Contact adhesion of plated contacts on industrial TOPCon rear sides – Microstructure analysis and module integration

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Metallization and Interconnection Workshop

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Motivation

Copper instead of silver

PV market will consume most of the silver reserves by 2050 in Tera Watt scenario [1]

→ Current all time high of silver price

Copper challenging in high temperature screen printing application (contamination, defects, …)

Copper Plating can replace silver completely for TOPCon solar cells

Why is Plating not used for solar cell metallization?

[1] Hallam, B., Kim, M., Zhang, Y., Wang, L., Lennon, A., Verlinden, P., Altermatt, P.P., Dias, P.R. (2023) The silver learning curve for photovoltaics and projected silver demand for net-zero emissions by 2050.

Showstoppers for Plating on TOPCon?

Current work @ISE

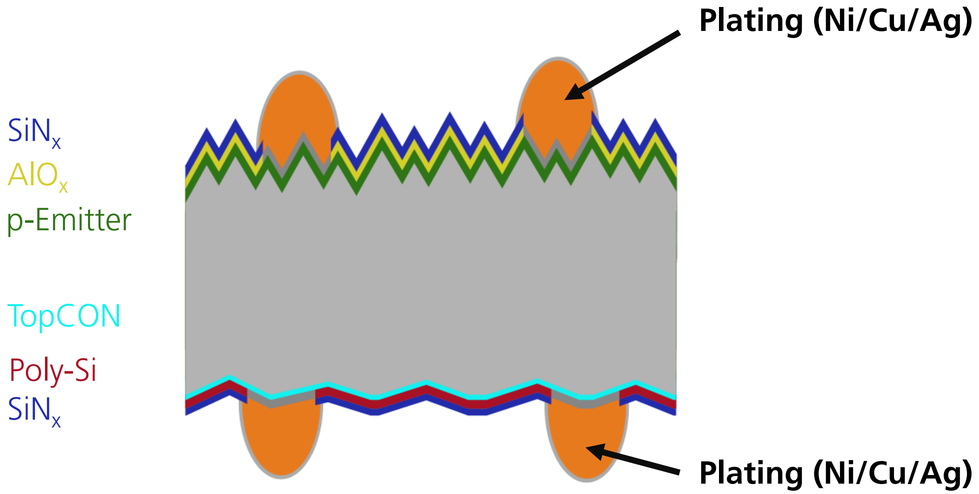
Frontside:

V_{OC} loss caused by contact recombination $J_{0,met,LCO}$

Rearside:

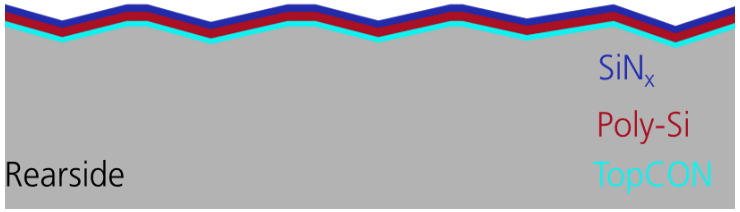
Module reliability

Mechanical contact adhesion



Mechanical Contact Adhesion

Tape test results



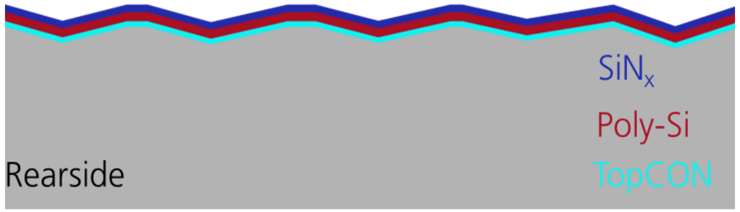
Experiment:

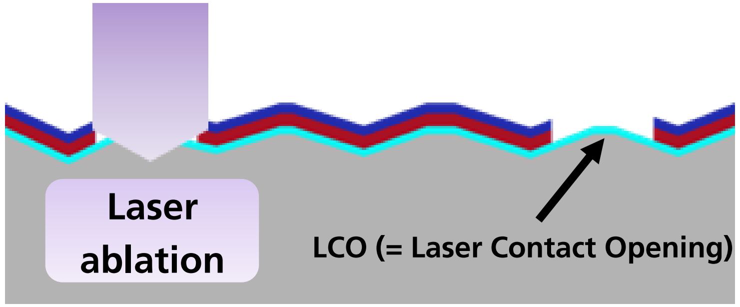
Mechanical Contact Adhesion

Tape test results

Experiment:

LCO on different industry & internal precursors





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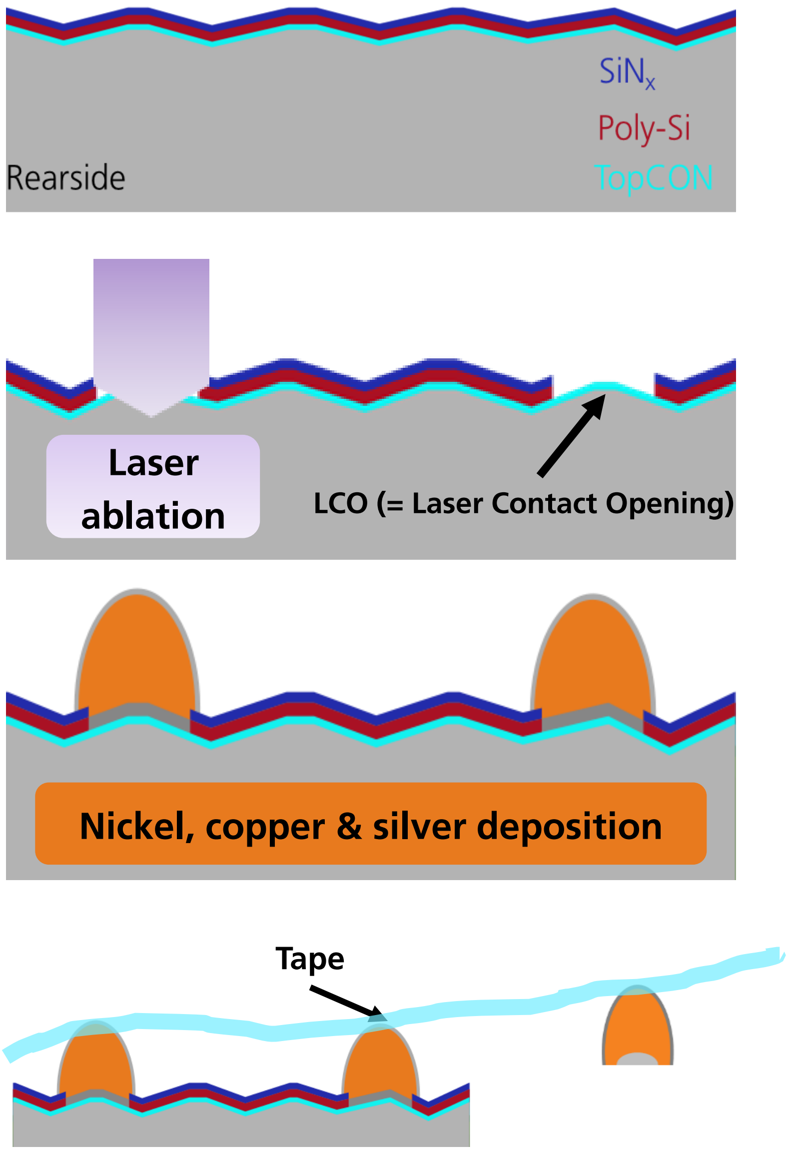
Tape Test (4 stripes, fingers only)



Mechanical Contact Adhesion

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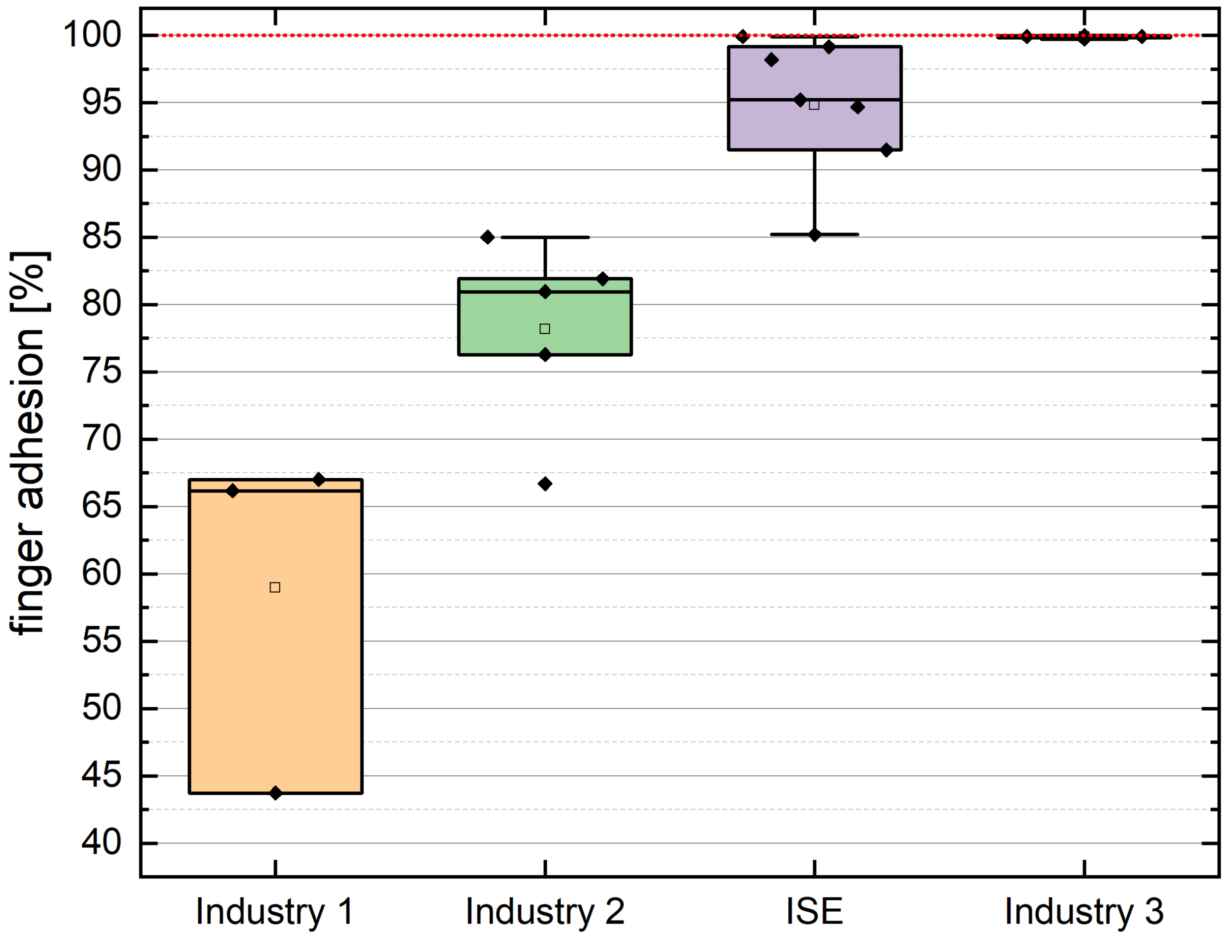
Experiment:

LCO on different industry & internal precursors

Tape Test (4 stripes, fingers only)

Counting remaining fingers = finger adhesion [%]

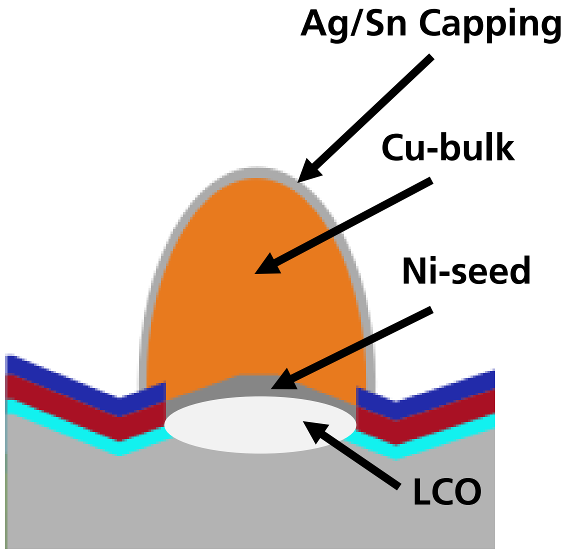
→ What is difference between the Precursors?



Rear-side Challenge

Mechanical contact adhesion

What are the influences on contact adhesion?



Rear-side Challenge

Mechanical contact adhesion

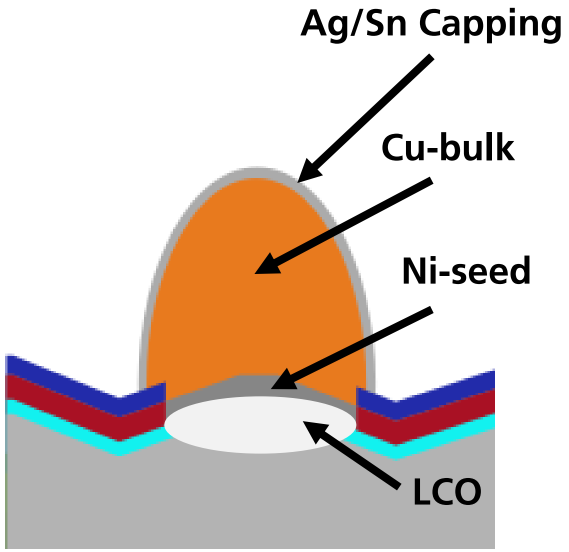
What are the influences on contact adhesion?

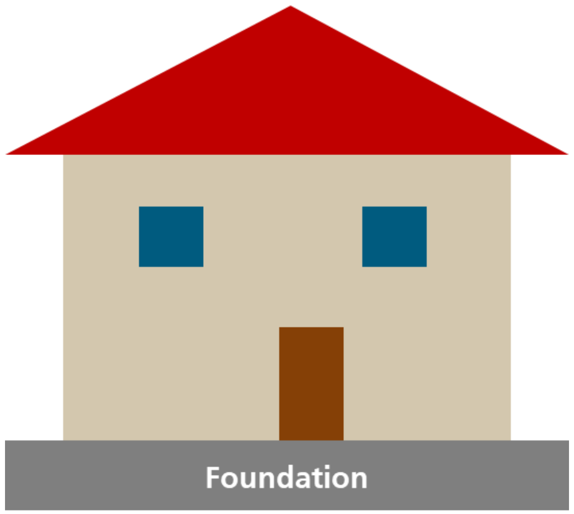
Laser Contact opening (= foundation interface)

- Laser source
- Beam shape (e.g. Top-Head, Gaus)
- Overlap

Precursor (= foundation material)

- Layer composition (SiNx, AlOx,…?)
- Rear side morphology





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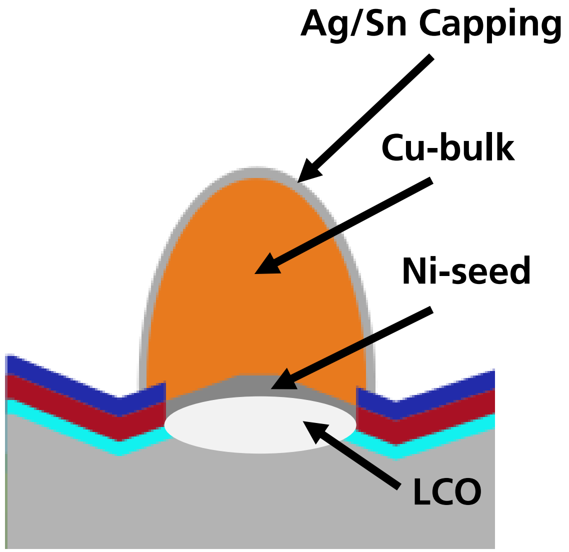

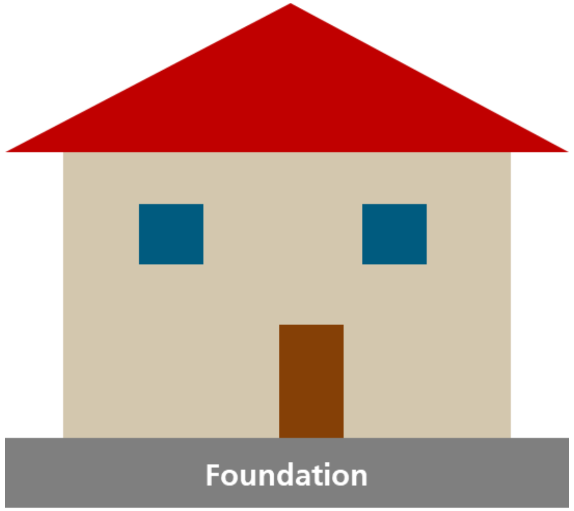

Finger composition (= house weight and stability)

- Ni layer thickness, finger thickness
- Internal stress

Process timings (= construction work)

- Oxide layer between Ni-Cu
- Oxide layer between Si-Ni

Rear-side Challenge

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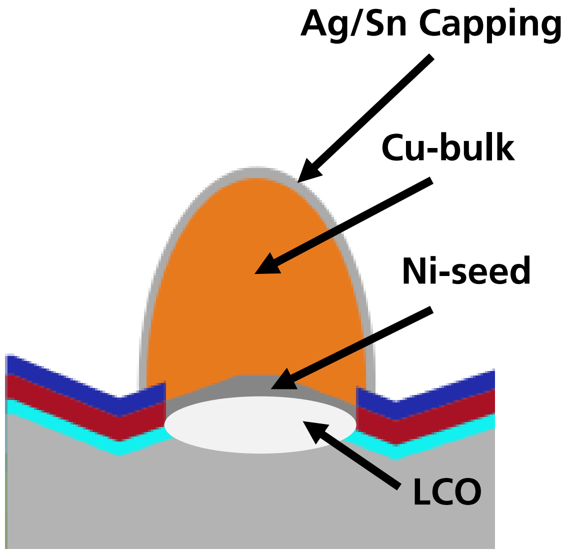

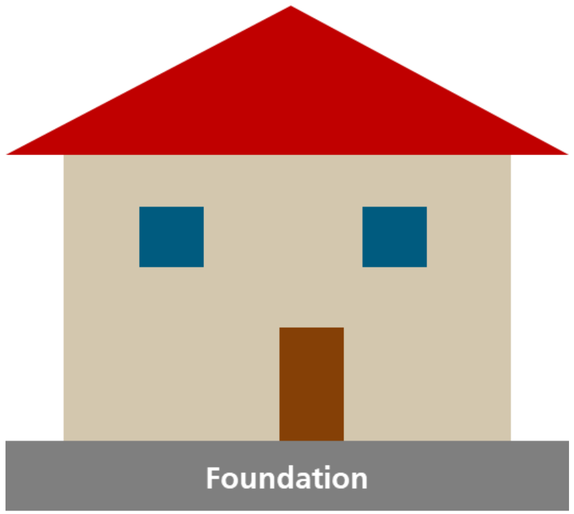

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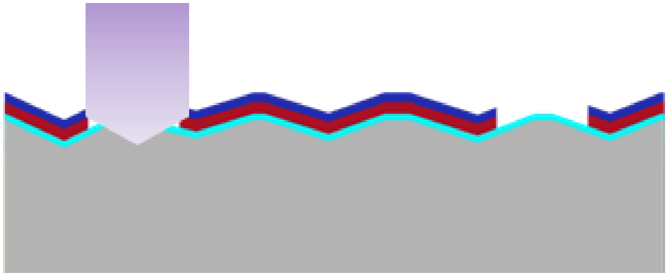
Precursor & LCO influences

SEM analysis

- TOPCon rear side is optimized for screen printing
- Industrial rear sides differentiate in morphology and stack composition



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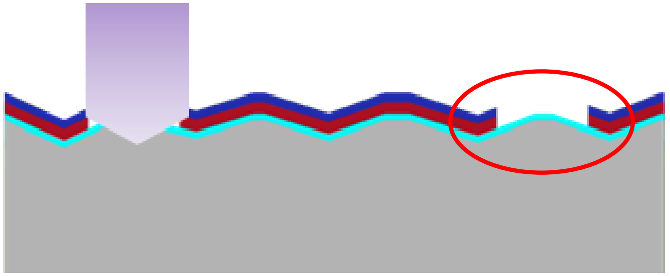

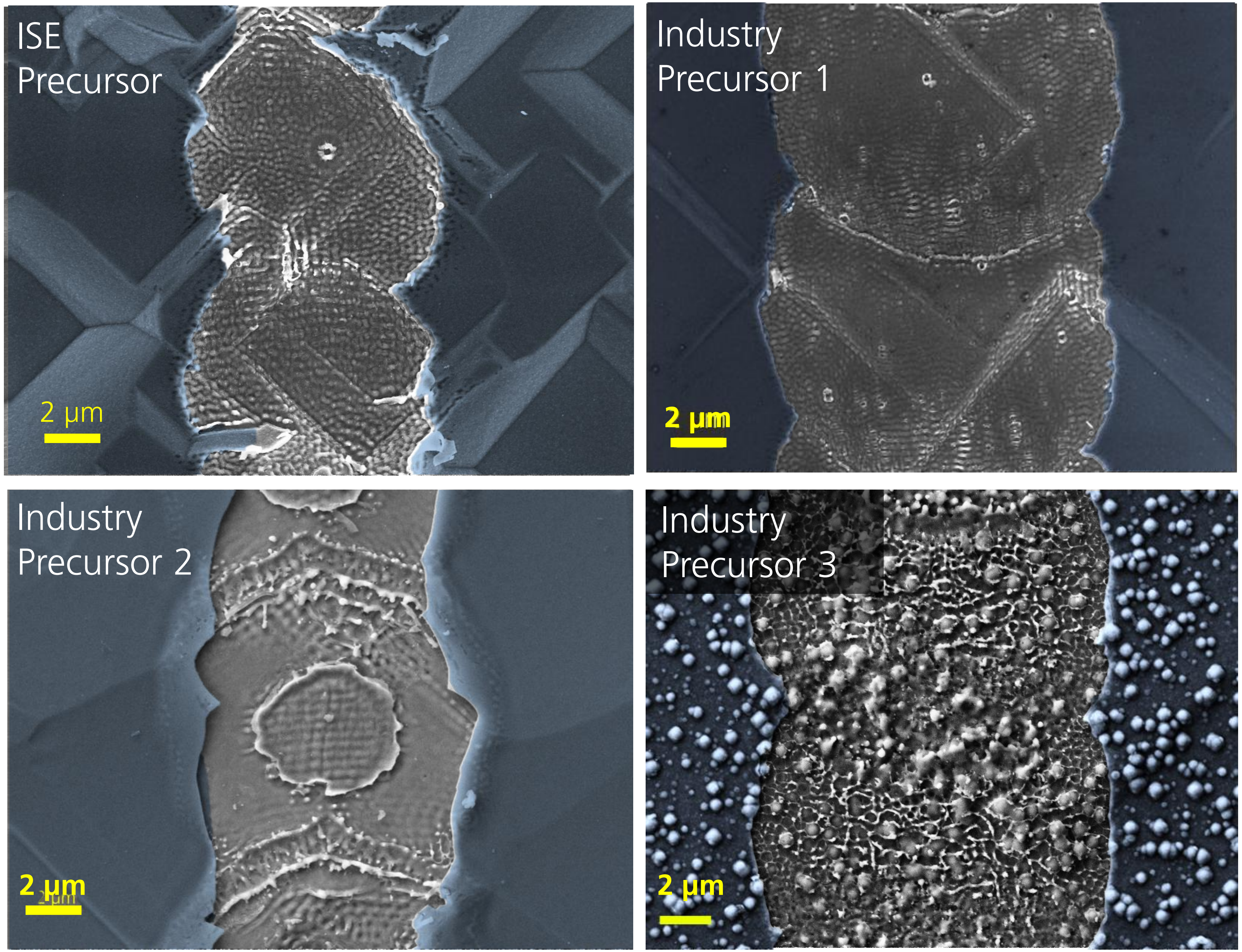

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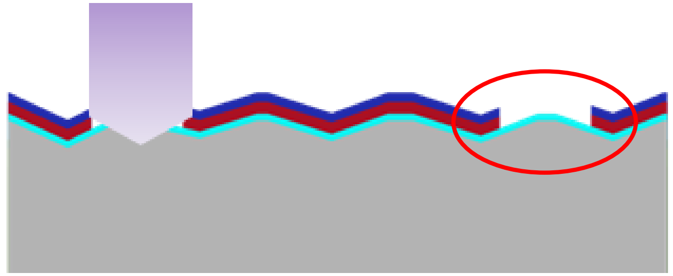
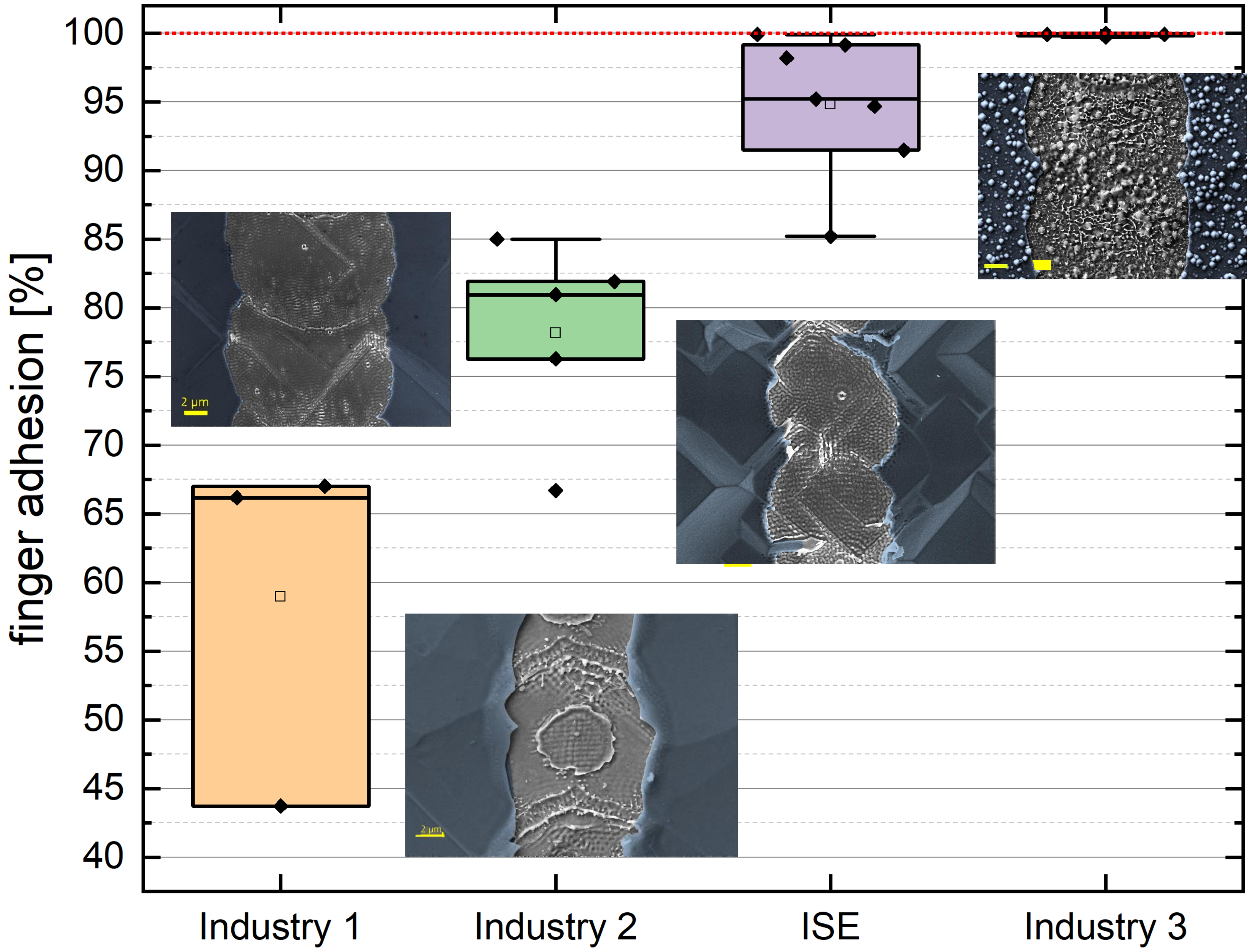


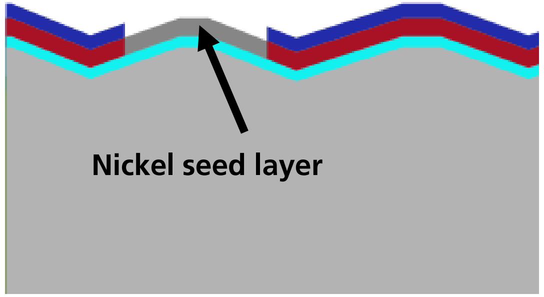


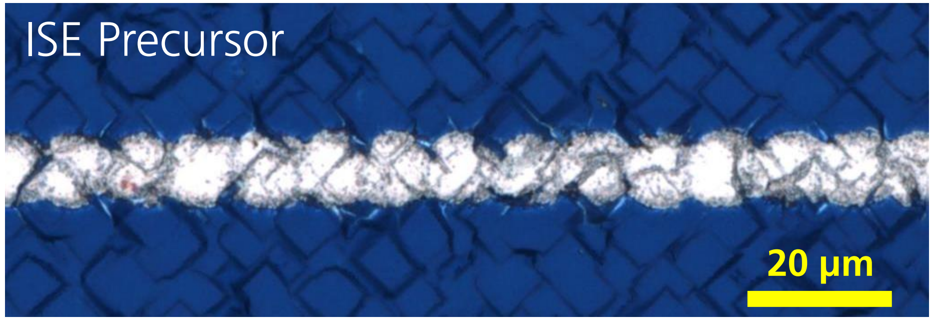
Nickel Seeding Behavior

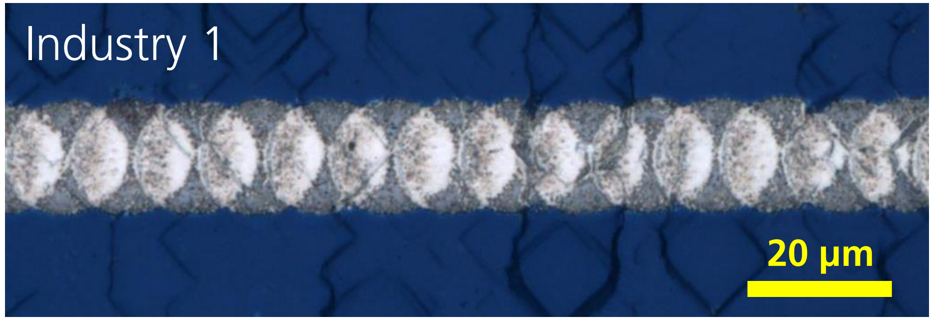
Optical microscopy

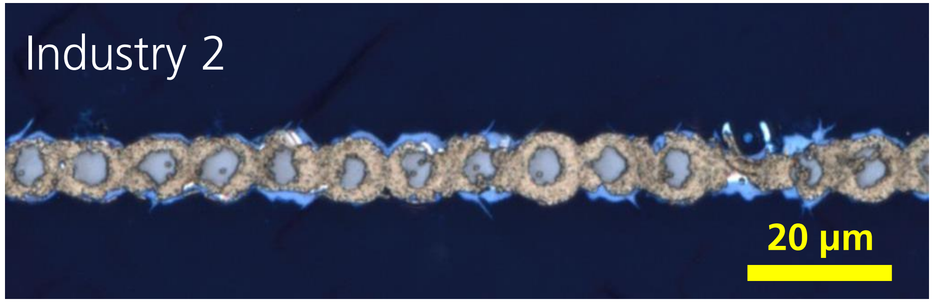
Nickel seeding procedure:

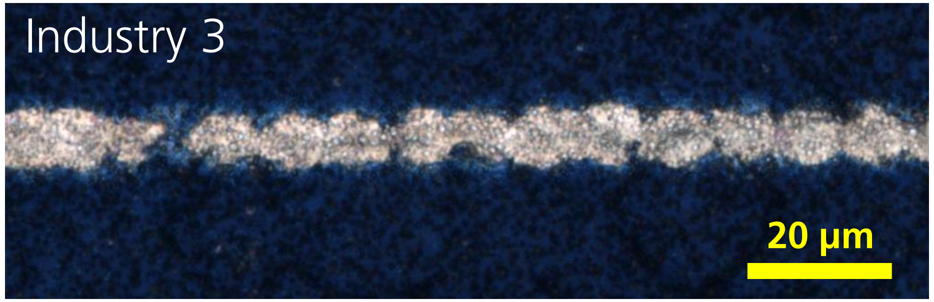
- Current density kept constant
- 1/10 of total charge applied











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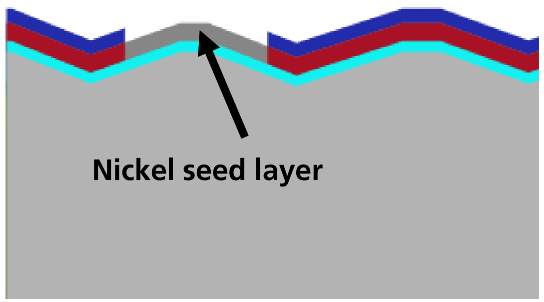
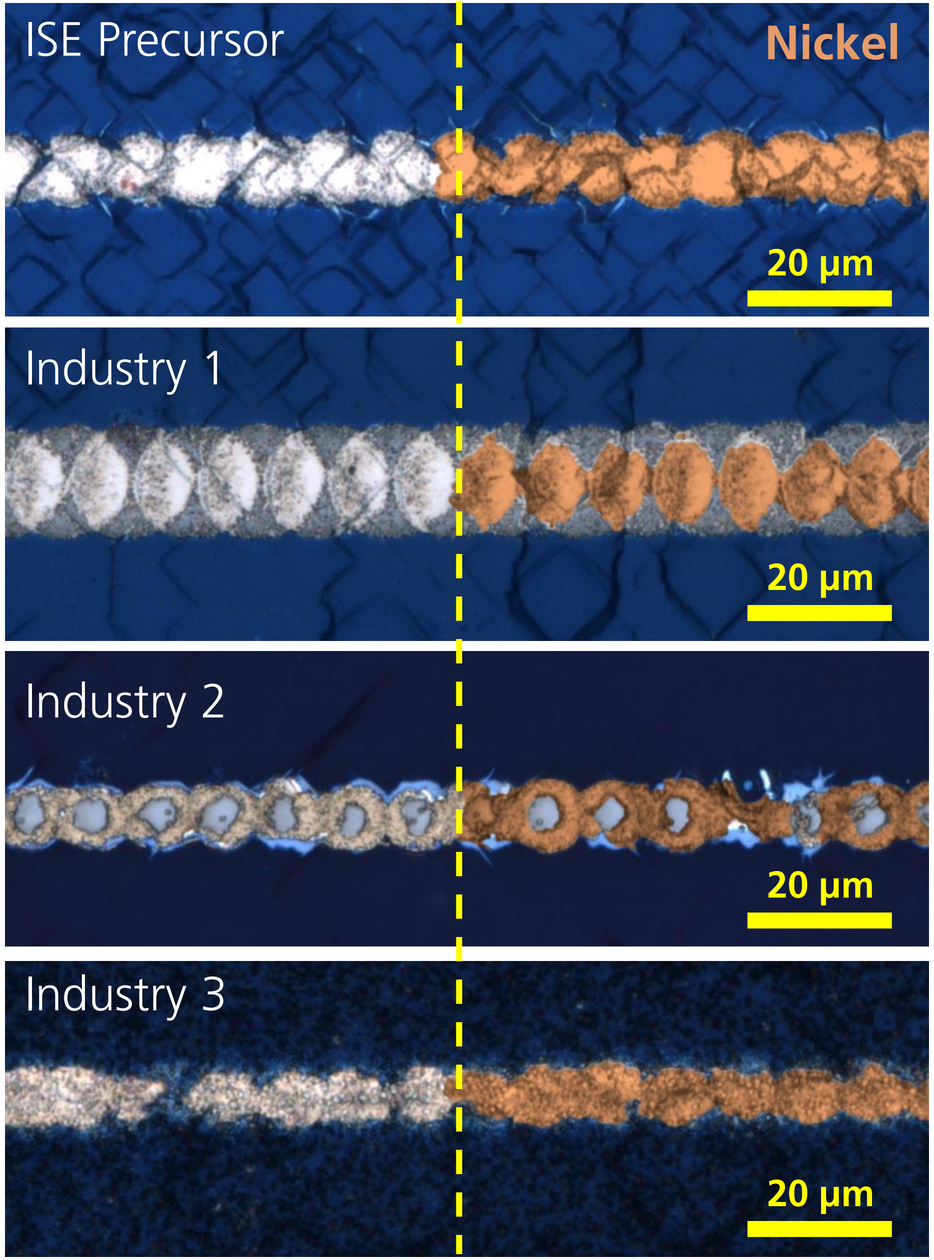
Nickel seeding is visibly different for each Precursor type

- Seeding only in overlap region Industry 1
- Ring shaped seeding for Industry 2
- Homogeneous seeding for ISE & Industry 3





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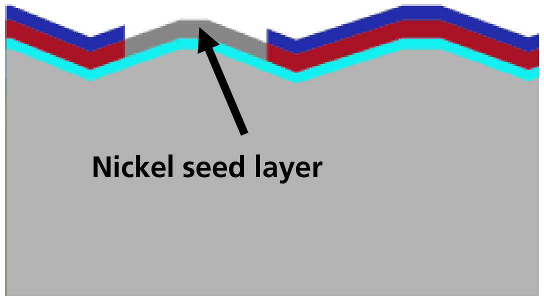
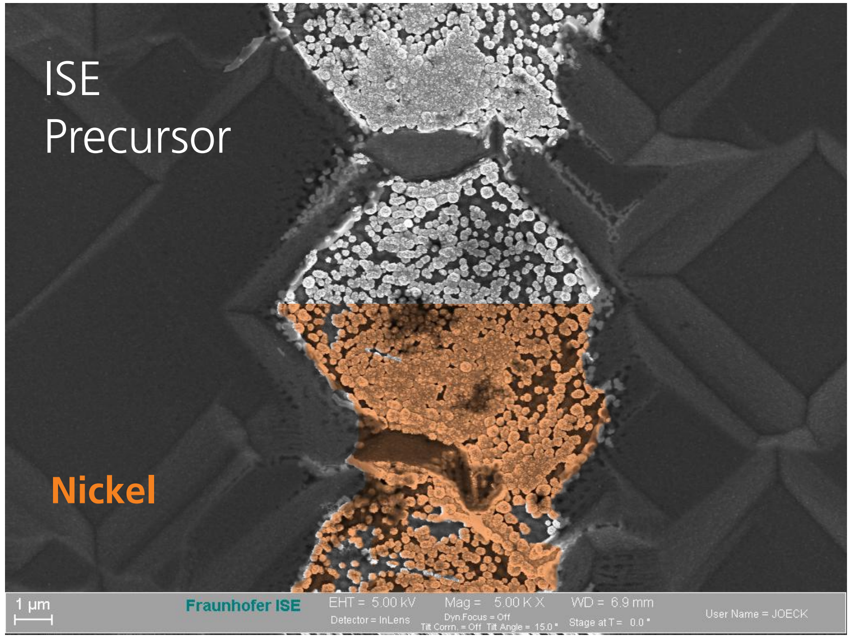
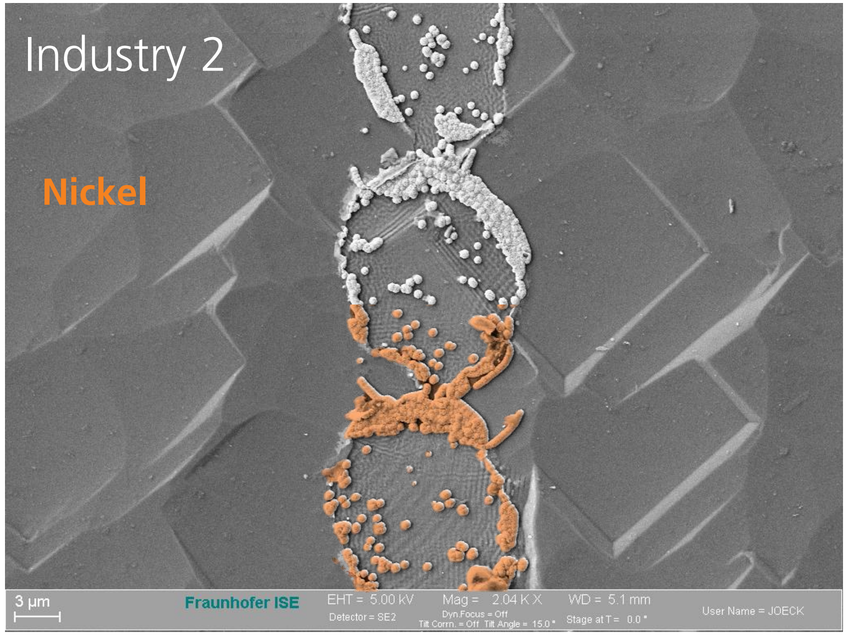
Nickel seeding under SEM
- Ring shaped seeding confirmed for Industry 2
- ISE Precursor has distributed seeds in LCO

Precursor type strongly influences seeding behaviour







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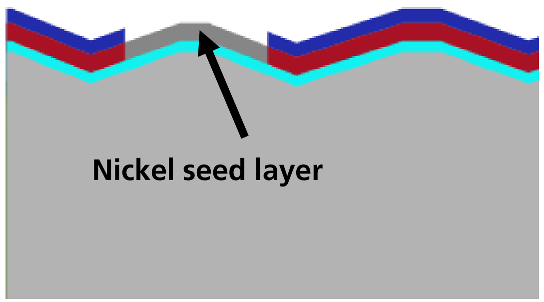
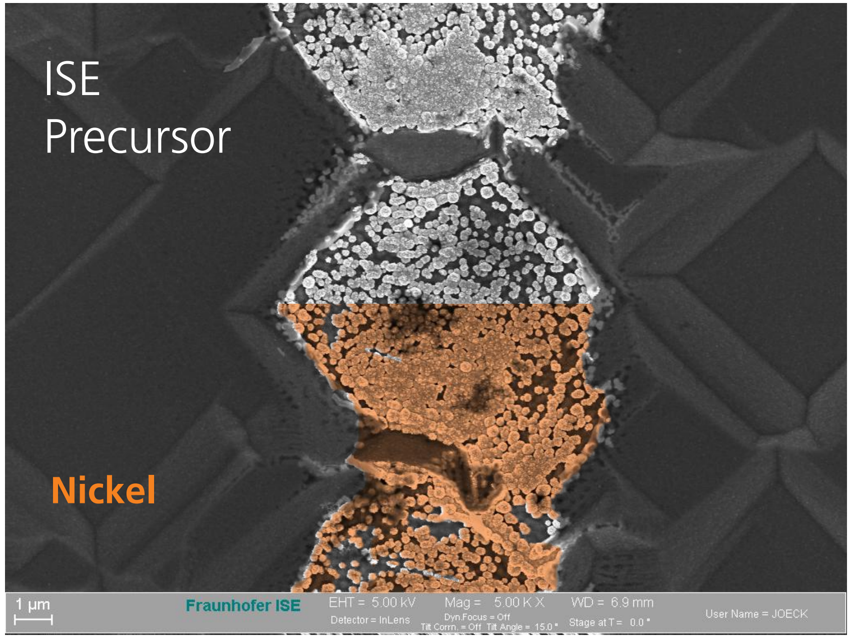
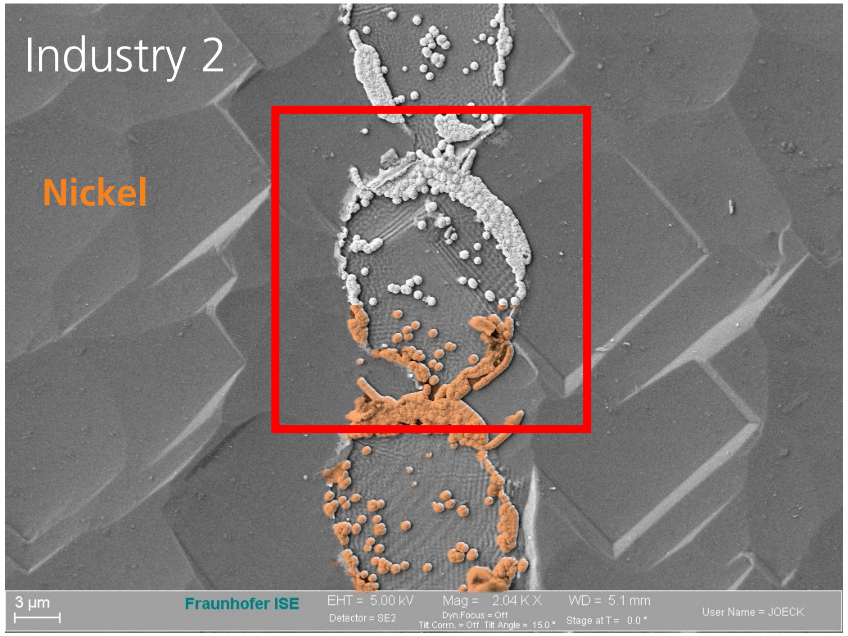




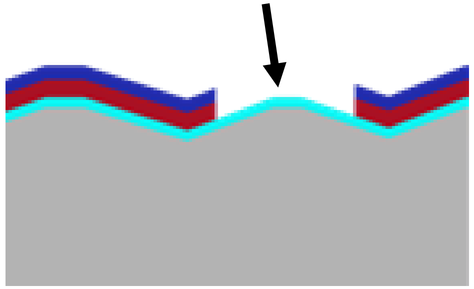


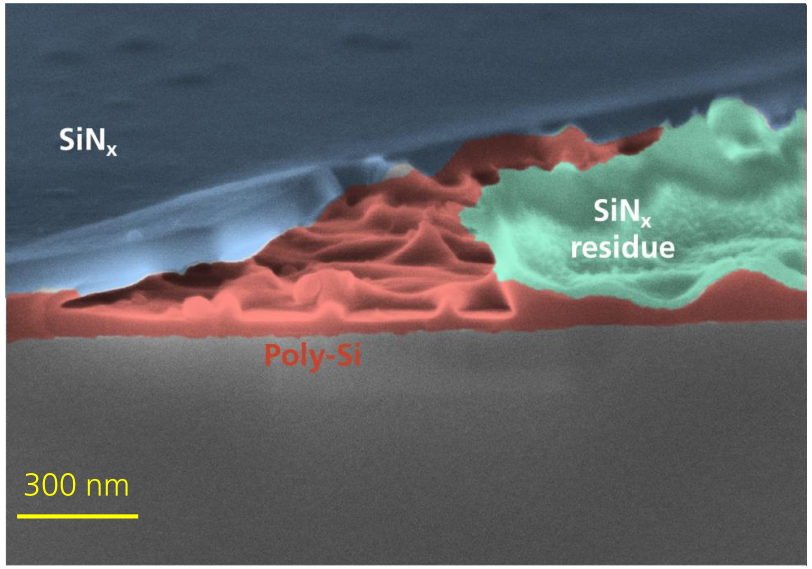
EDX Characterisation

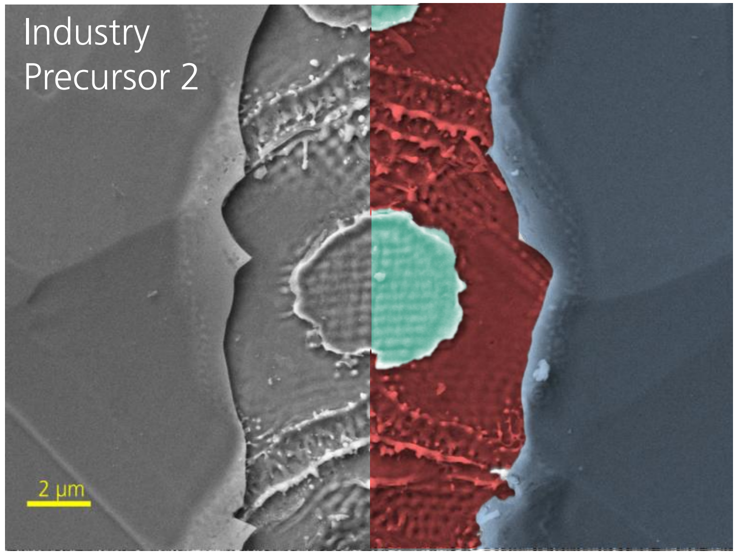
Industry 2 – insulating layer

SiN_x residue in the LCO center with insulating properties

LCO (= Laser Contact Opening)







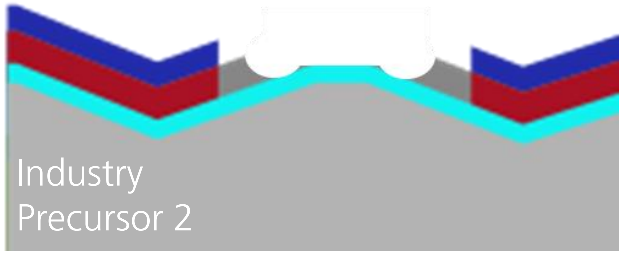
EDX Characterisation

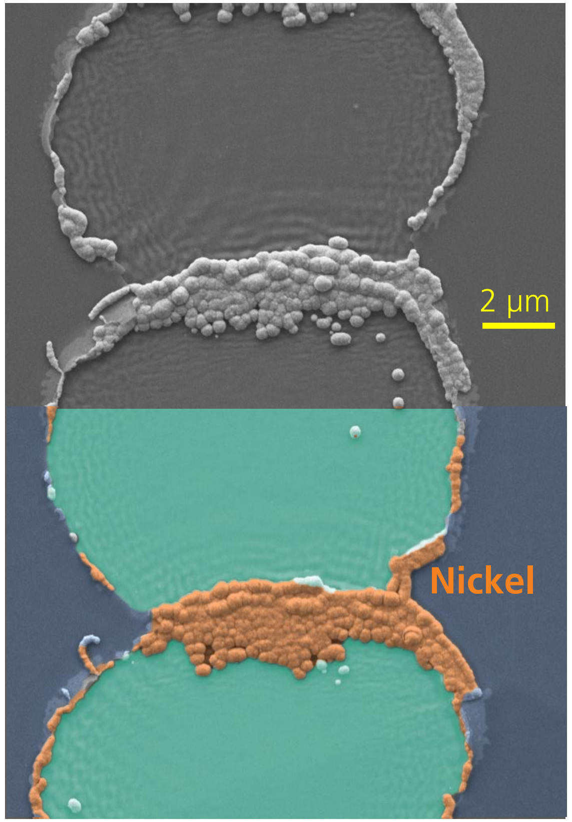
Industry 2 – insulating layer

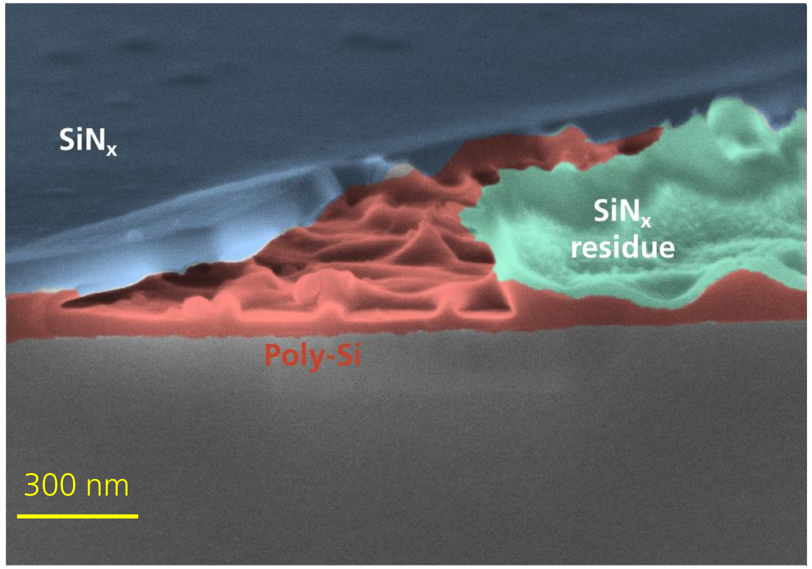
SiN_x residue in the LCO center with insulating properties → no nickel seeding

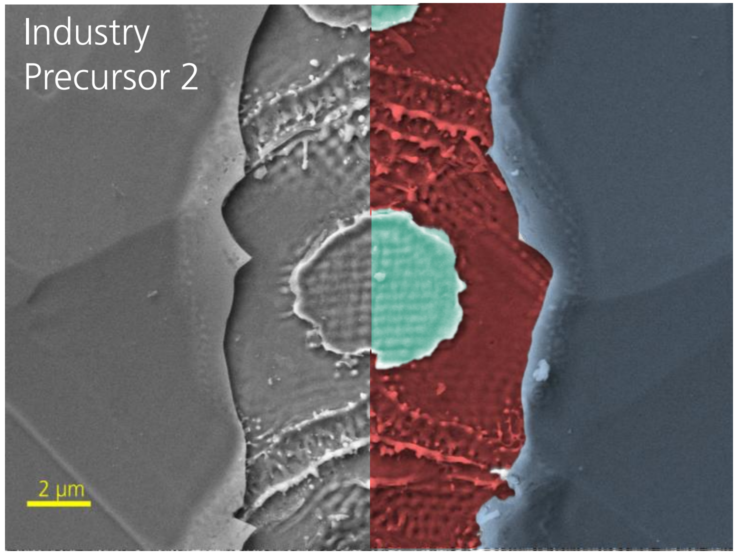
Two effects:

1. **Less area for adhesion → adhesion ☹**
2. **Local current density is different → layer stress → adhesion ☹**









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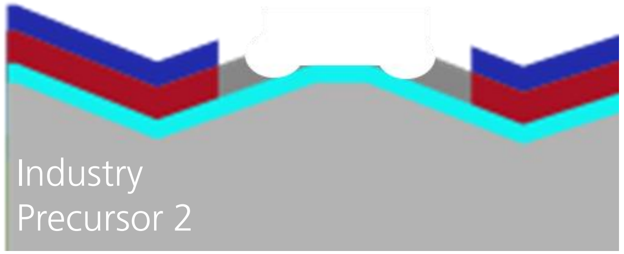
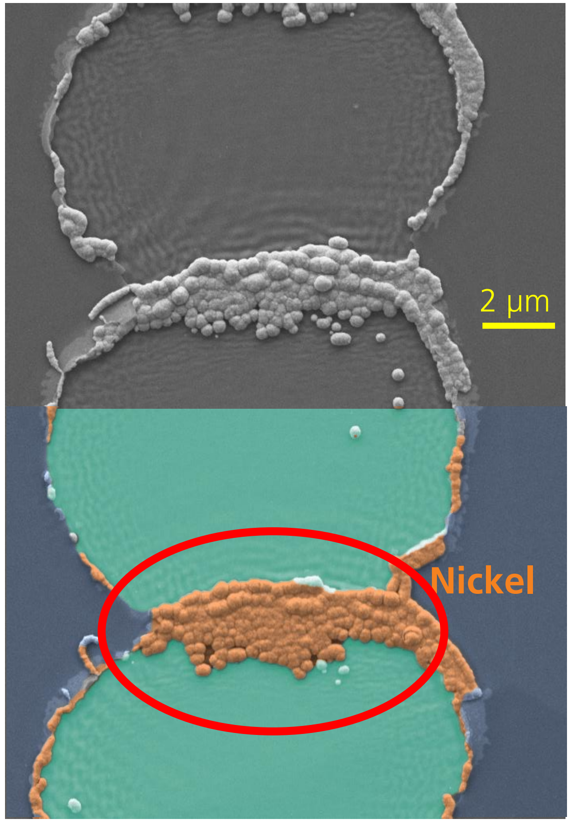
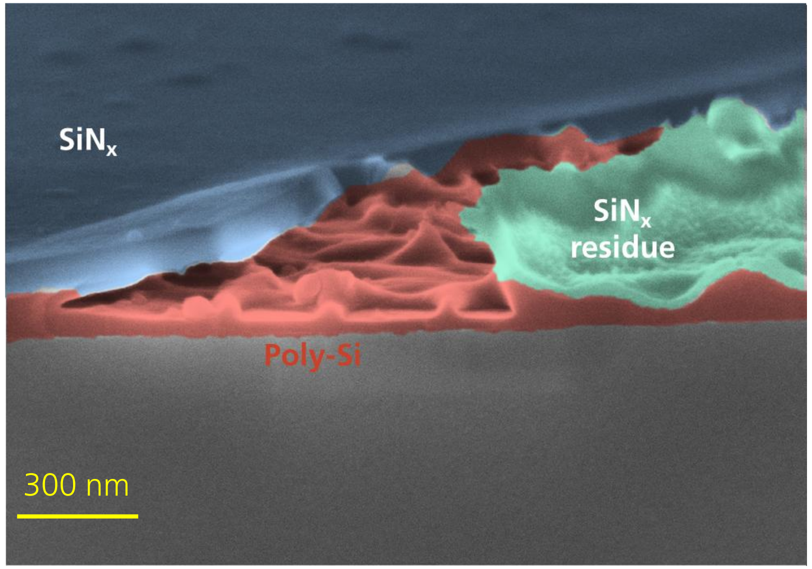
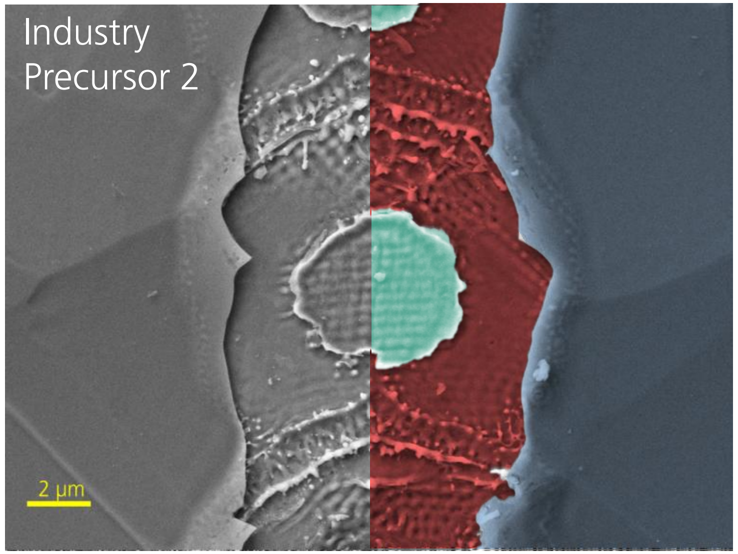






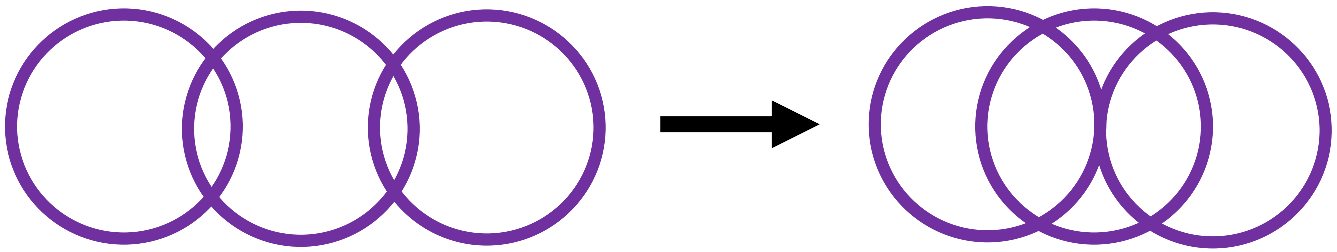


Removal of Residues

Industry 2 – insulating layer

Tested: Variation of Laser power, Pulse overlap and chemical pretreatment

Laser pulse overlap



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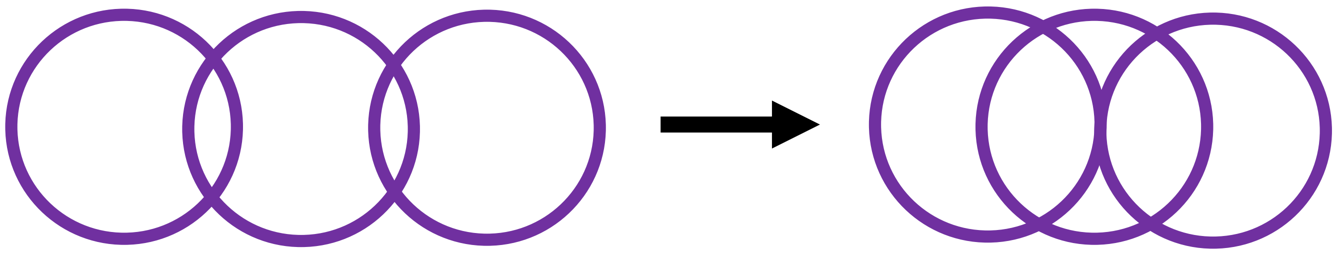

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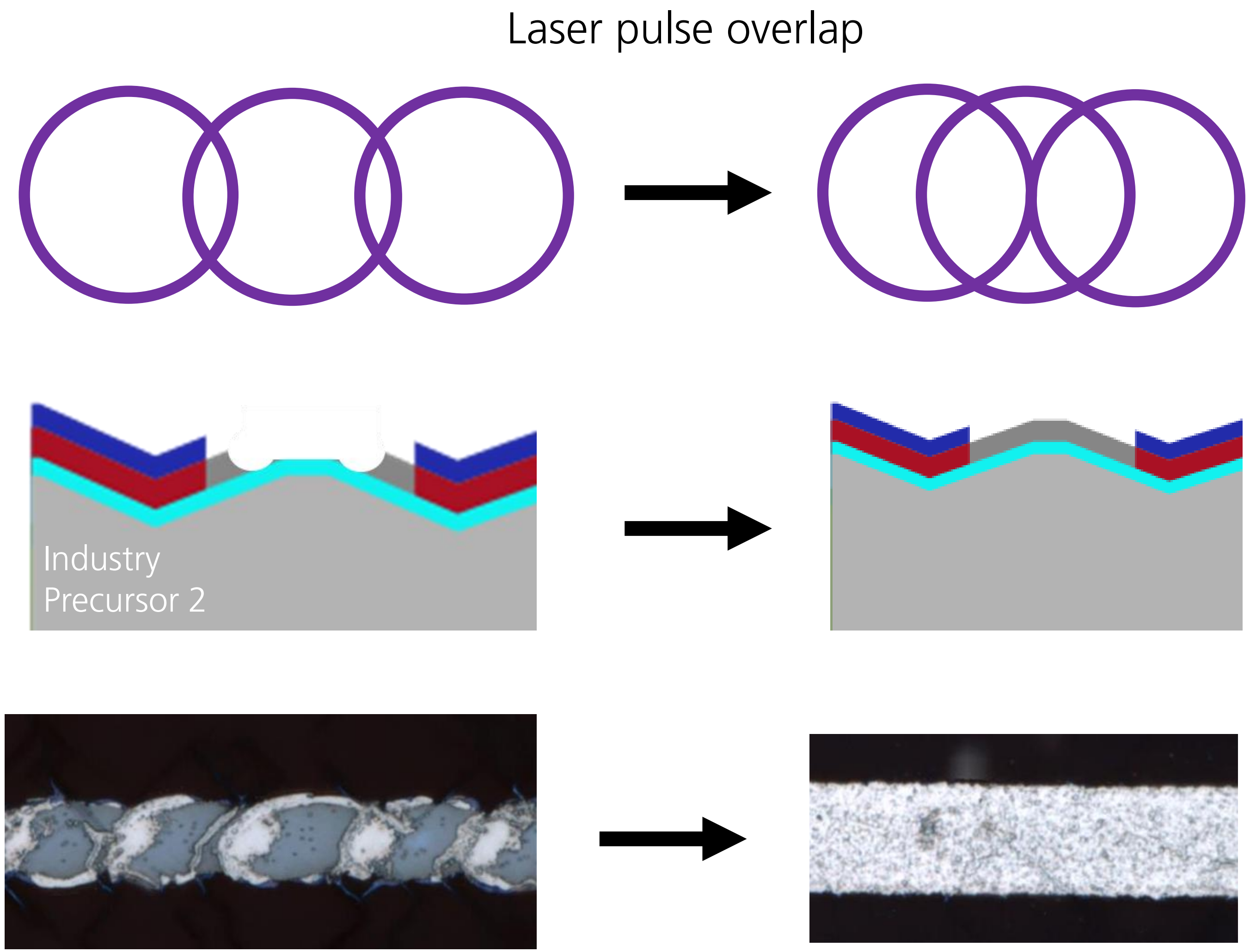
→ Adhesion improved but not sufficient



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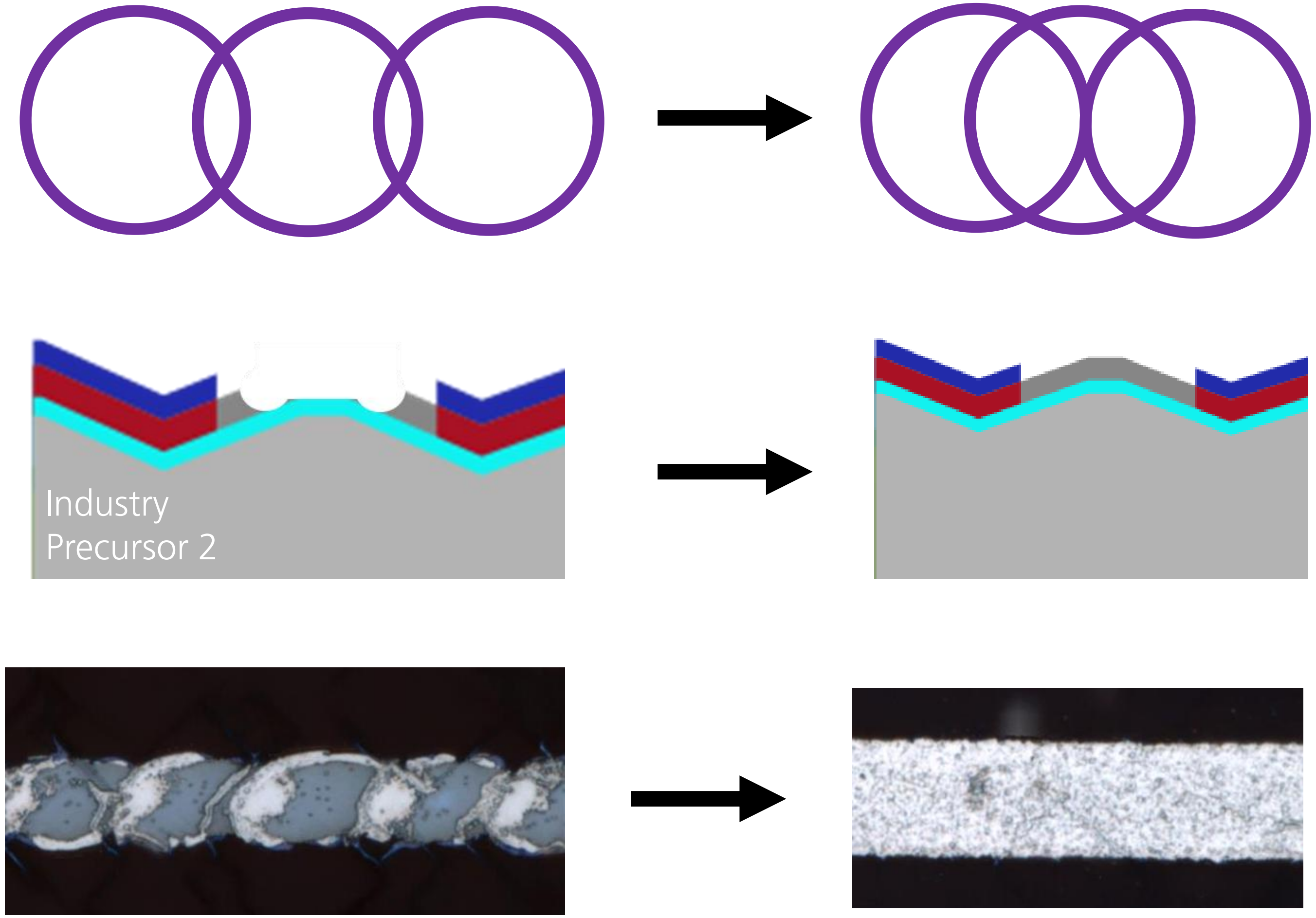

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- Laser power = no effect

Pulse overlap or chemical pretreatment = Two effects:

1. Nickel seeding homogeneous

→ Adhesion improved but not sufficient

2. V_{oc} loss

→ Cell performance decreased

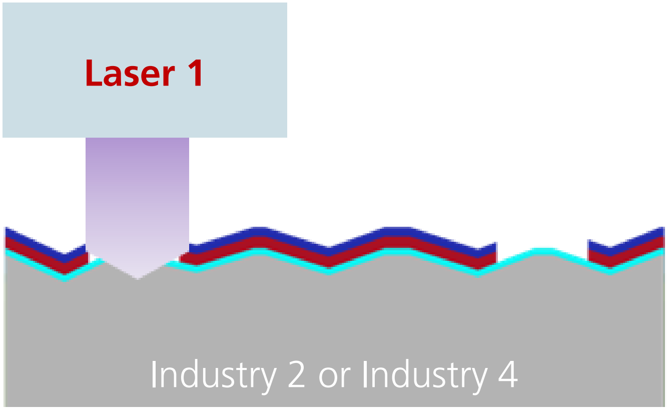
Laser parameters can influence adhesion properties

Laser Variation on Industrial Precursor

Laser tool comparison

Is there an influence of the Laser tool?

Laser 1 = 343 nm, 3 ps



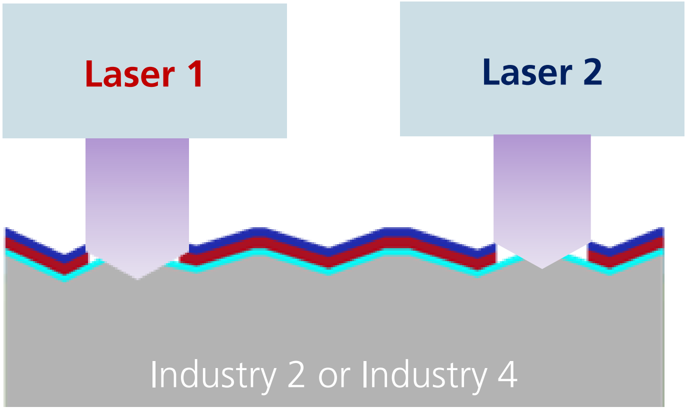
Laser Variation on Industrial Precursor

Laser tool comparison

Is there an influence of the Laser tool?

Laser 1 = 343 nm, 3 ps

Laser 2 = 355 nm, 10 ps



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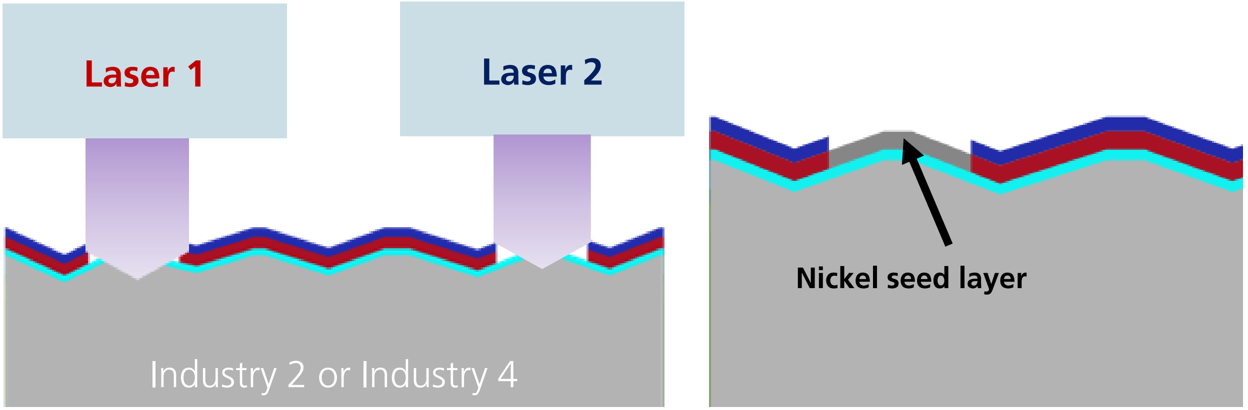

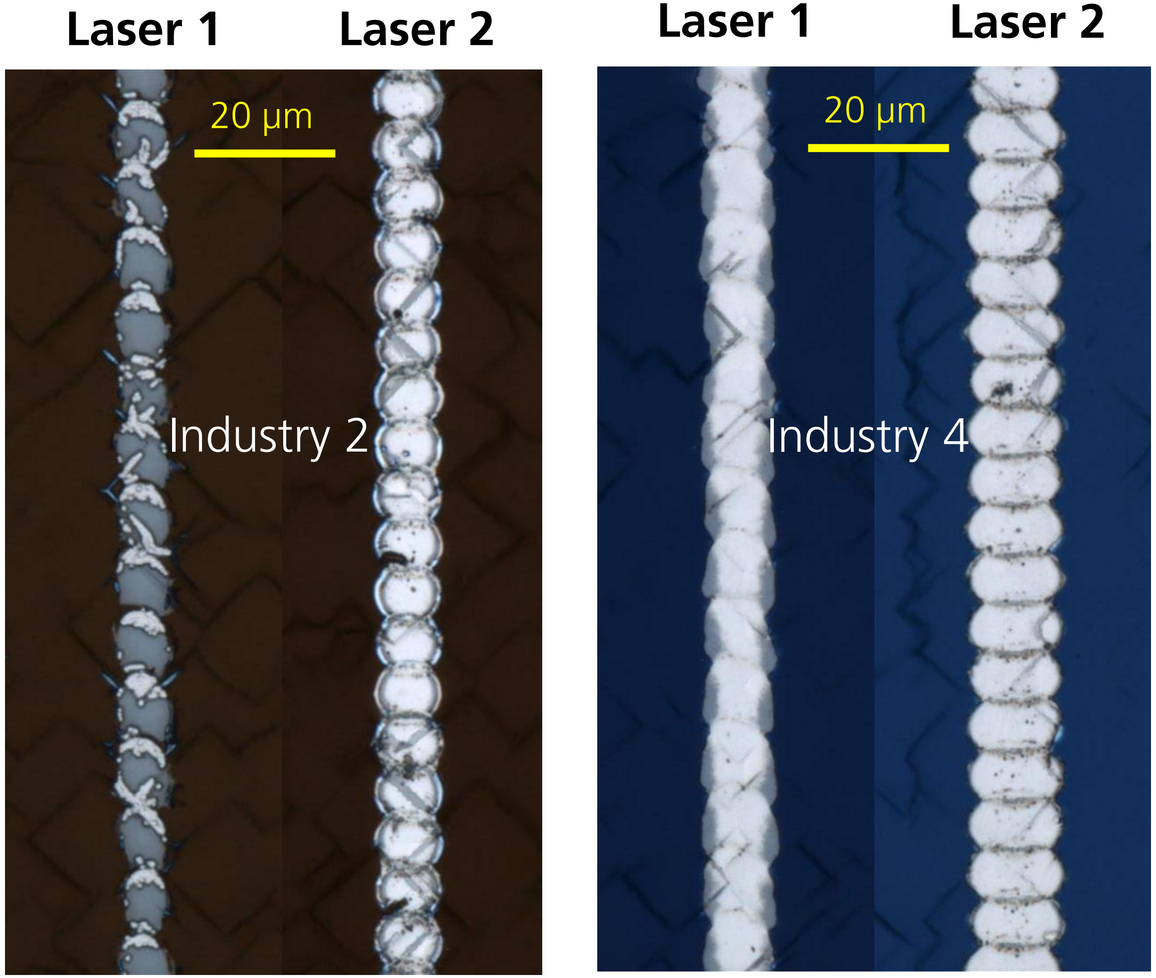

Laser Variation on Industrial Precursor

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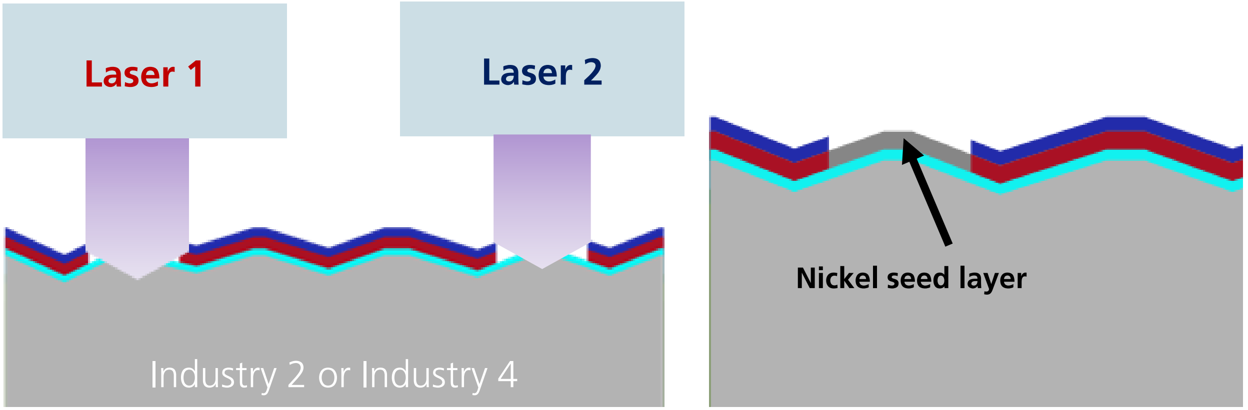
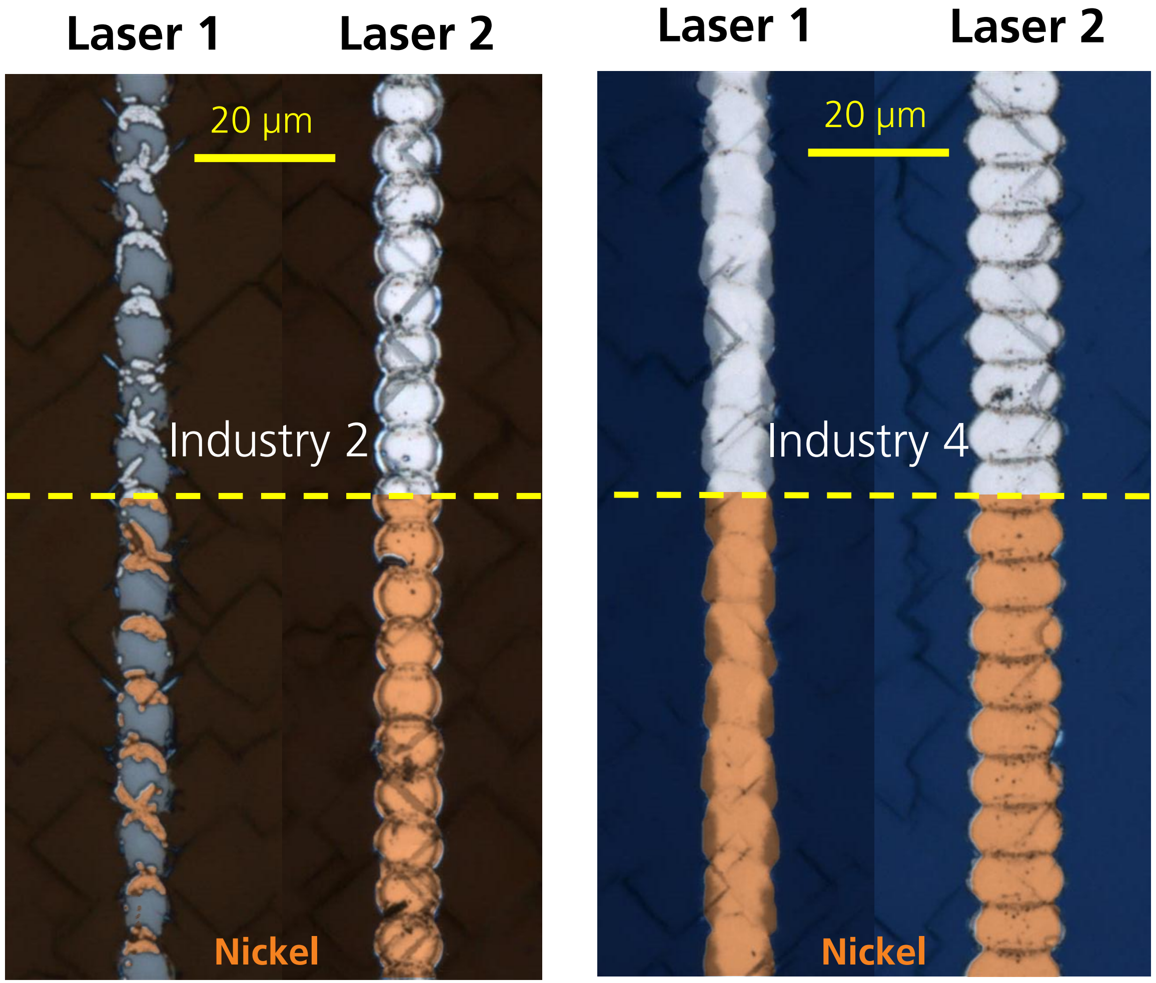
Nickel seeding also visibly different for Laser tools

- Both Precursors homogeneous Ni-seeding for Laser 2
- Laser 2 on Industry 4 performs better than on Industry 2

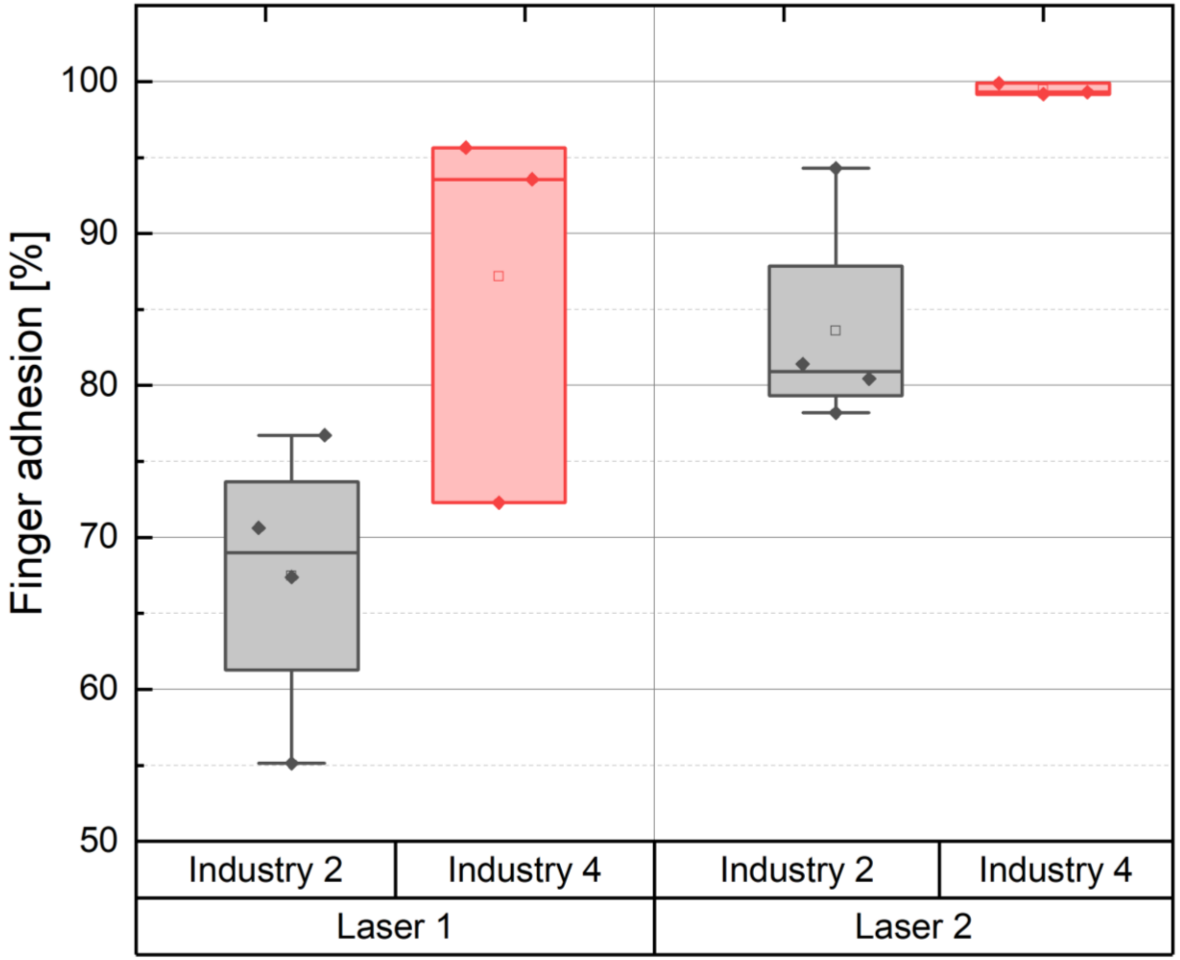




Mechanical Contact Adhesion

Tape test results

Laser 2 is superior to Laser 1 **but** precursor influence still visible



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Open question: What is the reason for the differences in laser ablation?

- Laser differences:
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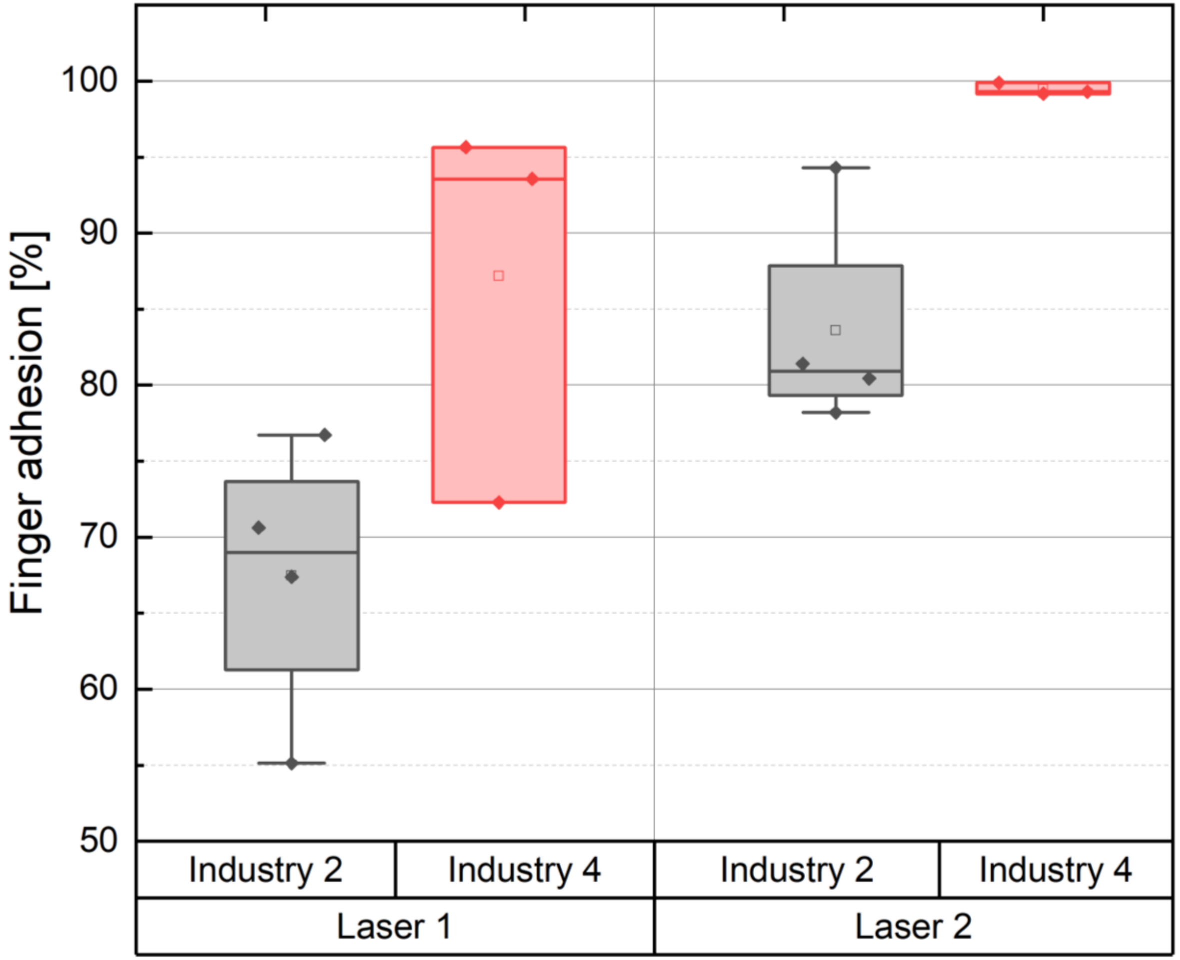
- Precursor differences:
  - Layer composition & morphology?



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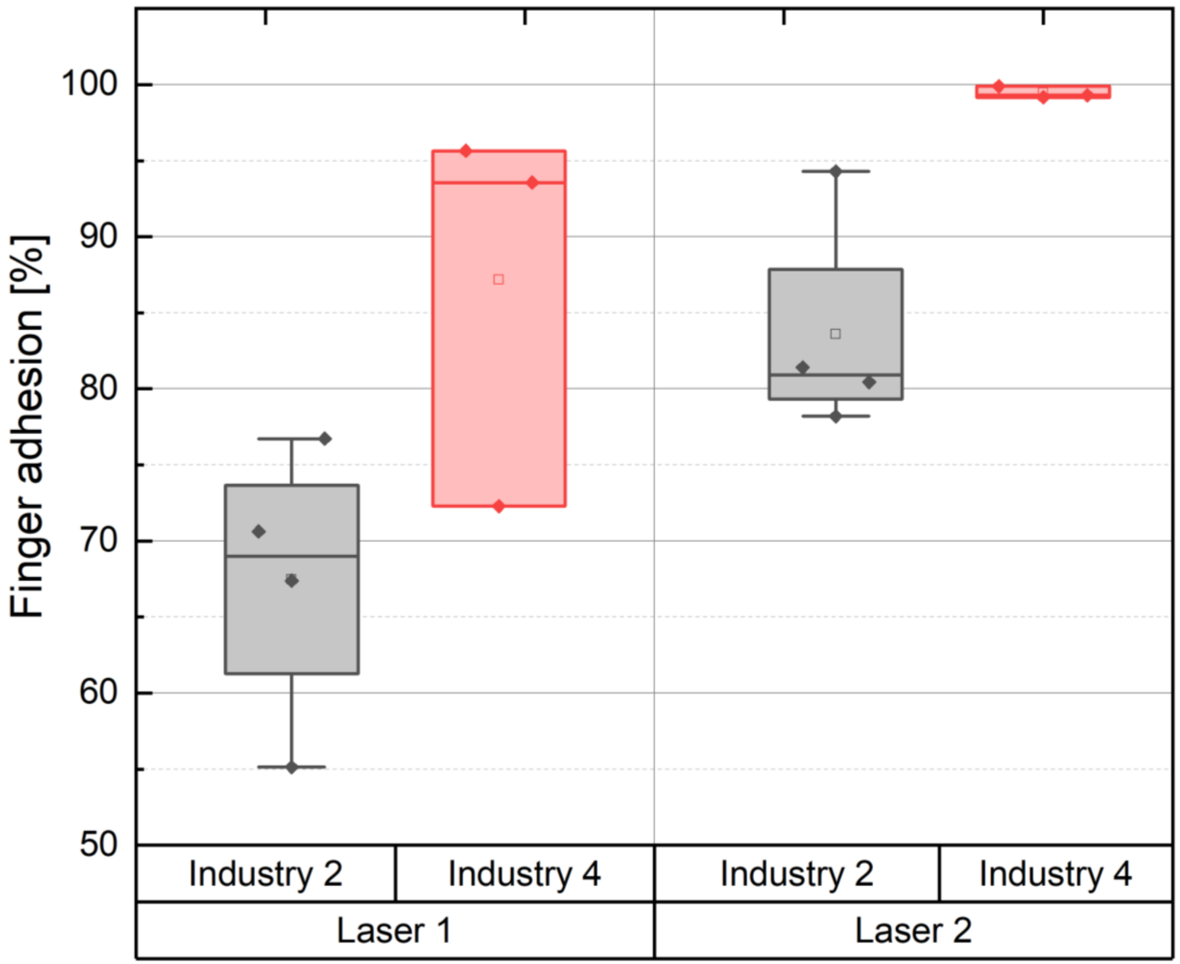
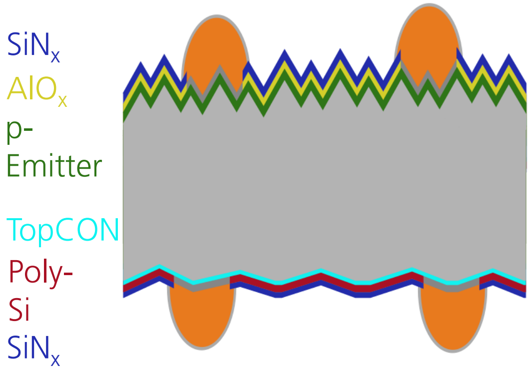
Foundation for good adhesion is homogenous nickel seeding

→ Interplay of laser & precursor is key



Plating for TOPCon Solar Cells

Module integration & results

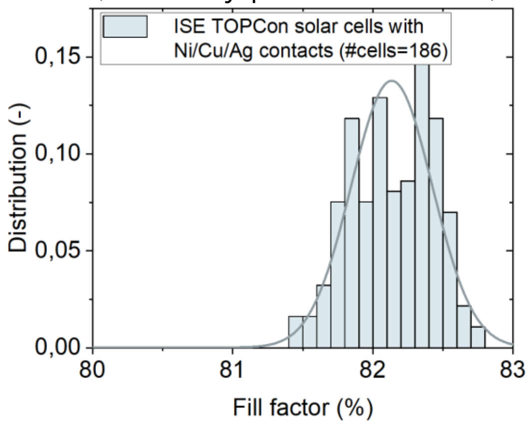


Module manufacturing

- Plated TOPCon is **compatible with all relevant interconnection technologies** (e.g. IR soldering, conductive glueing (ECA)
- Mini module reliability demonstrated **< 2% degradation** in 140h **PC**, 2000 **DH** and 400h **TC** similar to literature [2]

Solar cell fill factor distribution

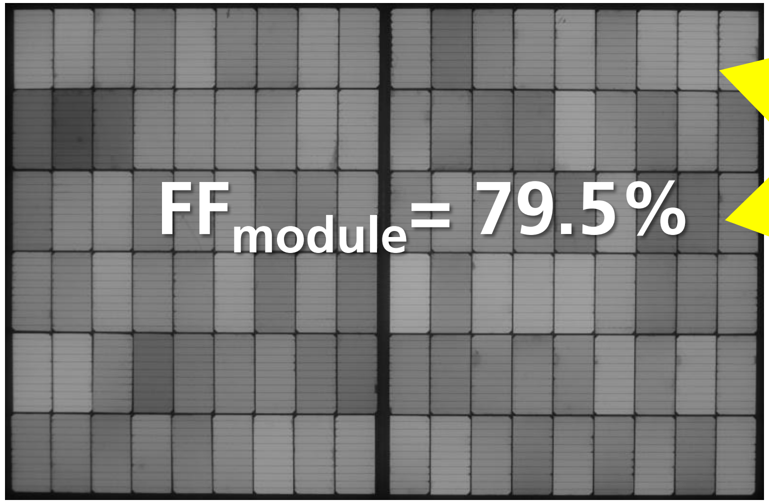
(Bifacially plated TOPCon)



Soldered interconnection

Fabricated module with bifacially plated TOPCon

(10 BB, soldered interconnection)



Module features
No Pb
2 mg/W Ag
Low CO_2 footprint

[2] Z. Wang *et al.*, "Study on excellent contact performance of double-sided copper-plated metallization," *J Mater Sci: Mater Electron*, vol. 36, no. 4, 2025.

FS limitations for Plating

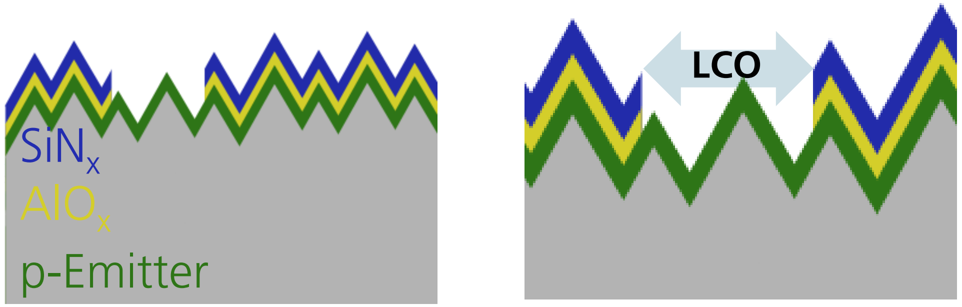
Plating vs. Screen Printing V_{oc}

Plating

Plating emitter contact

LCO area **=** Contact recombination area $J_{0,met,LCO}$

Higher effective J_0 → **Lower** V_{oc} potential

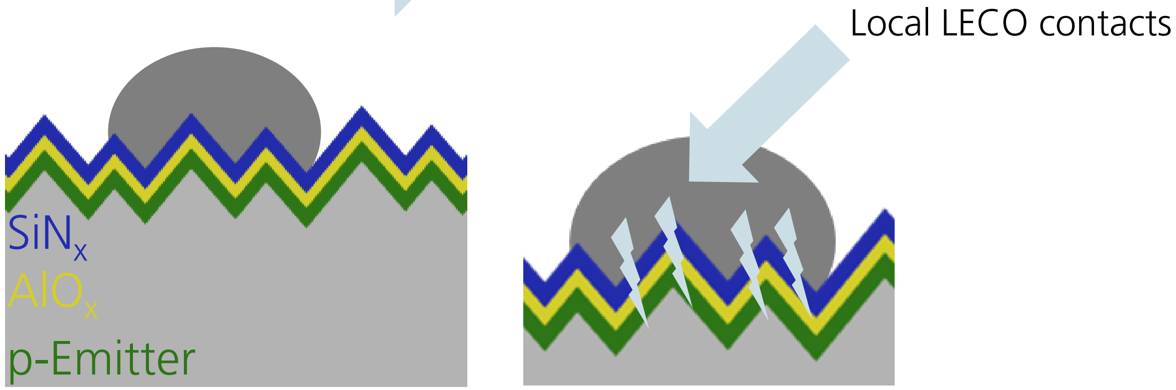


Screen Printing

Screen printed emitter contact

Printed width **>>** Contact recombination area $J_{0,met,SP}$

Lower effective J_0 → **Higher** V_{oc} potential



FS limitations for Plating

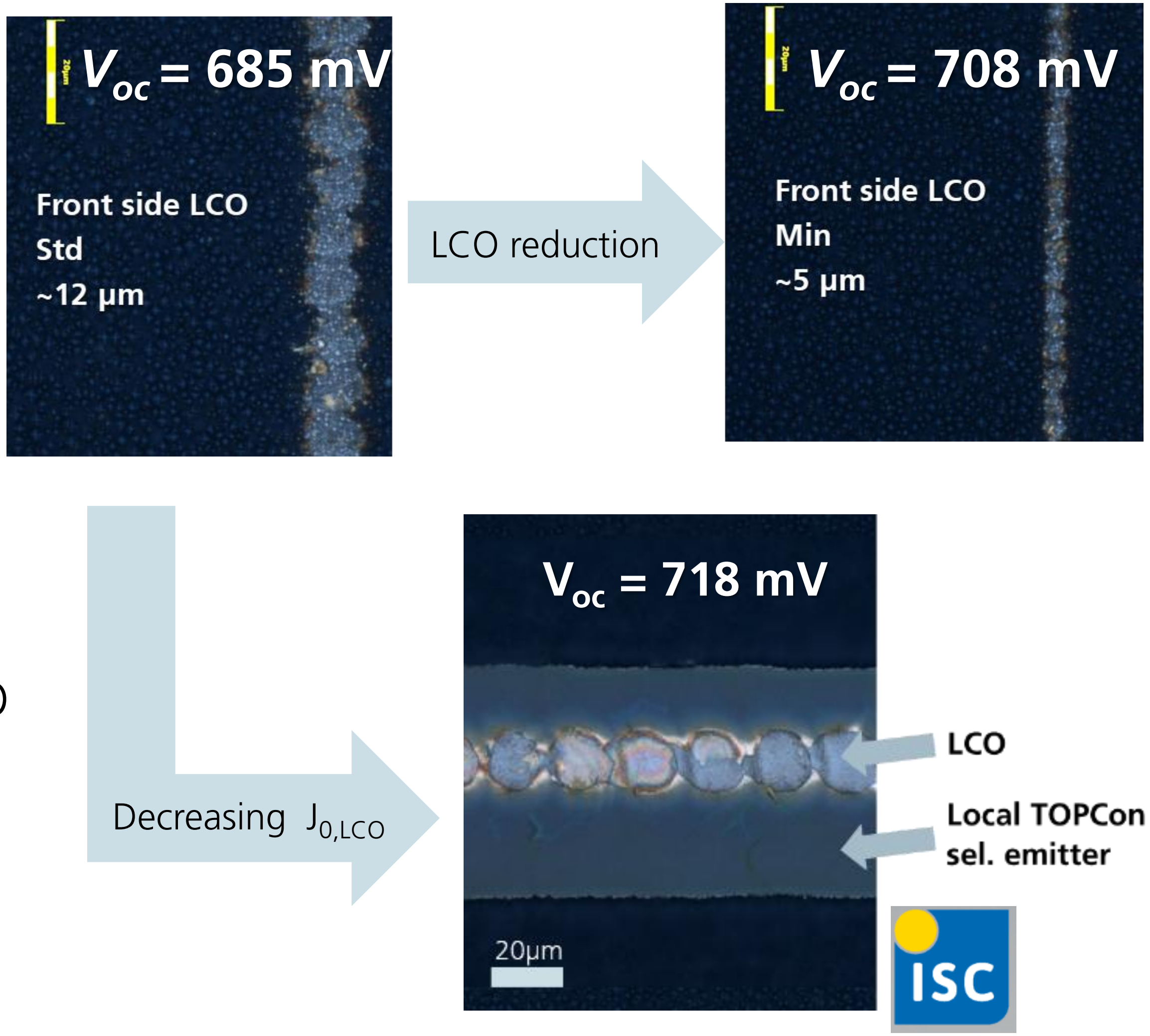
Mitigation strategies

Decreasing contact area

- **LCO reduction improves V_{oc}** but still below LECO level
  → Minimum limitation ~3µm due to contact resistance

Reducing $J_{0,LCO/met}$

- Diffused selective emitter further improves V_{oc} potential
- **Local TOPCon selective emitter** closes the gap to Ag LECO contact
  → Simulations show **η potential ≥26%**



RENA Fraunhofer ISE

Plating for TOPCon solar cells

TOPCon solar cell results

Hybrid metallization design (screen printing & plating)

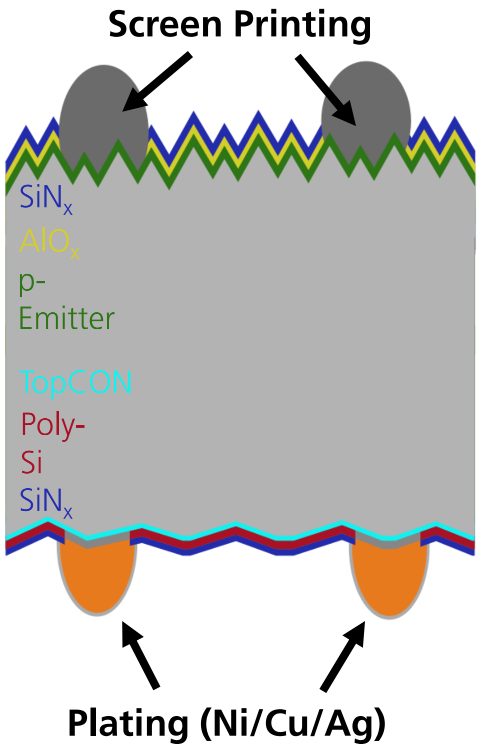
- Hybrid design exploits η-developments of LECO screen printing

M10 TOPCon solar cell	η (%)	V_{oc} (mV)	j_{sc} (mA/cm²)	*FF* (%)	Ag* consumption (mg/W_p)
Hybrid: FS: SP+LECO / RS: Ni/Cu/Ag	**24.3**	721	41.5	81.3	**8.1**

Ag reduction

- Screen print (SP) reference solar cell features approx. **15 mg/W Ag consumption**
  → **50% reduction for hybride approach**

Hybrid design



*Wet paste Laydown

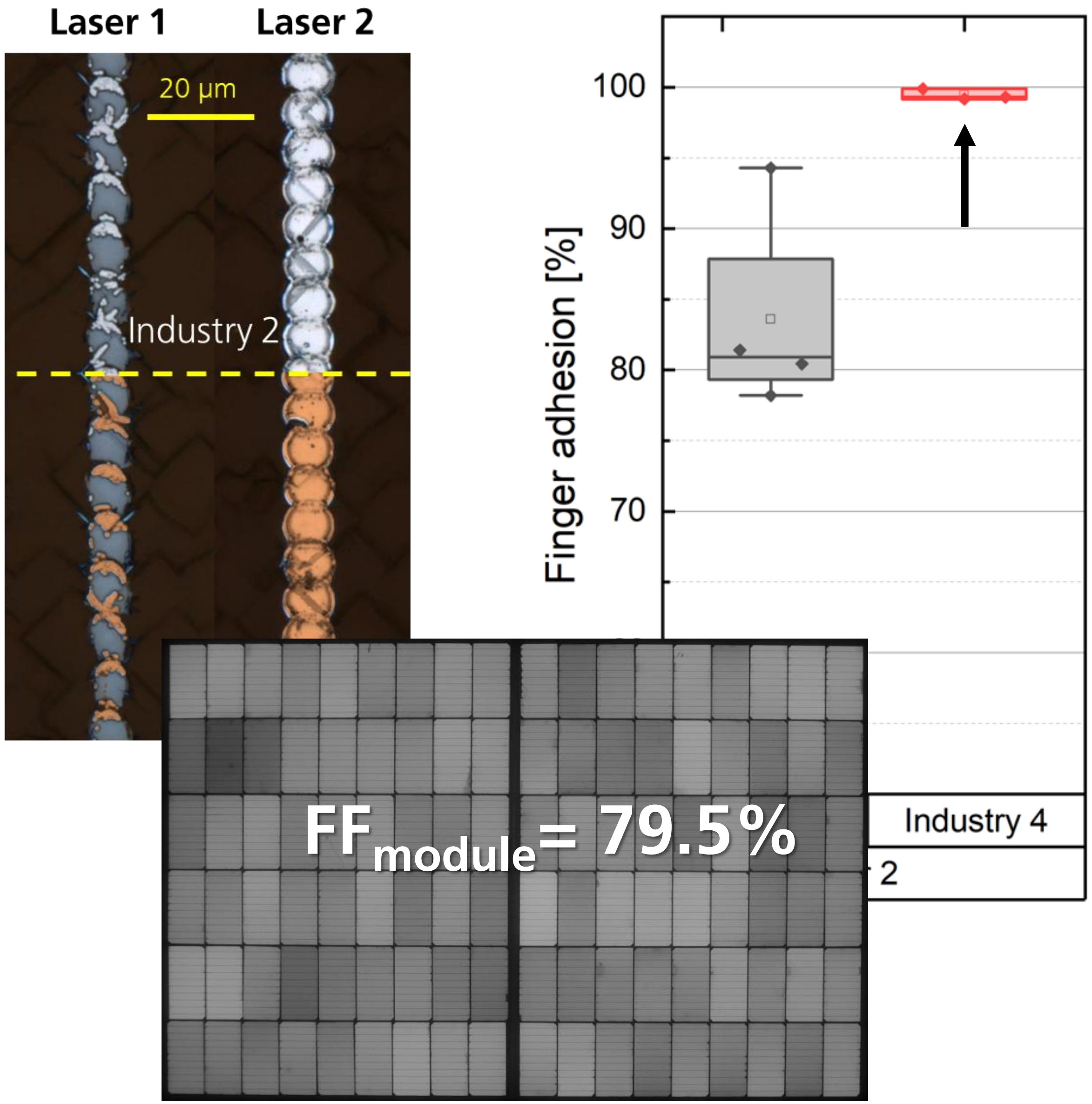
Summary

LCO + Nickel **seeding quality differentiates** regarding used **Precursor and Laser tool**

Homogenous Nickel seeding = **sufficient adhesion** for module interconnection

Module Reliability demonstrated for bifacially plated solar cells

Hybrid metallization showcased with **η = 24,3%** and **8.1 mg/Wp** silver consumption



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