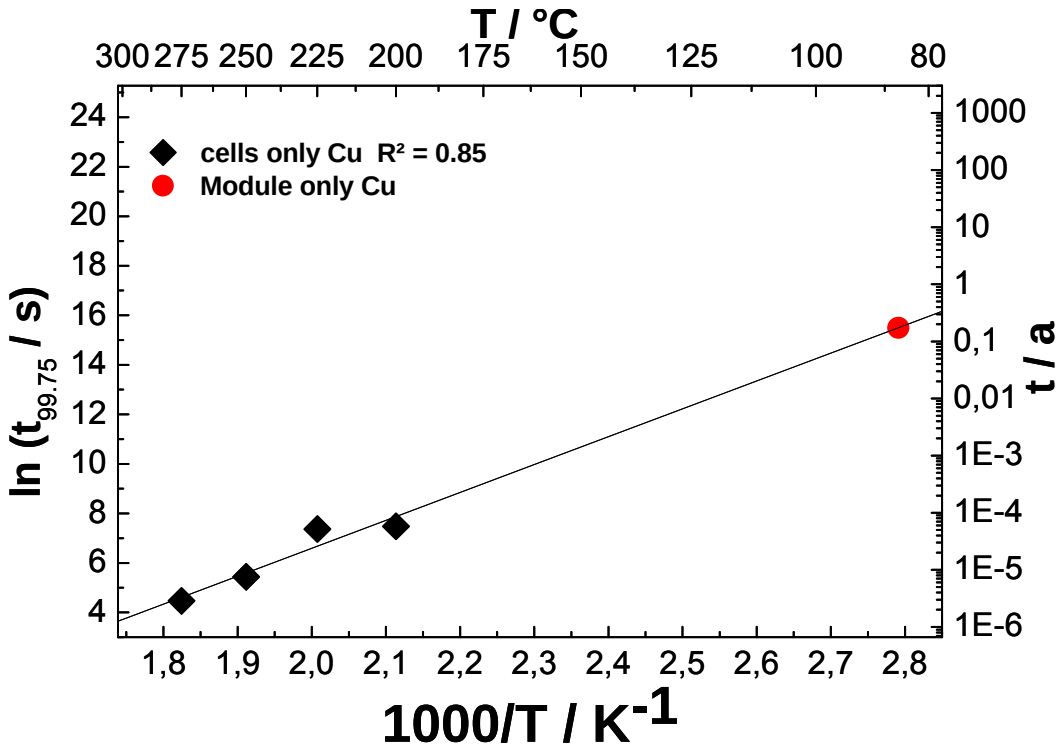
Effectiveness of Nickel Diffusion Barrier

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.**

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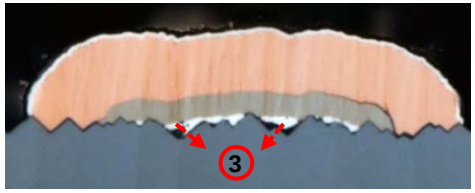
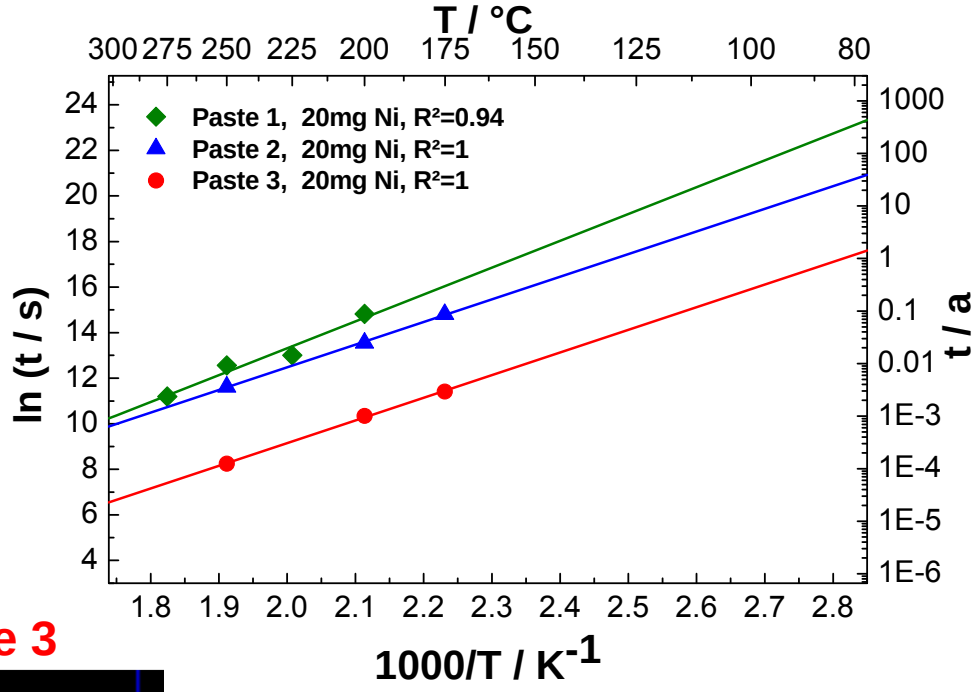
Influencing Factors of Cell Degradation
Seed-layer

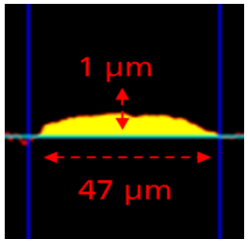


- Degradation of cells with screen-printed Ag-seed-layers using different pastes
- Metallized area is varied

→ Degradation depends on the used seed-layer



Paste 1



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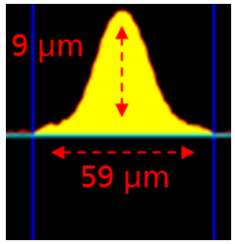

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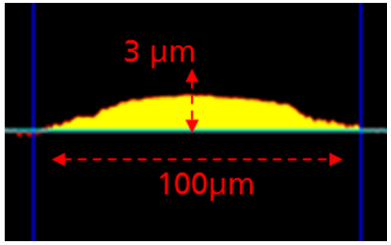

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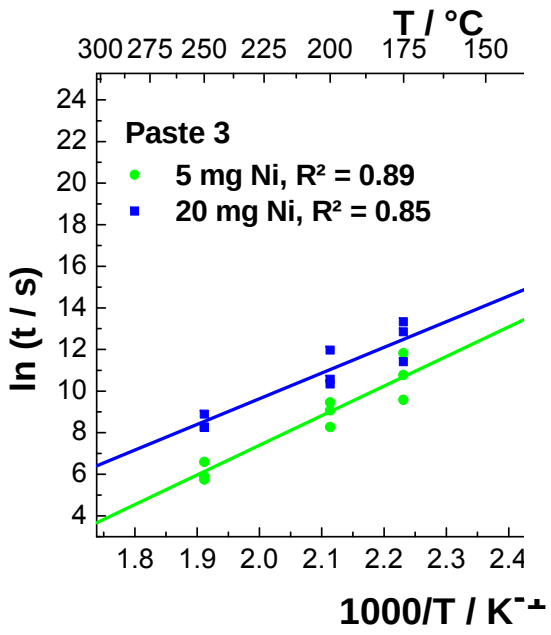
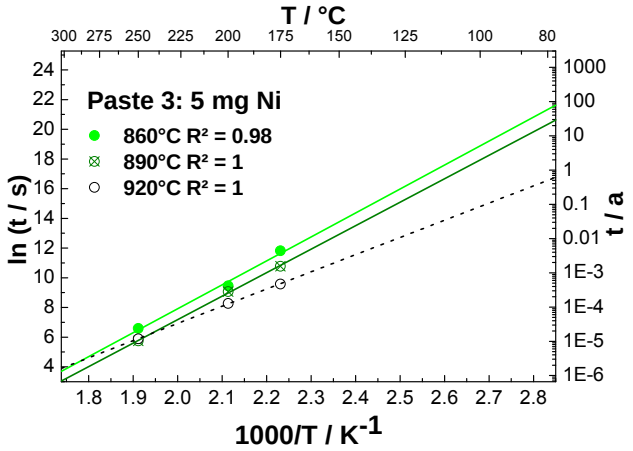
Influencing Factors of Cell Degradation

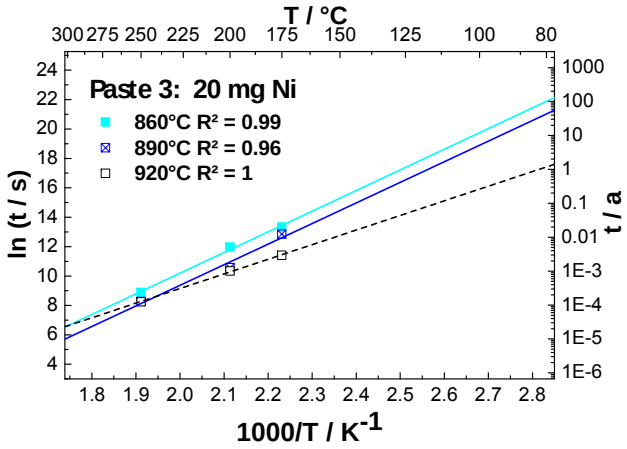
Firing Temperature

- Degradation of cells with seed-layer firing temperatures of 860°C, 890°C, and 920°C

→ Higher firing temperature leads to faster cell degradation







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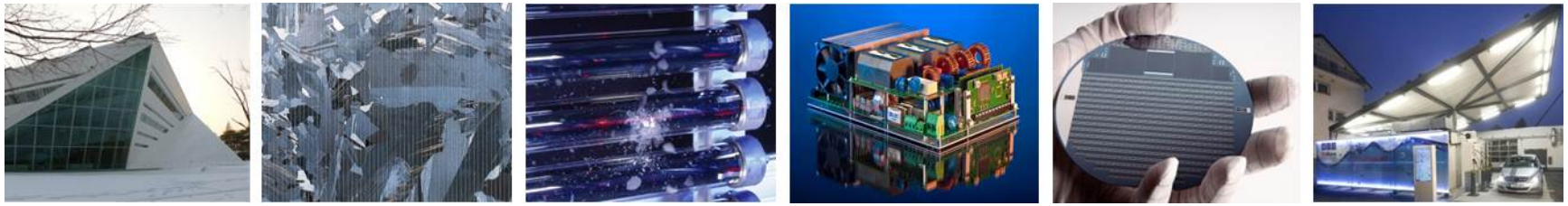
Summary

- 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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