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Progress on the Reduction of Silver Consumption in Metallization of SHJ Solar Cells

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[4]ASADA MESH CO., LTD.

Metallization and Interconnection Workshop 2023
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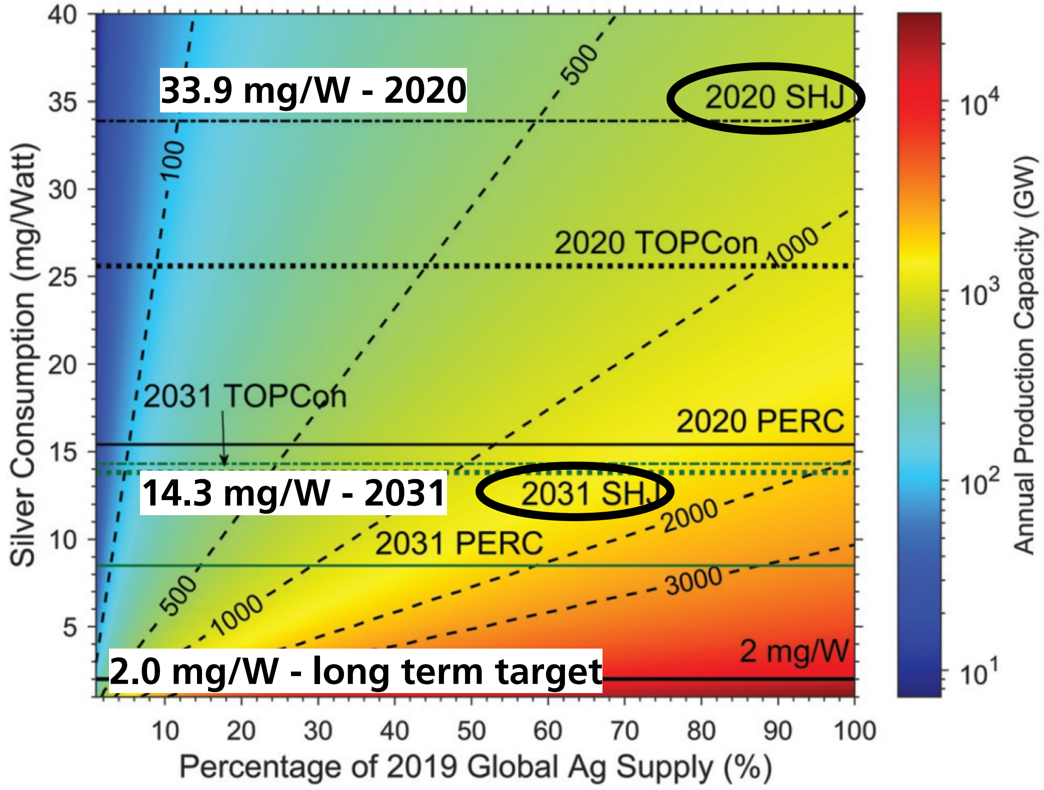
Motivation and Approach

Enable SHJ Mass Production by Reducing the Consumption of Scarce Materials

Motivation

- Scarce materials in SHJ production[1,2]: **Ag, In, Bi** …
- **Reduce Ag consumption**[2] → **target 2 mg/W**
- SHJ with high Ag consumption vs. PERC



Graph taken from [2]

[1]E. Gervais, EPJ PV, 2021, https://doi.org/10.1051/epjpv/2021005
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[4]A. Lorenz, 2022, https://doi.org/10.1002/ente.202200377
[5]J. Schube, 2022, https://doi.org/10.1002/ente.202200702
[6]K. Gensowski, 2022, https://doi.org/10.1016/j.solmat.2022.111871
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[10]T. Hatt, 2021 http://dx.doi.org/10.13140/RG.2.2.30042.47042

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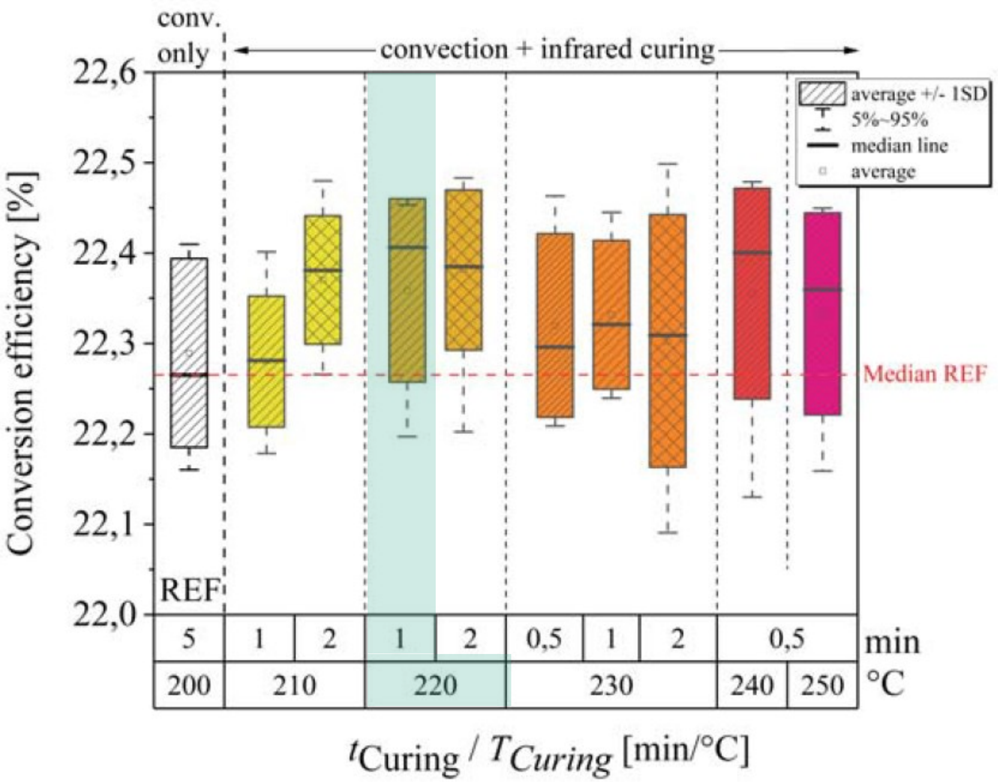
  → **Low-temperature Paste (LTP)**
- Industrial standard SHJ metallization: **screen printing (SP),** at ISE fast inline curing 220°C 1 min[3]



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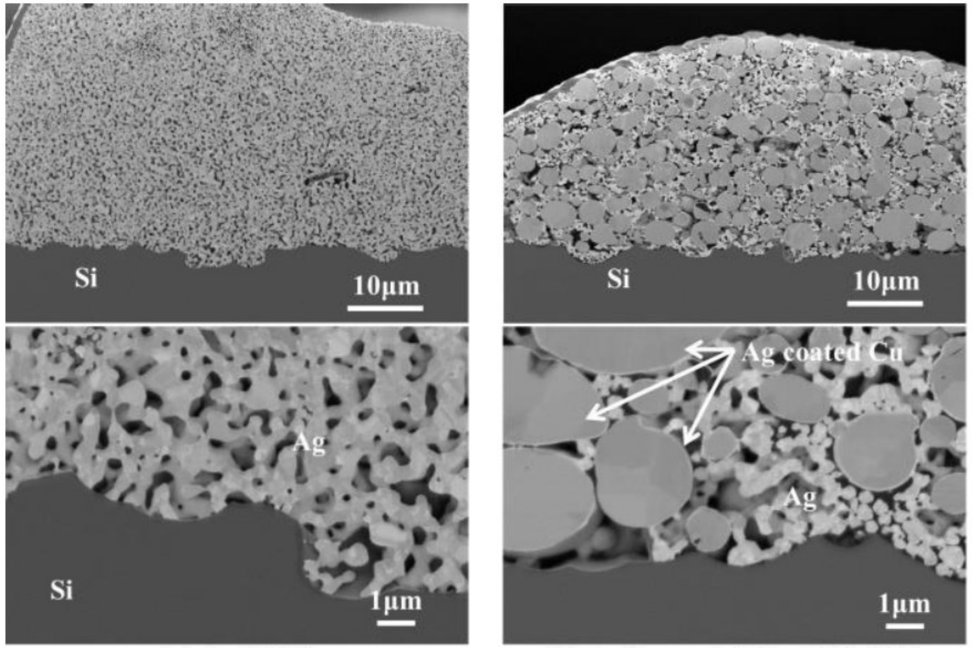
Approaches with lower Ag consumption

1. **Fine-line SP**
   Alternatives: Rotary SP[4], FlexTrail[5] and Dispensing[6,7]
2. **Reduce Ag content in LTP**
   Ref LTP Ag ~92%→ Ag-coated Cu particles[8]
3. **Avoid Ag "completely"**
   Cu-LTP[9]/-Plating[10] (challenges: oxidation, contamination)



(a) Ag 100% (b) Ag/Ag coated Cu=37%/63%

AgCu SEM taken from [8]

[1]E. Gervais, EPJ PV, 2021, https://doi.org/10.1051/epjpv/2021005
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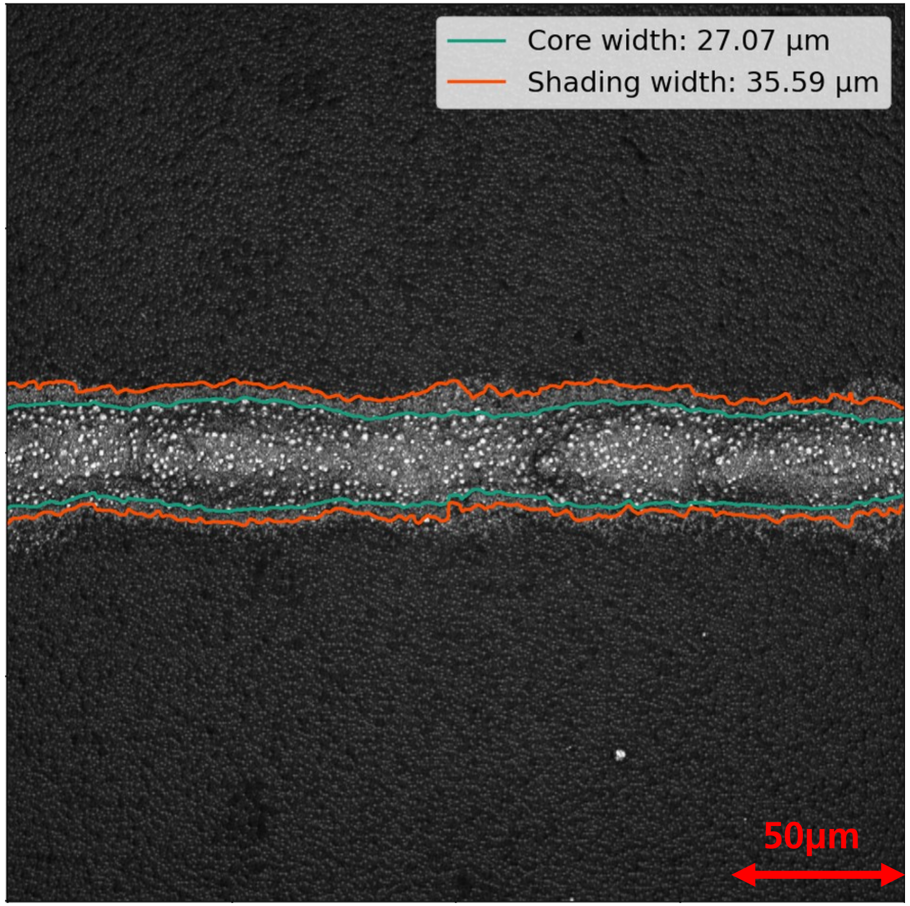


Reduce silver consumption by application of fine-line screen printing

Evaluation of Screens to Reduce Ag Consumption

Process Flow

***ASADA wires:**
SHS: super high strength
UHS: ultra high strength
SHS-T: tungsten type

Base	n-type SHJ precursors (M2+)						
SP-RS	Ag LTP reference metallization | Drying @ 200°C 1 min						
SP-FS	Ag LTP metallization with varied …						
Mesh	380x14 22.5°	380x11 0° SHS-T*	520x11 22.5° SHS*	520x11 22.5° UHS*	520x11 30° SHS*	520x11 0°	430/460x13/11 0°
Screen	Opening range: w_n 10 – 60 µm						
Cure	Curing @ 220°C 1 min						
Char	Resistance measurement, 3D-microscopy → finger geometry analyzed with DASH[11]						

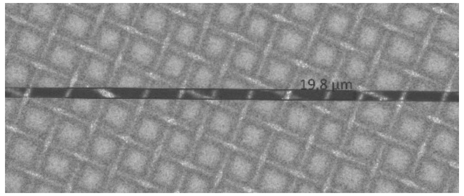
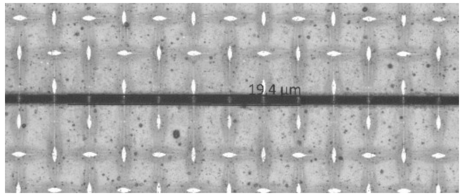
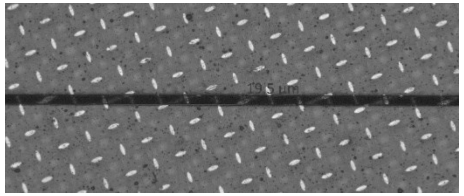
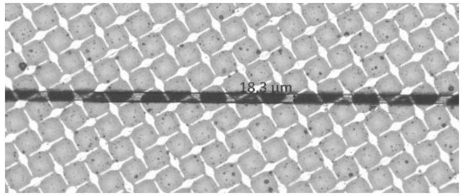
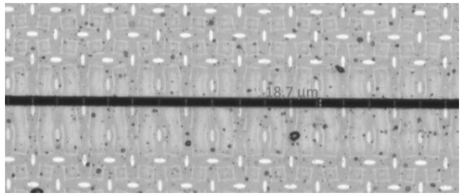
[11]T. Wenzel, 2022, https://dx.doi.org/10.2139/ssrn.4034227

Evaluation of Screens to Reduce Ag Consumption

Ingredients for Fine-Line Printing

Screens

- Variation of mesh type (mesh count and wire diameter) and angle, shown for w_N ~ 20µm

380x14x22.5°	380x11x0°	520x11x22.5°	520x11x30°	520x11x0°
				
Reference screen	Knotless fine mesh large mesh count	Fine mesh reference	Larger angle	Fine mesh knotless

LT paste

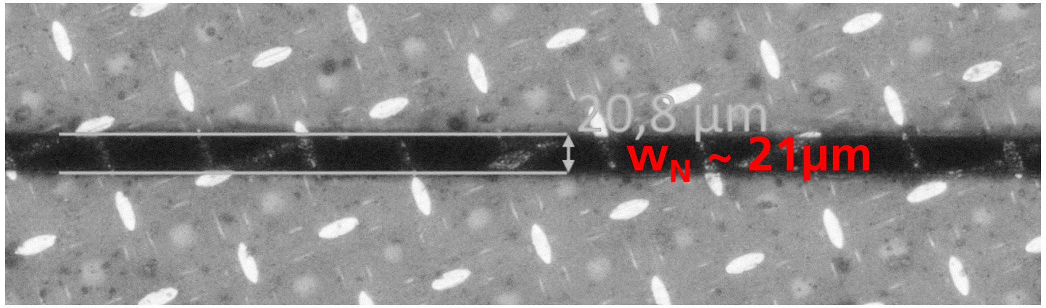
- Fine-line compatibility, good printing characteristics

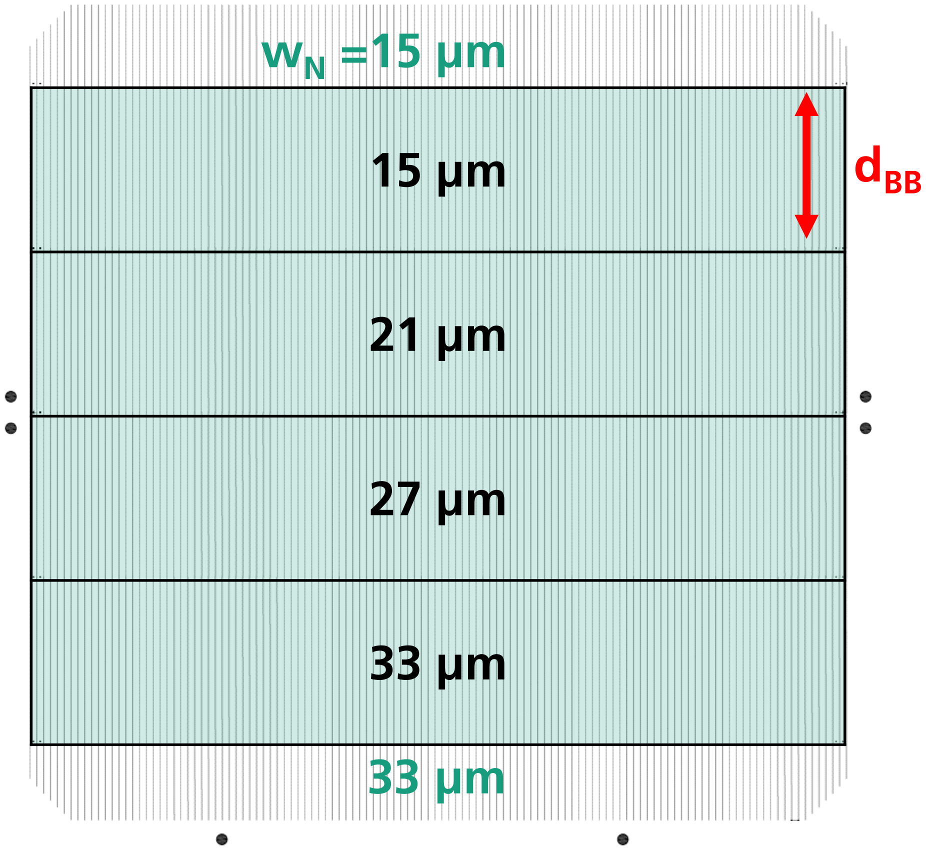
High quality printing process

Evaluation of Screens to Reduce Ag Consumption

Printing Forms to Test for Fine-Line Compatibility

- Layout with n_F = 120 fingers, pitch 1.3 mm
- **Variation:**
  - Four segments with **varied opening w_N**



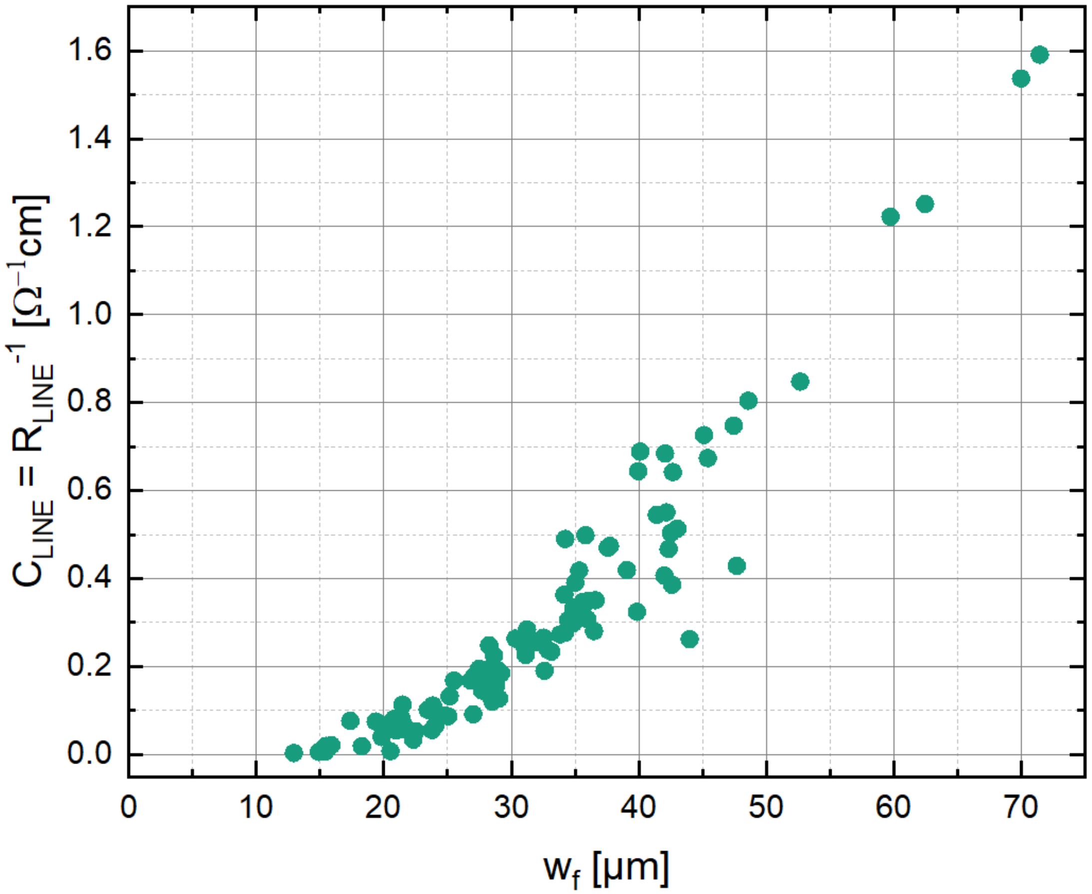


Evaluation of Screens to Reduce Ag Consumption

Results for Line Conductance C_{LINE} and Shading Width w_f

- Measurement of grid resistance with cell tester
  - R_{grid} → Line Resistance $\mathbf{R_{LINE}} = R_{grid} \times n_F / d_{BB}$
  - Line Conductance $\mathbf{C_{LINE}} = R_{LINE}^{-1}$
- Wide range covered (C_{LINE}~3 orders of magnitude)

Parameter	Units	min	max
C_{LINE}	$[\Omega^{-1}cm]$	0.004	1.6
R_{LINE}	$[\Omega cm^{-1}]$	0.63	272
w_f	[µm]	**13**	**71**



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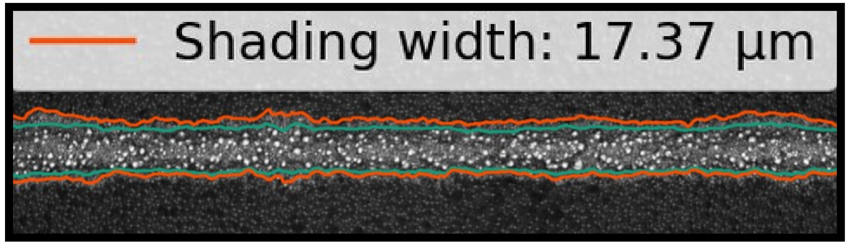
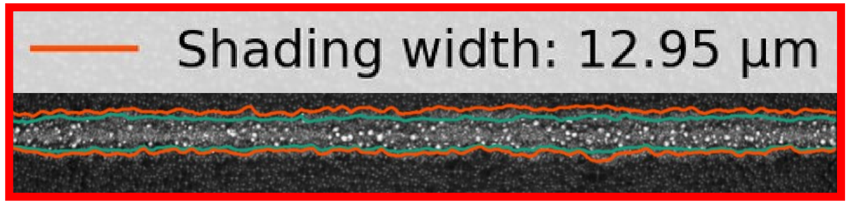
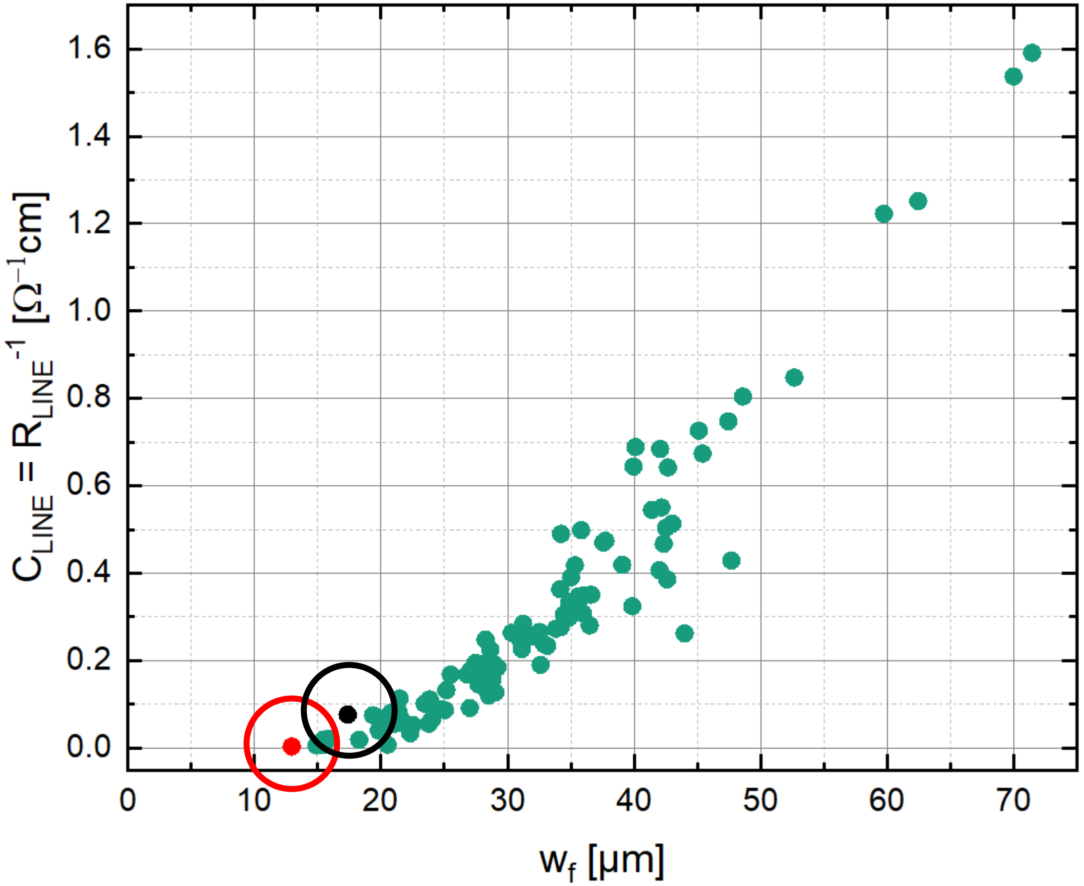
- Excellent fine-line results for Ag LTP







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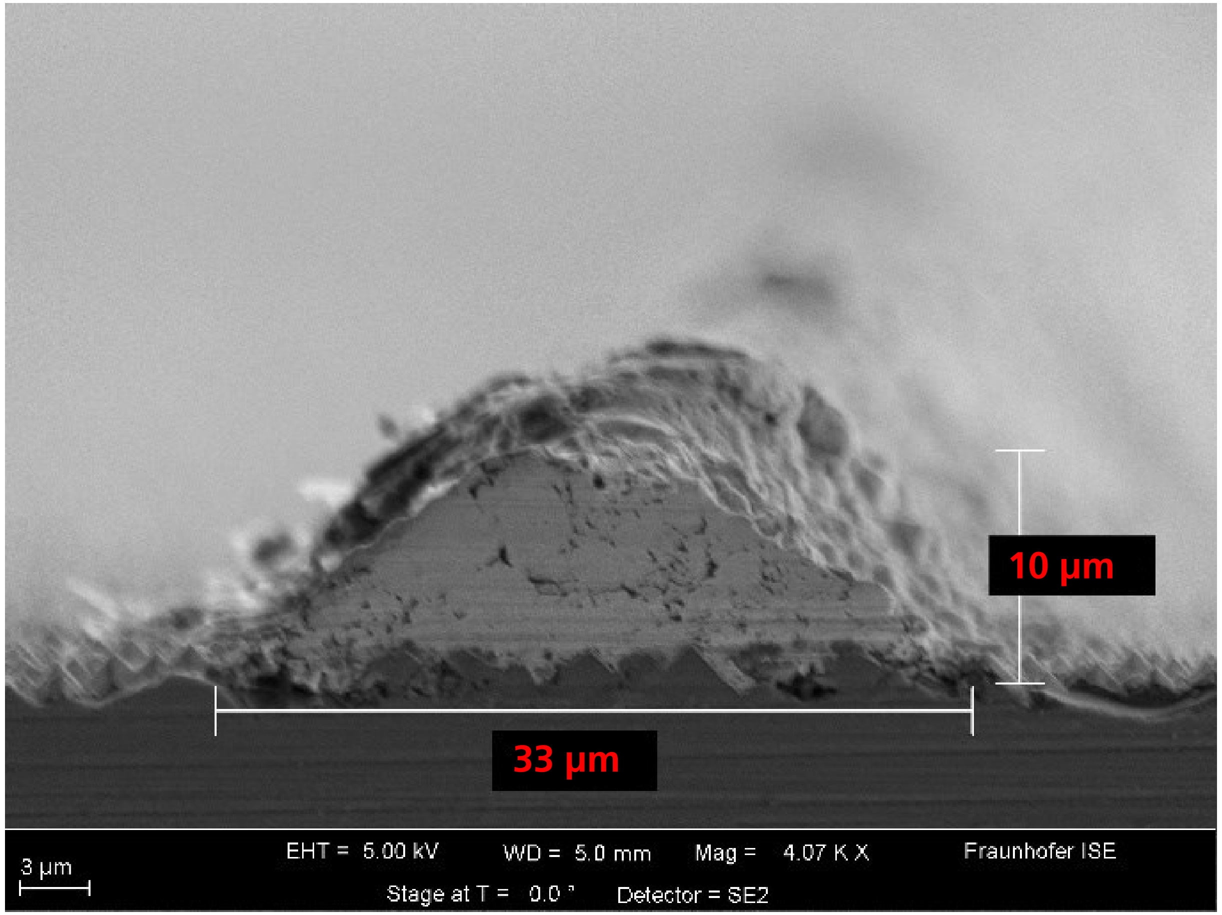


Are these fingers suitable for a given module layout?

Test Form Screening

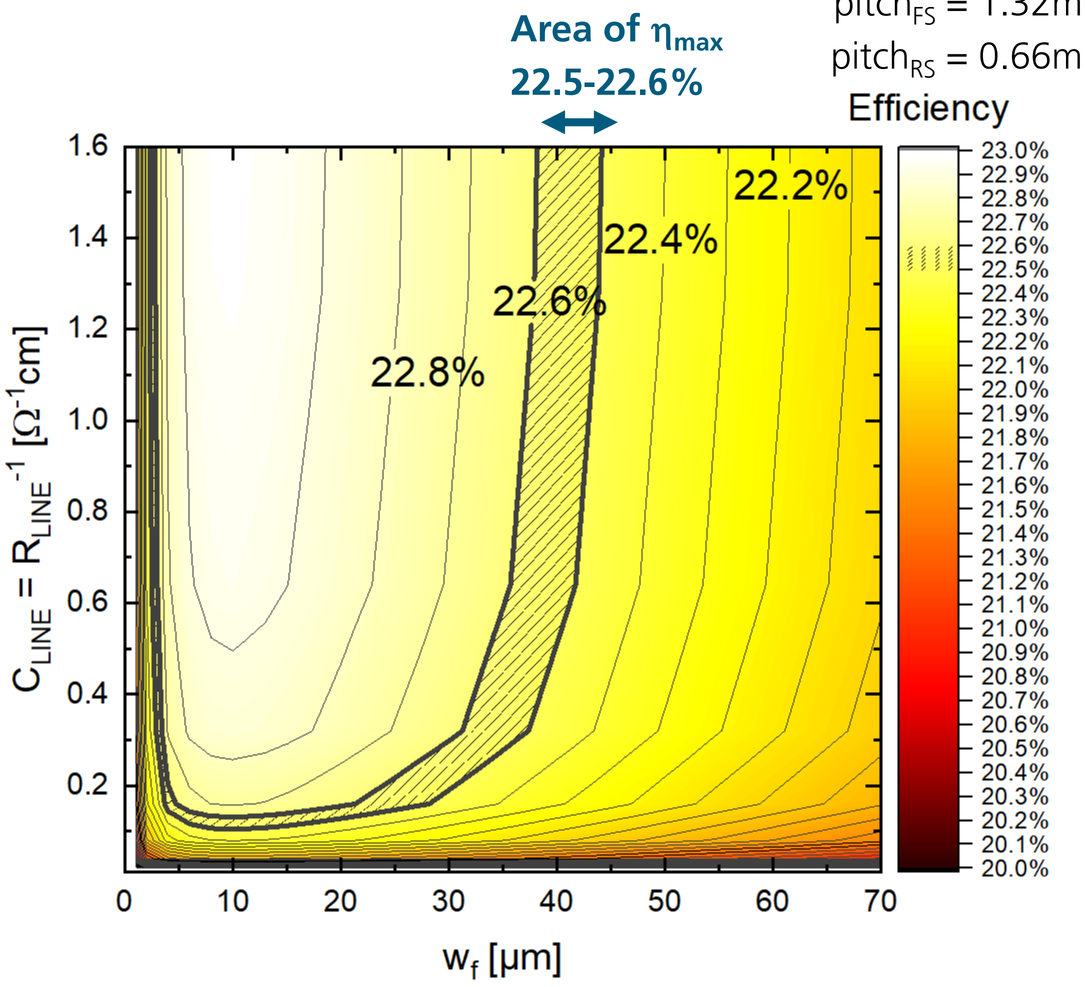
Cell- / Module-Layout Compatibility of the Printed Fingers

GridMaster[12] simulation

- M6 wafer half-cut cell (precursor $\eta_{pot}^{*} \sim 24\%$)
- Fix number of grid fingers FS: 63, RS: 126
- 9 MBB Layout: effective wire shading 70%[13]
- **Simulation of string-level designated area η**
- **Variation of:**
  - **Finger width w_f** (1-70µm)
  - **Line Conductance C_{LINE}** (up to 2 cm/Ω)

- For w_f < 10 µm contact resistivity $\rho_{metal,TCO}$ more relevant (simulation with ρ = 1.0 mΩcm²)

9MBB M6 HC
$pitch_{FS}$ = 1.32mm
$pitch_{RS}$ = 0.66mm



[12] T. Fellmeth, https://doi.org/10.1109/JPHOTOV.2013.2281105
[13] S. Braun, MIW 2013, https://doi.org/10.1016/j.egypro.2013.11.092

* η_{pot} : w/o metal shading and metal resistive losses

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Cell- / Module-Layout Compatibility of the Printed Fingers

Data of test form fingers:

- Different types of mesh, screen openings w_N and printing settings (e.g. print speed)
- Most promising fingers for a given cell / module layout can be easily identified.

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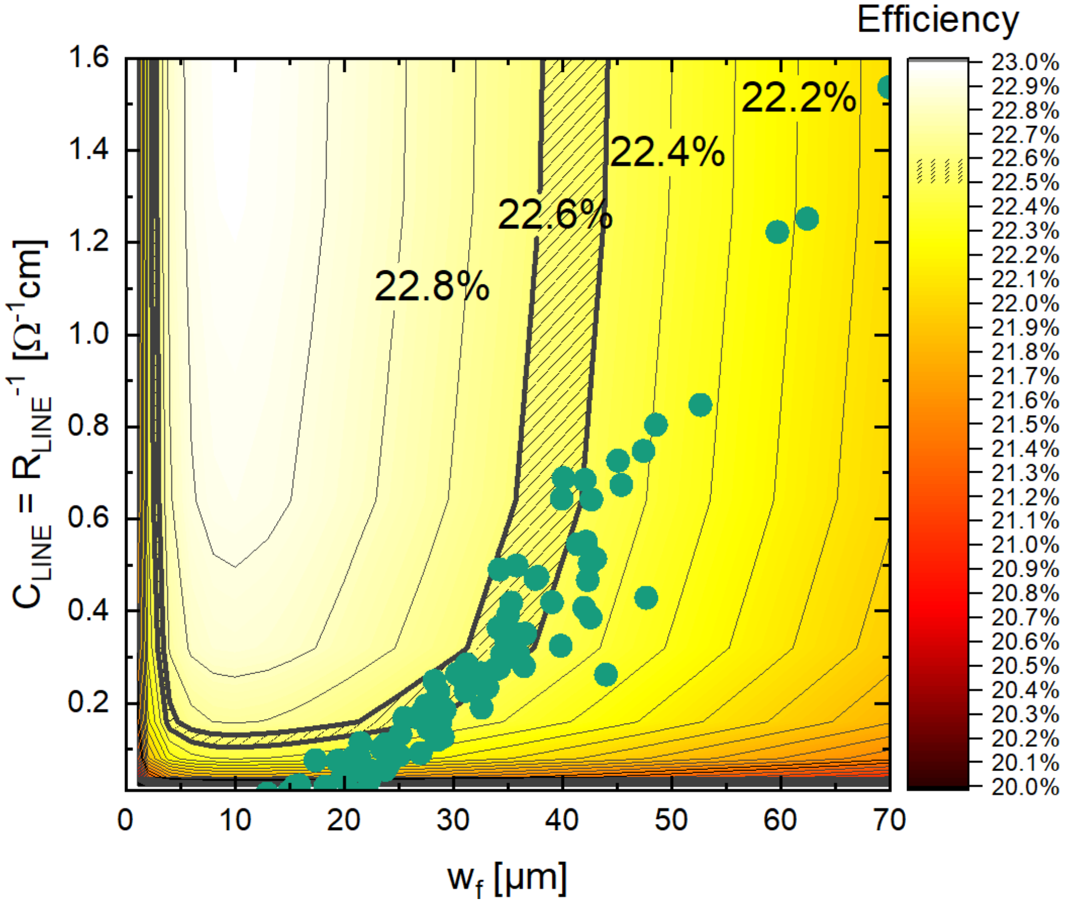

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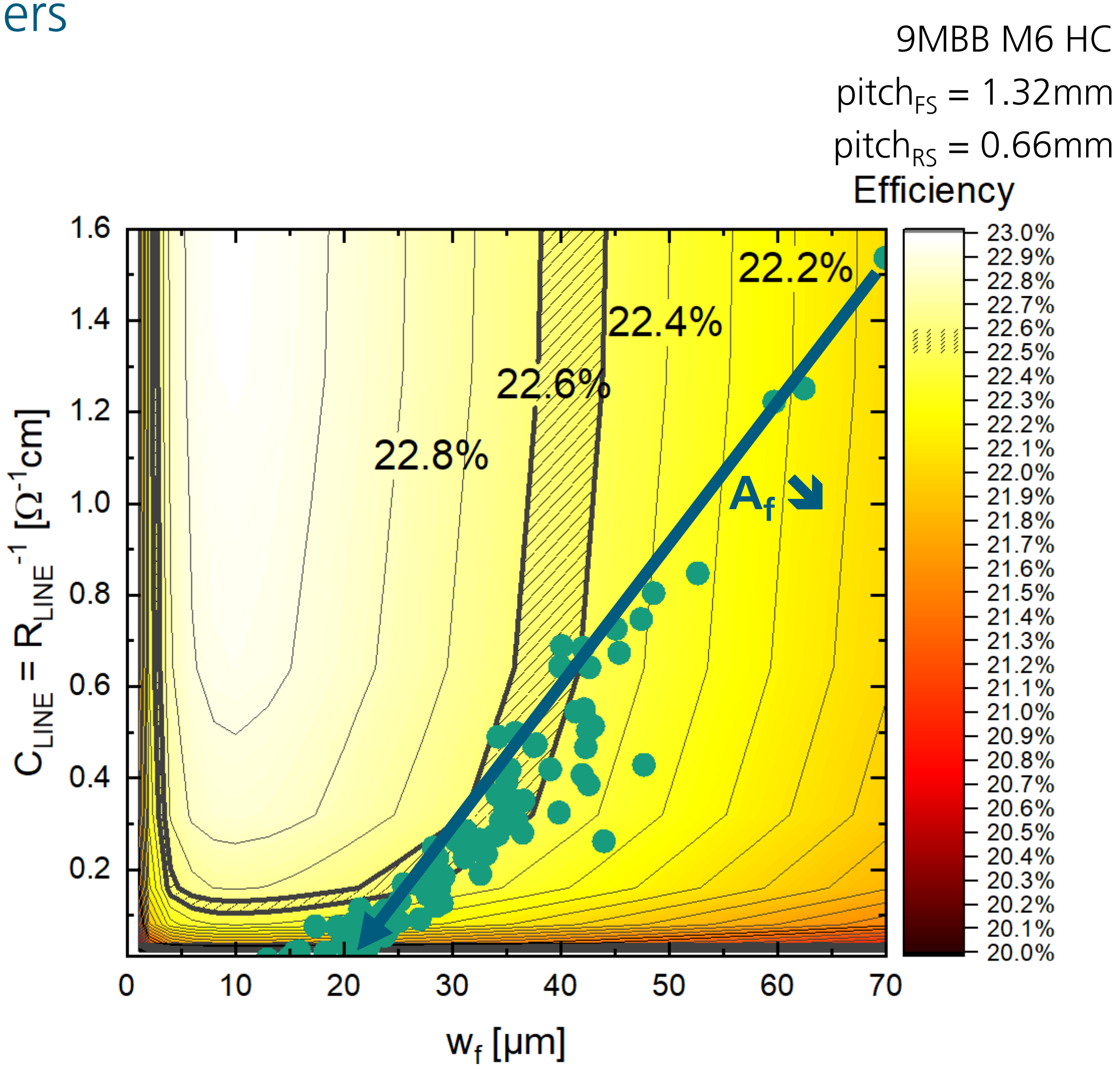

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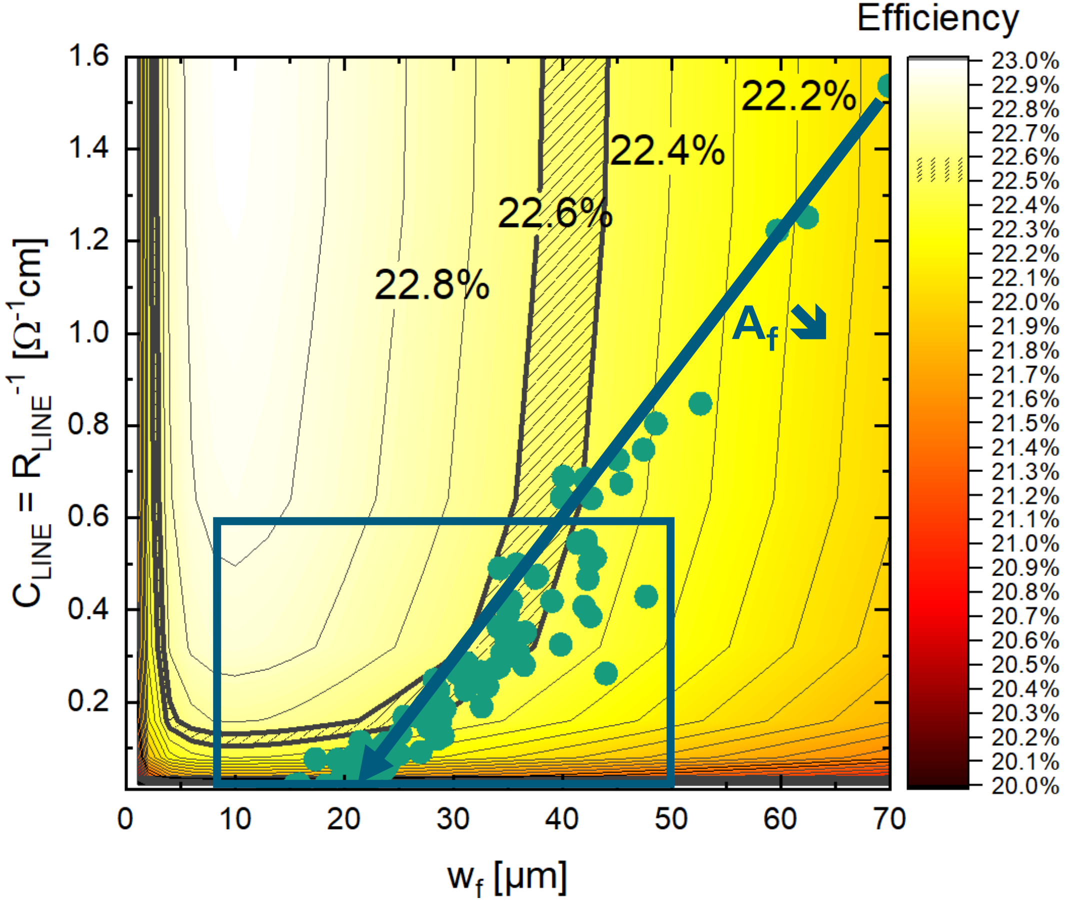

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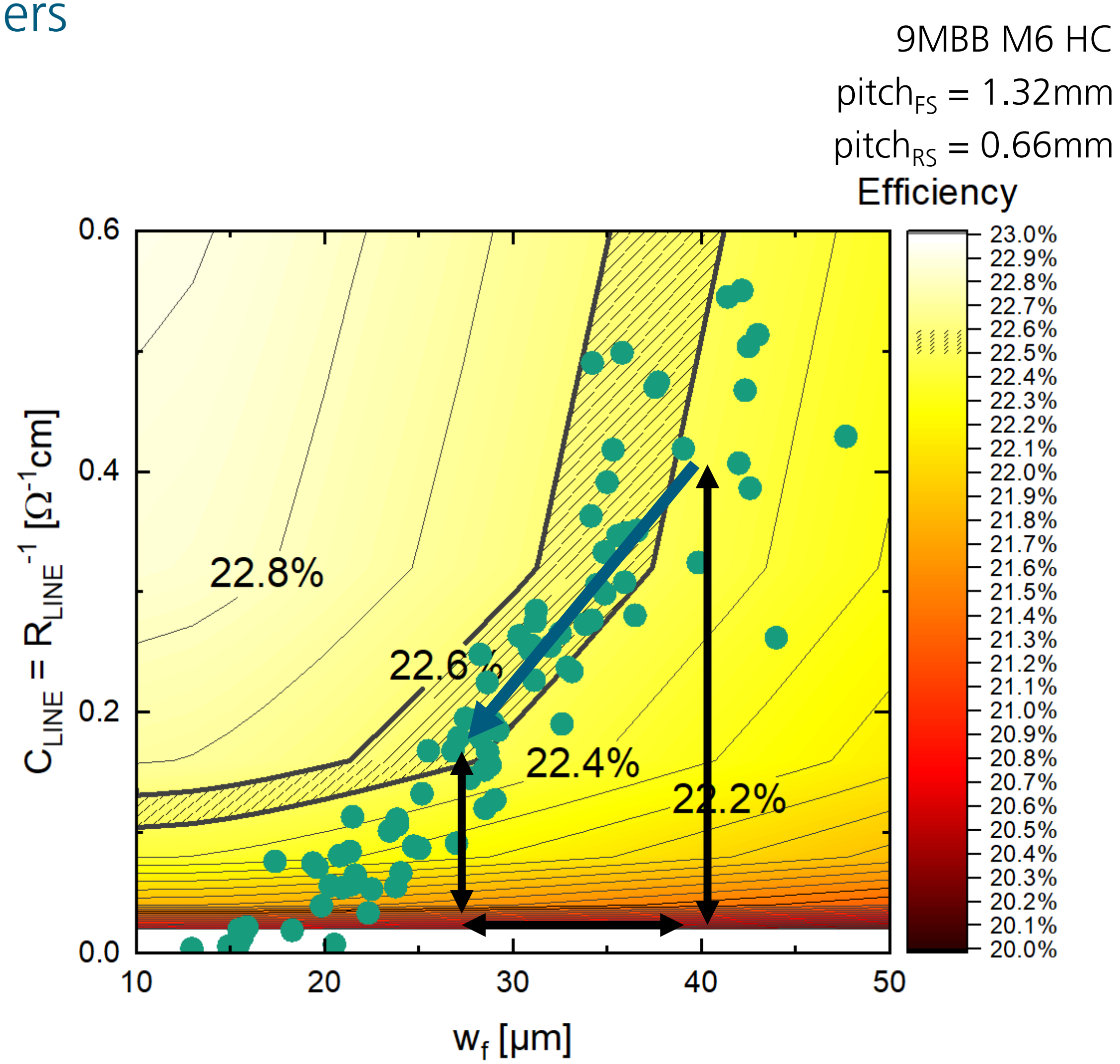

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Impact of the screen type ASADA vs. reference:

- Here all fingers printed with **300 mm/s**
- Highest non-0° performant finger with low Ag laydown **520x11x22.5° UHS mesh**

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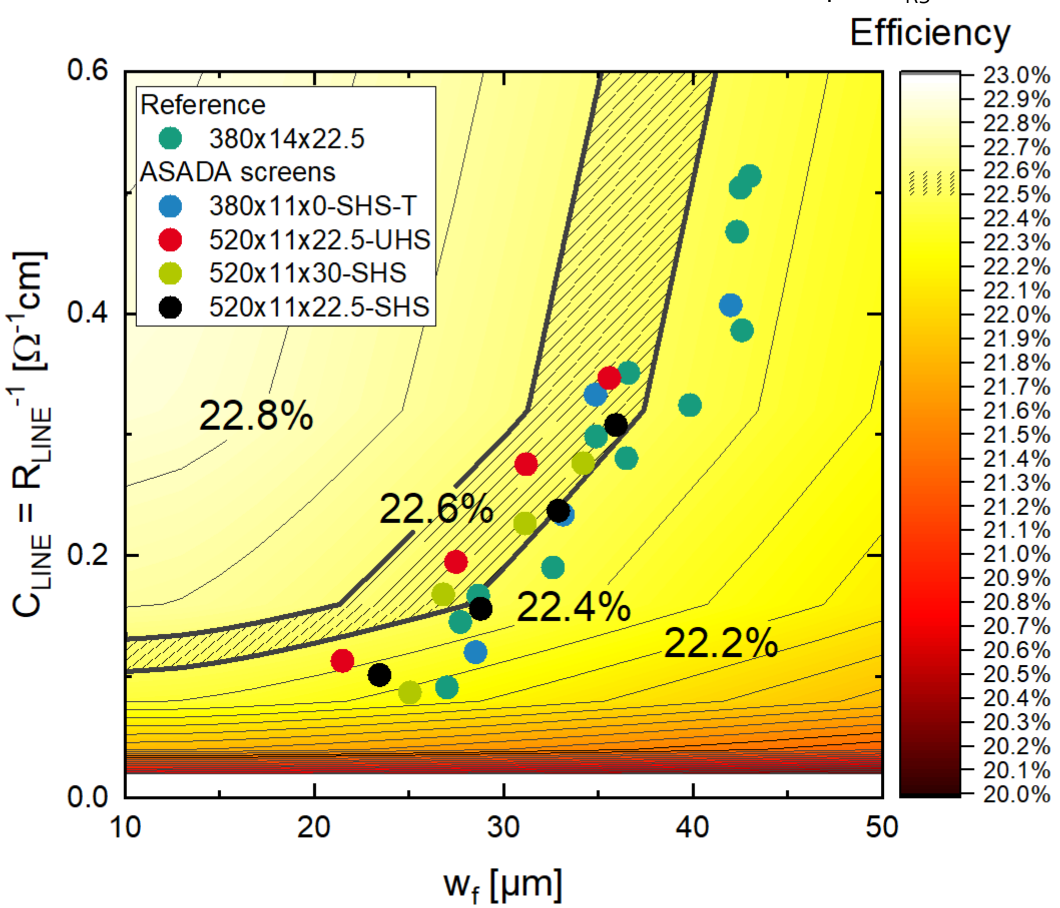

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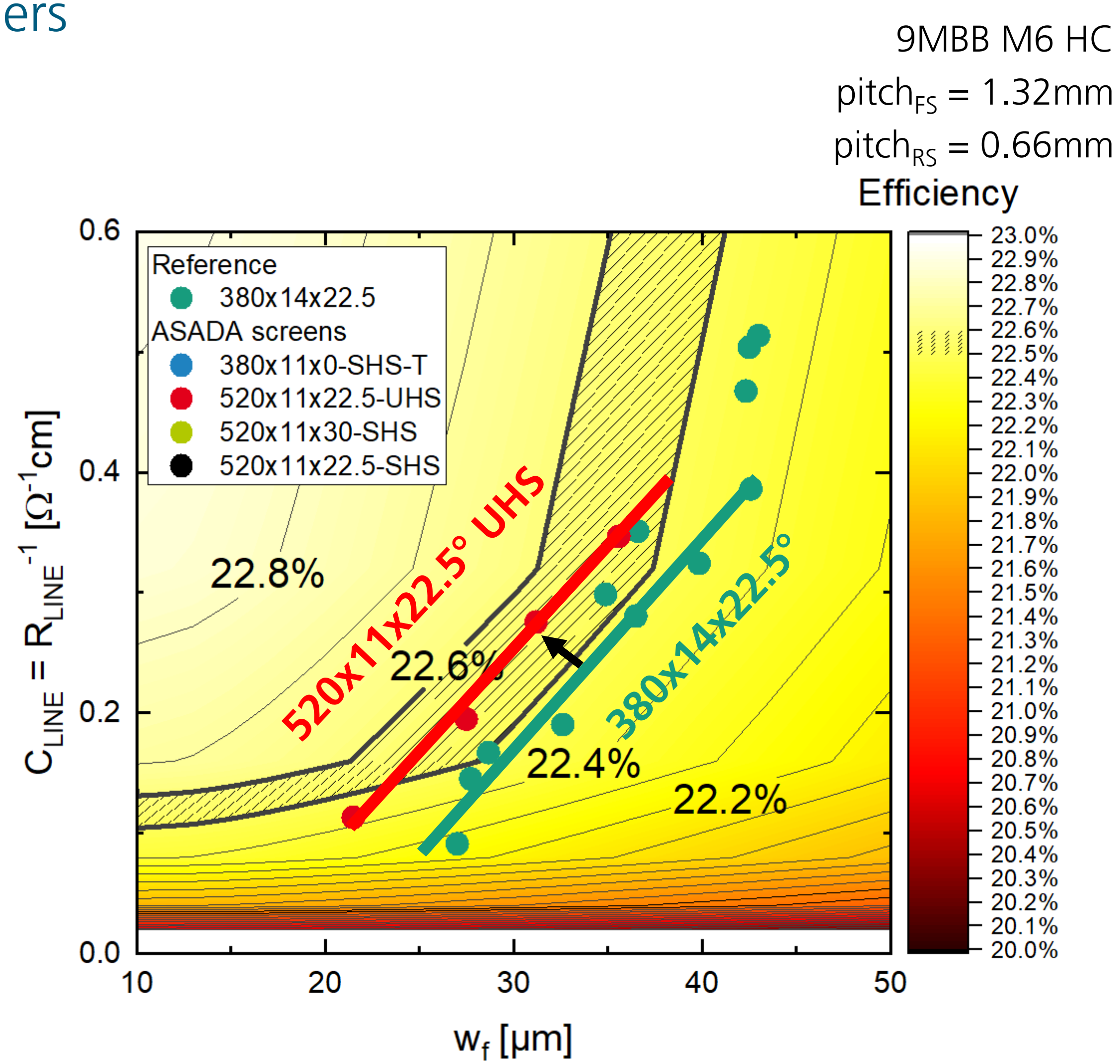

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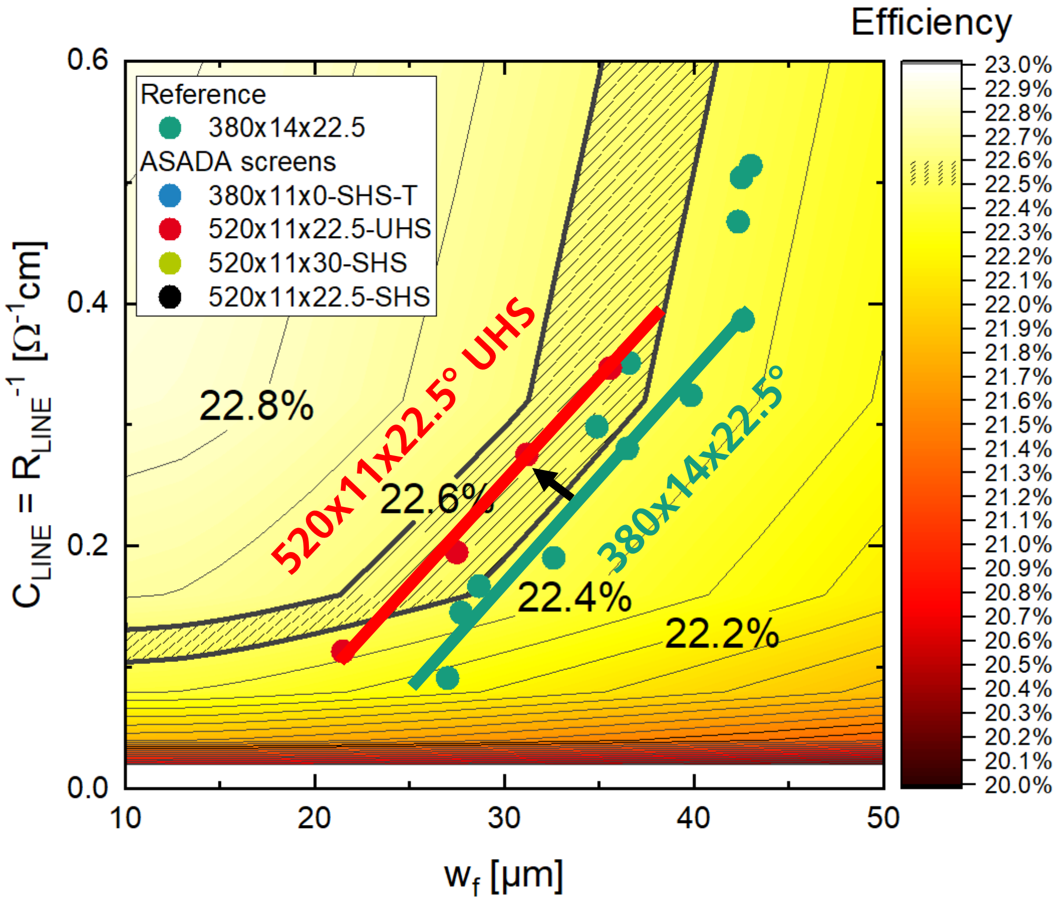
- **Average data for fingers with A_f < 300µm²**

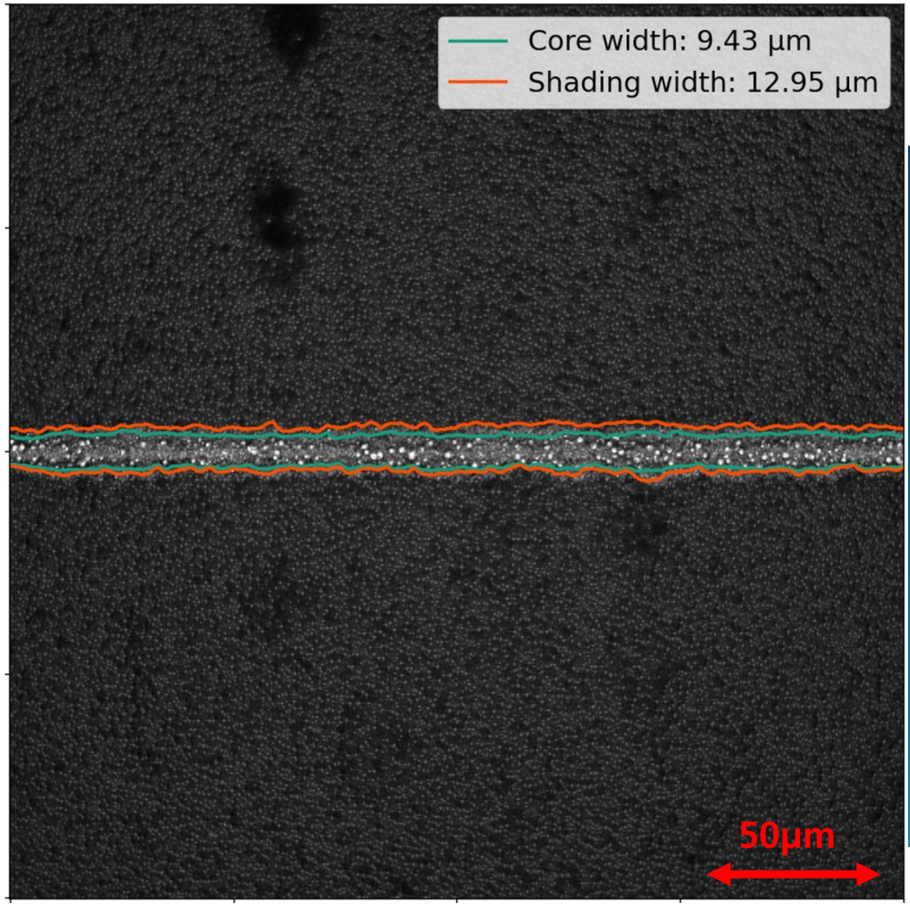
Mesh	R_{LINE} [Ω/cm]	w_f [µm]	A_f [µm²]	η_{GM} in %
380x14x22.5	5.6	33	166	22.46
520x11x22.5-UHS	5.1	29	140	22.54
Rel. Deviation	-8%	-11%	-15%	+0.36%

- **Laydown* reduced by 15%**
- Shading reduced by 10%
- R_{LINE} reduced by 8 %

} η↗ **0.08%$_{abs}$**



*scales with A_f



Finer mesh enables printing of narrow high-quality fingers.

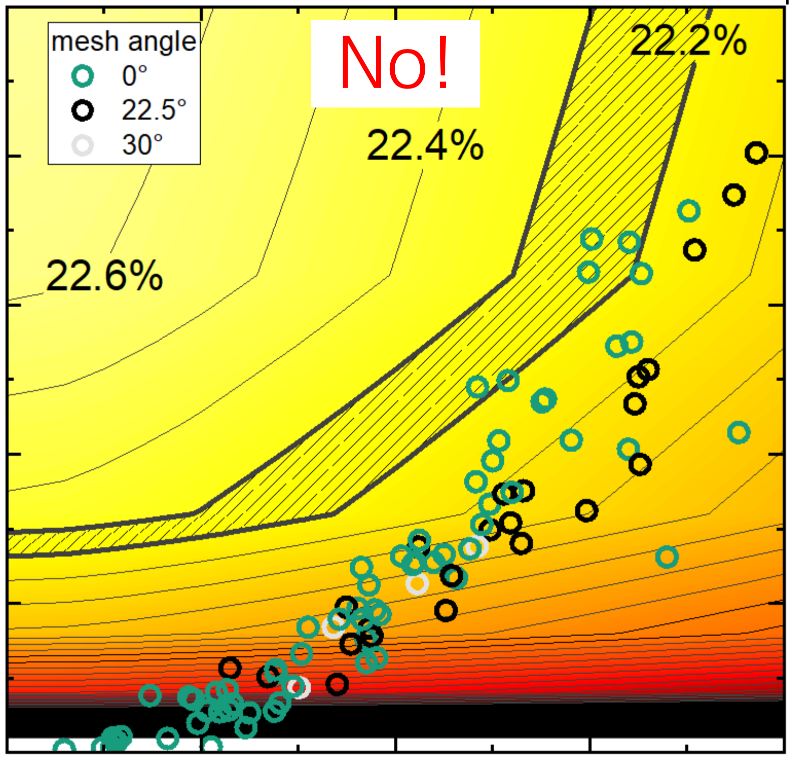
Can the fine-line fingers be module compatible?

Test Form Screening

Which Cell- /Module-Design is Suitable for Finest Lines

M6 HC
$pitch_{FS}$ = 1.32mm
$pitch_{RS}$ = 0.66mm

5 wires (300µm)



η_{peak} <22.3% (**w_f = 35-45µm**)

Scale y: C_{LINE} 0 - 1 cm/Ω **Scale x: w_f 10 - 50 µm**

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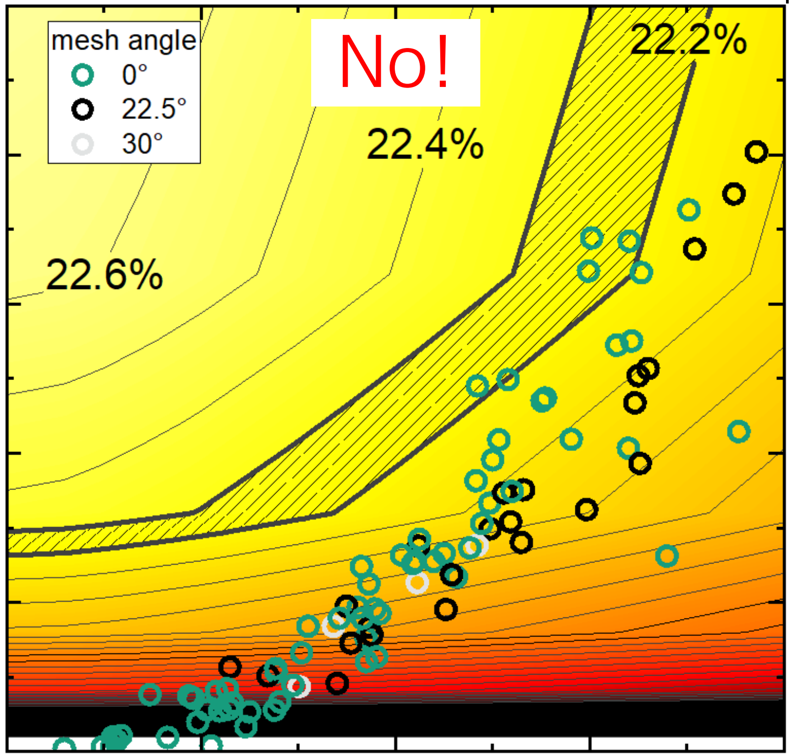
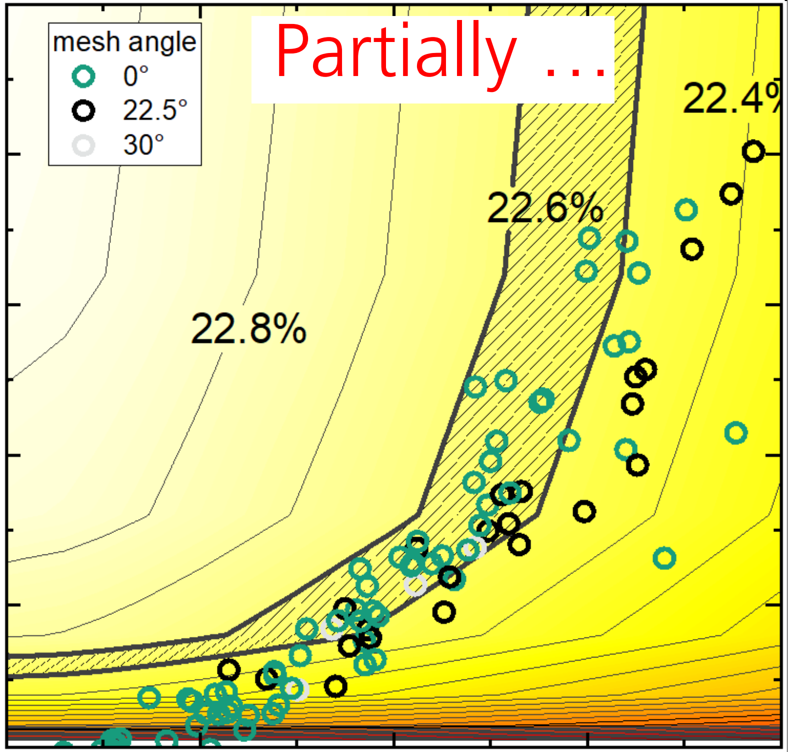
Test Form Screening

Which Cell- /Module-Design is Suitable for Finest Lines

M6 HC
$pitch_{FS}$ = 1.32mm
$pitch_{RS}$ = 0.66mm

5 wires (300µm)	9 wires (300 µm)
	
η_{peak} <22.3% (**w_f = 35-45µm**)	η_{peak} <22.6%(**w_f = 25-40µm**)

Scale y: C_{LINE} 0 - 1 cm/Ω **Scale x: w_f 10 - 50 µm**

Fraunhofer ISE

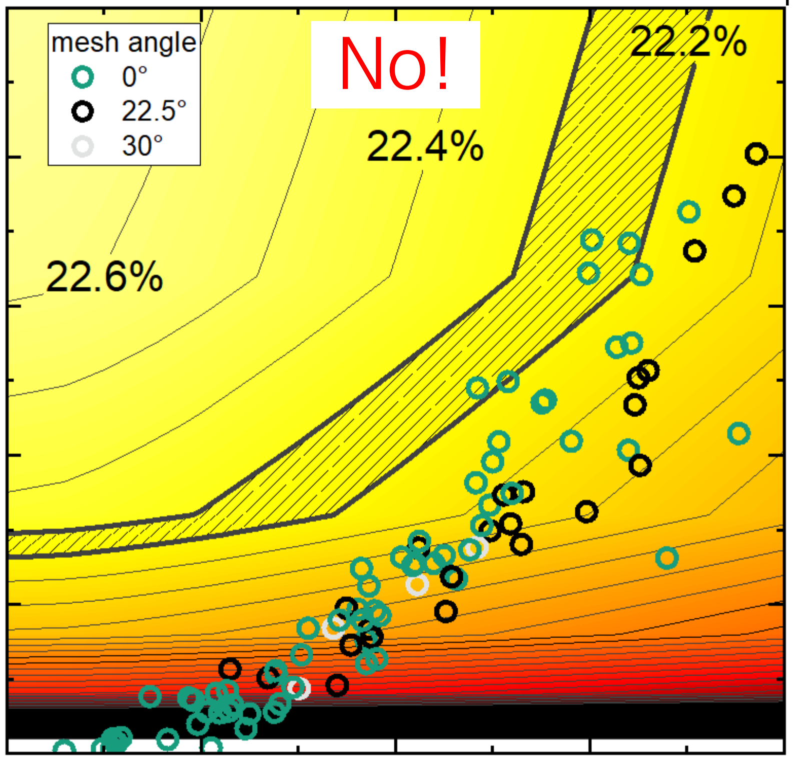
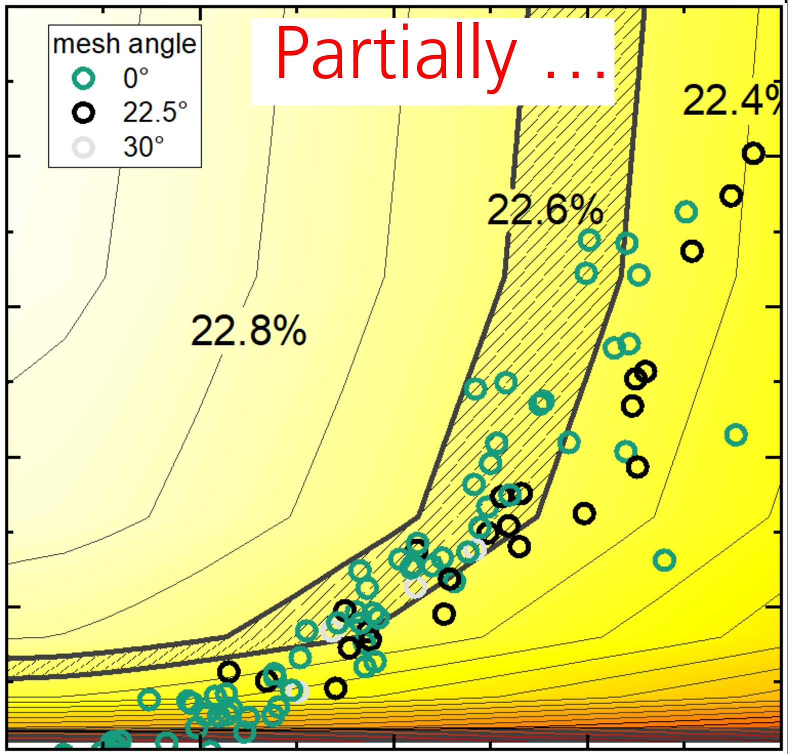
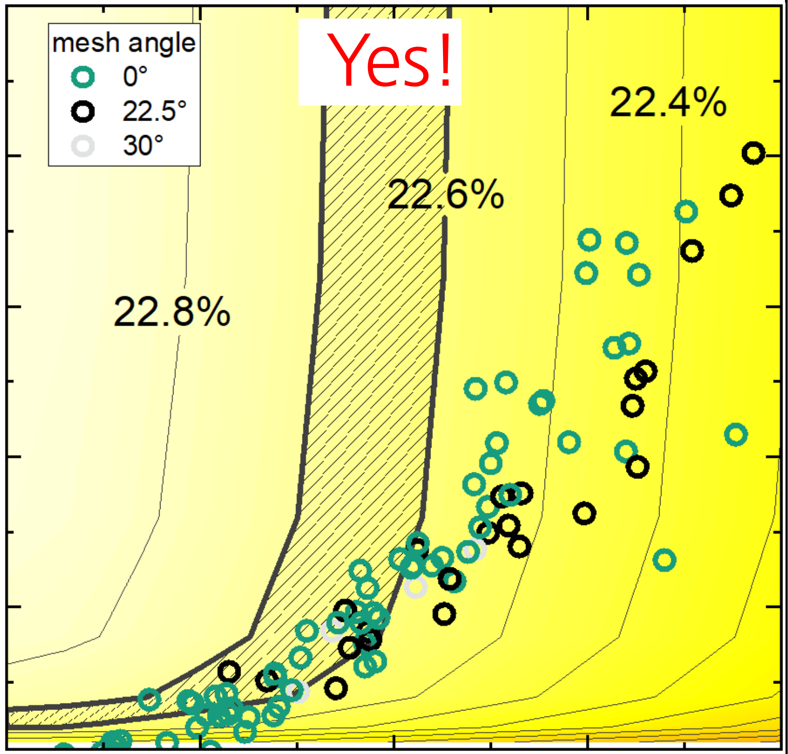
Test Form Screening

Which Cell- /Module-Design is Suitable for Finest Lines

M6 HC

$pitch_{FS}$ = 1.32mm

$pitch_{RS}$ = 0.66mm

5 wires (300µm)	9 wires (300 µm)	18 wires (250 µm)
		
η_{peak} <22.3% (**w_f = 35-45µm**)	η_{peak} <22.6%(**w_f = 25-40µm**)	η_{peak} <22.7%(**w_f = 15-30µm**)

Plot labels (5 wires): mesh angle 0° 22.5° 30°; No!; 22.2%; 22.4%; 22.6%

Plot labels (9 wires): mesh angle 0° 22.5° 30°; Partially …; 22.4%; 22.6%; 22.8%

Plot labels (18 wires): mesh angle 0° 22.5° 30°; Yes!; 22.4%; 22.6%; 22.8%

Scale y: C_{LINE} 0 - 1 cm/Ω **Scale x: w_f 10 - 50 µm**

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Which Cell- /Module-Design is Suitable for Finest Lines

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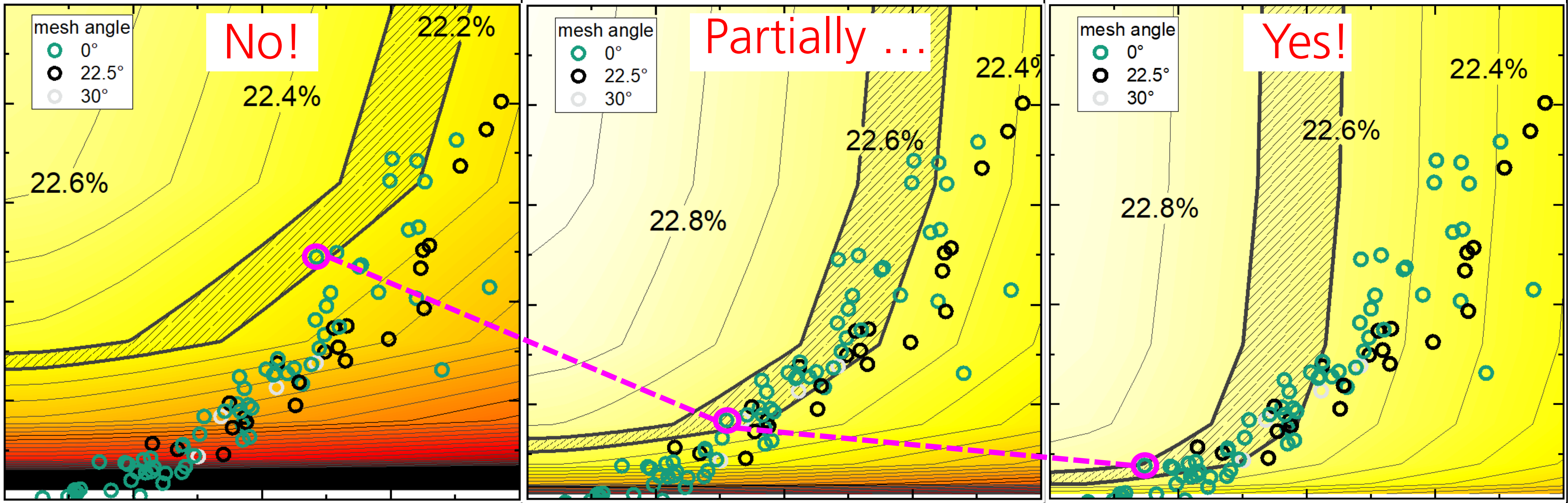
5 wires (300µm)	9 wires (300 µm)	18 wires (250 µm)



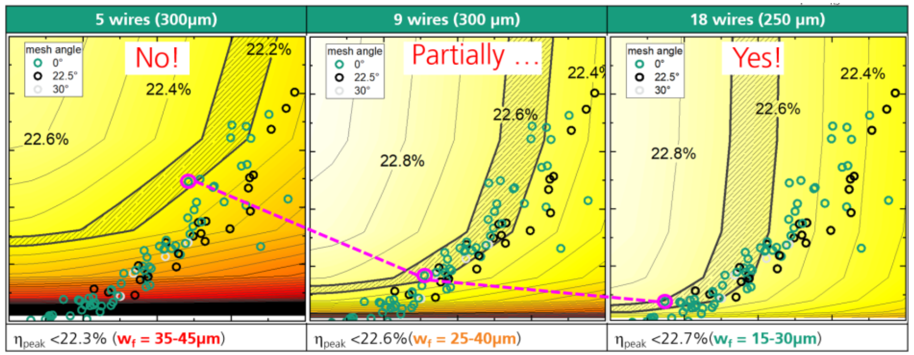
η_{peak} <22.3% (**w_f = 35-45µm**)	η_{peak} <22.6%(**w_f = 25-40µm**)	η_{peak} <22.7%(**w_f = 15-30µm**)

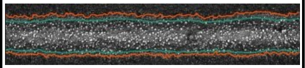
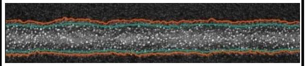
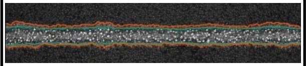
Scale y: C_{LINE} 0 - 1 cm/Ω **Scale x: w_f 10 - 50 µm**

Test Form Screening

Simulation Impact of FS Finger Pitch

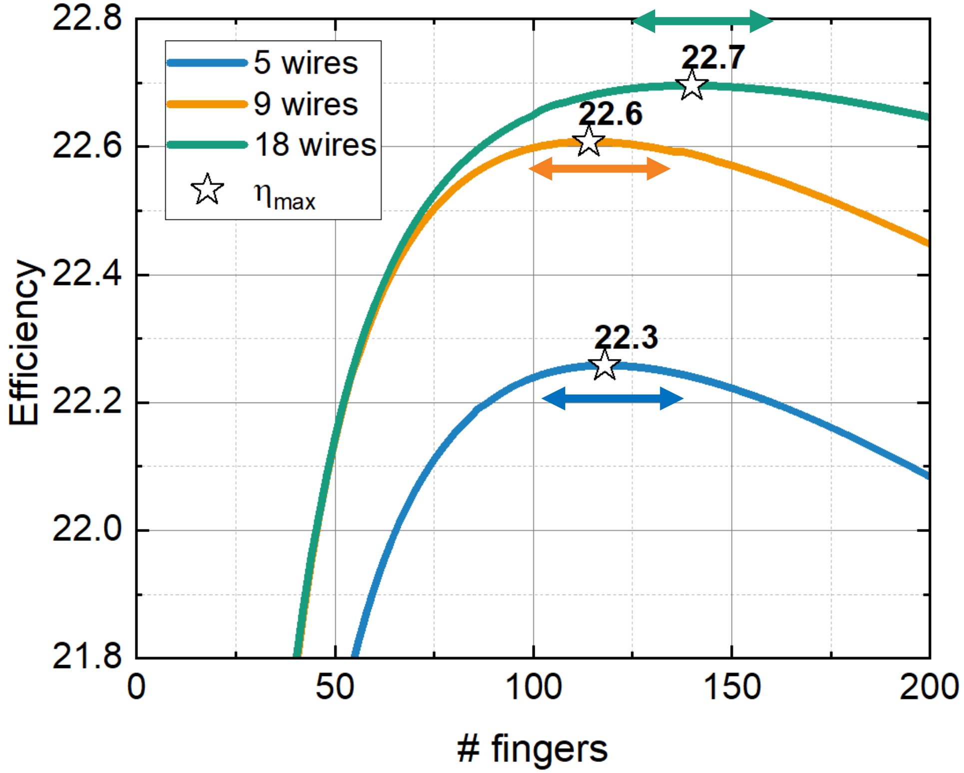
- Selection of best fine-line fingers for η_{max}
- All printed with fine mesh and knotless screens



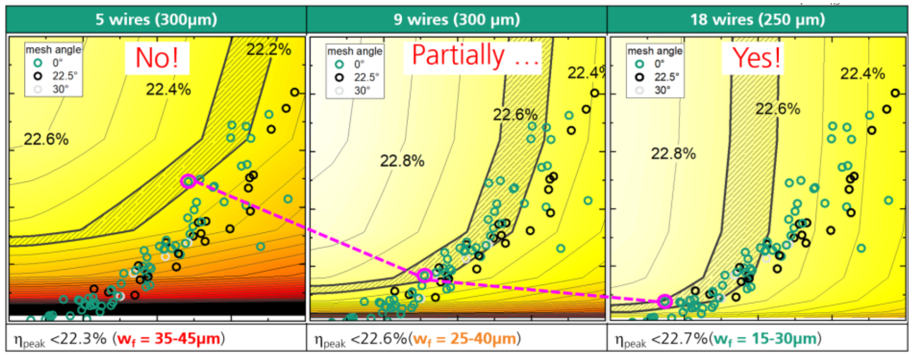
Module	5 wires	9 wires	18 wires
LEXT			
R_{LINE} [Ω/cm]	2.0	4.0	13.1
w_f [µm]	34.2	28.3	17.4
A_f [µm²]	243	149	47

Test Form Screening

Simulation Impact of FS Finger Pitch



- Optimal number of grid lines ~ 100-160
- 9 and 18 wires superior in η compared to 5 wires



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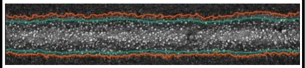
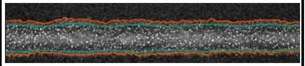
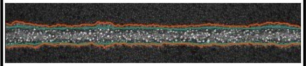
LEXT			
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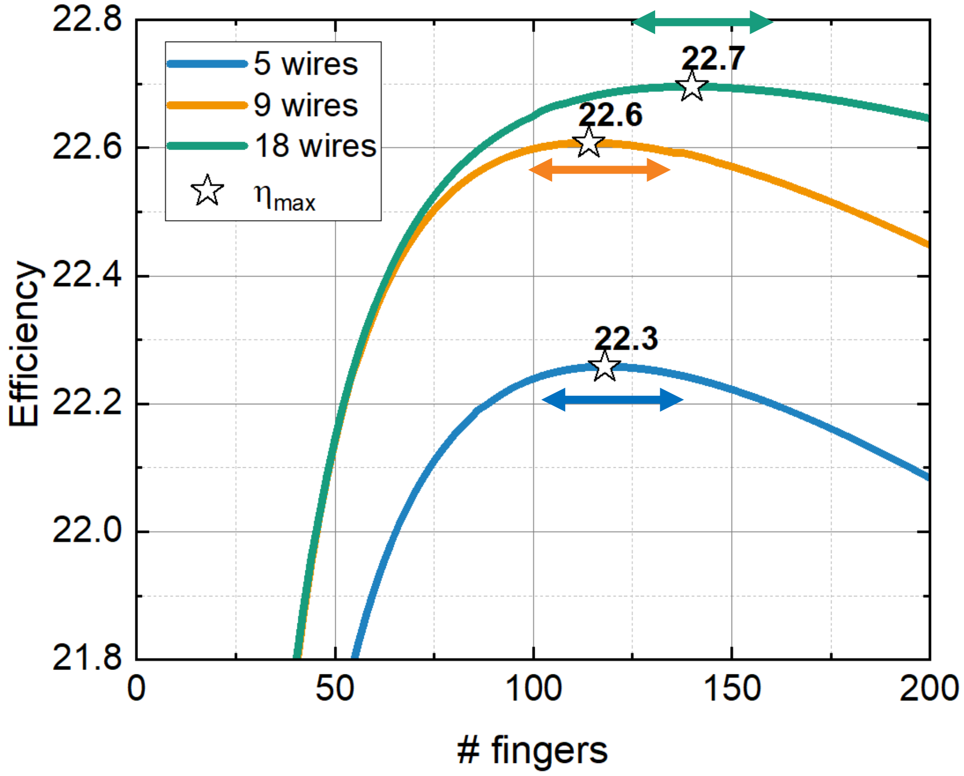
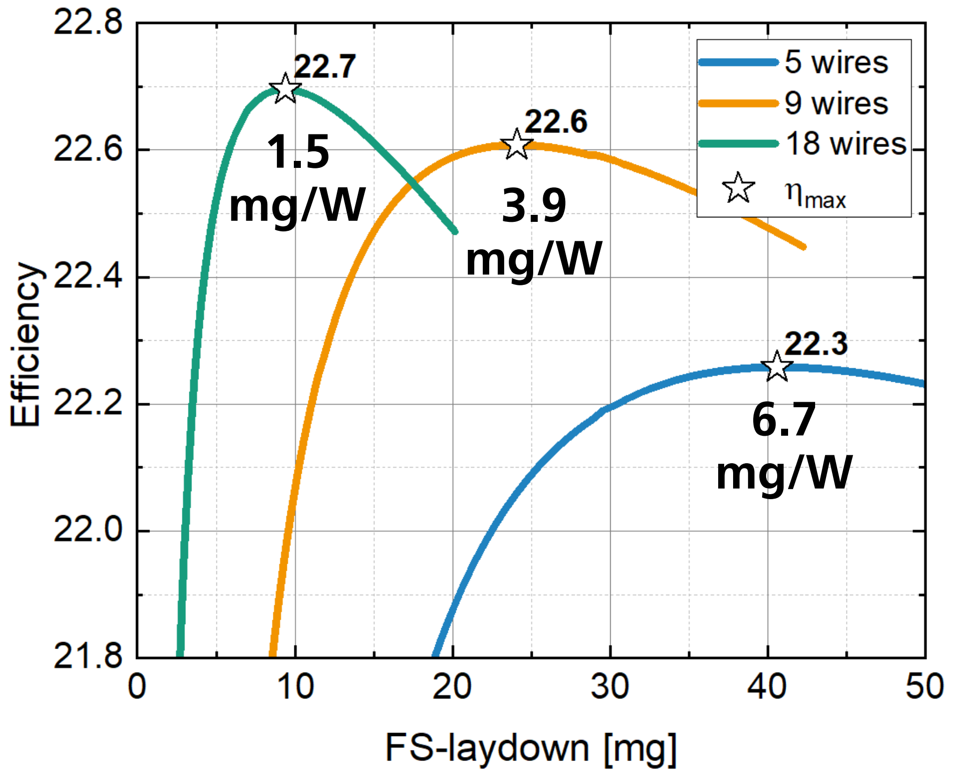
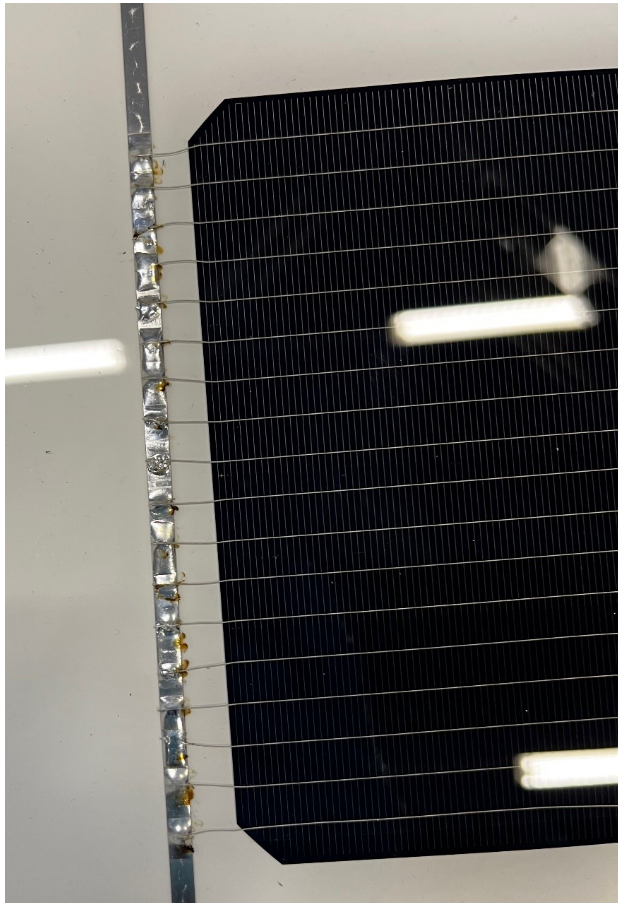




- Optimal number of grid lines ~ 100-160
- 9 and 18 wires superior in η compared to 5 wires

- Finer lines allow to reach η_{max} at lower laydown
- **$\eta_{max,18\ wires}$ with 1.5 mg/W FS contribution**



Simulations show:

Small module wire pitch allows

- Narrow lines and
- Small finger cross-section area

at high efficiency level.

But what happens in real modules?

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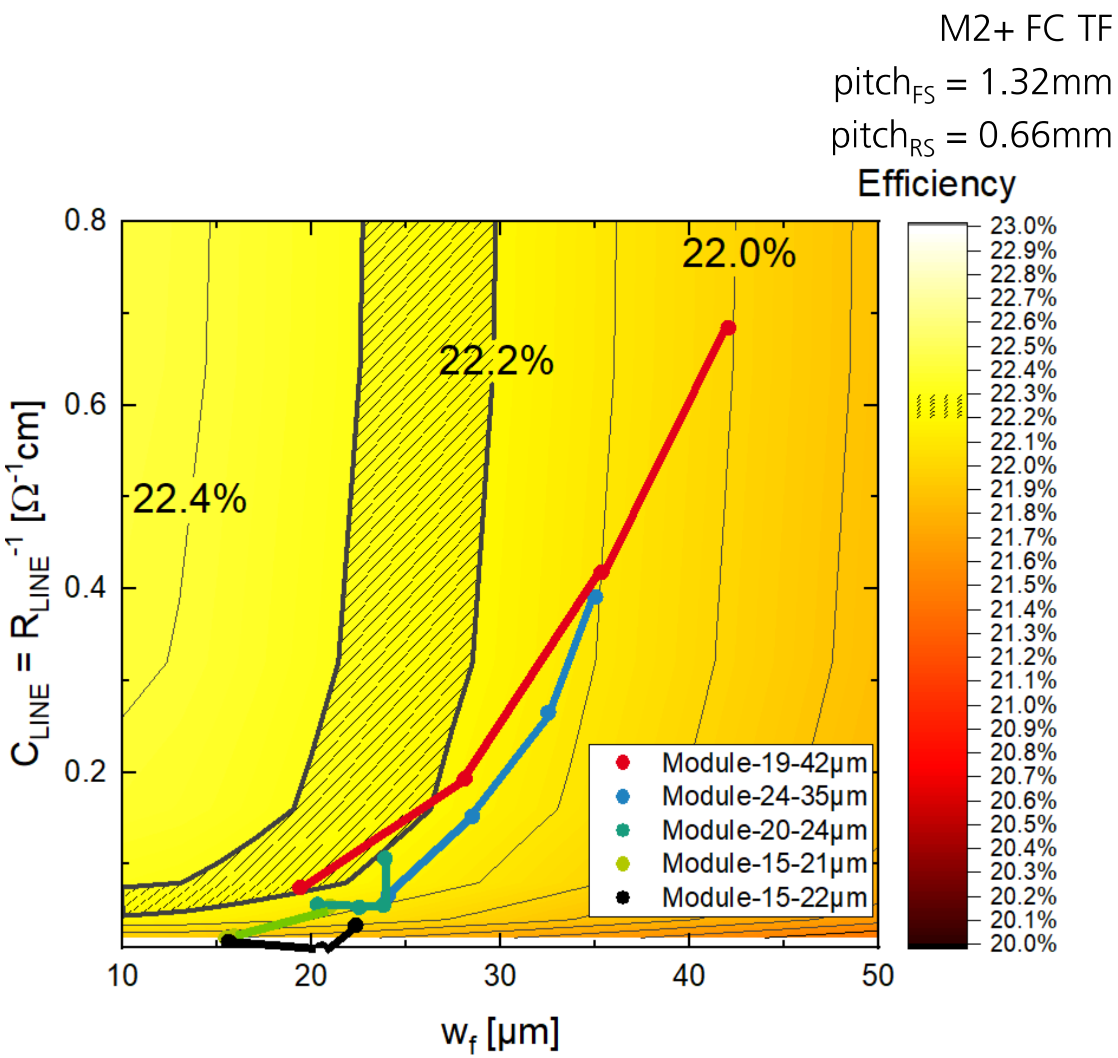
Test Form Screening

Samples for Module Integration

- Module platform: **SWCT with 18 wires (∅ 250 µm)**
  - Tolerant µ-cracks, TC-testing, mech. load, …
  - Manual mini-module integration of **test forms (TF) samples** (5 groups, 2 per group)
- Basis: **M2+ SHJ precursor** post PVD η_{pot} ~ 24%
- **Full M2+ test form cells (FC)**
  - Simulation M2+ **HC → FC**: η-drop ~0.45%$_{abs}$

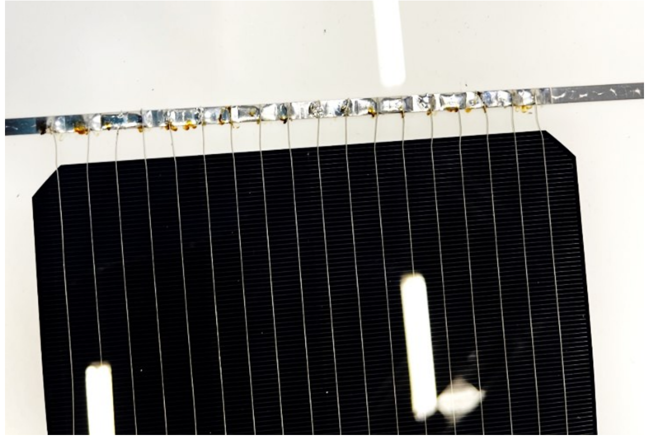


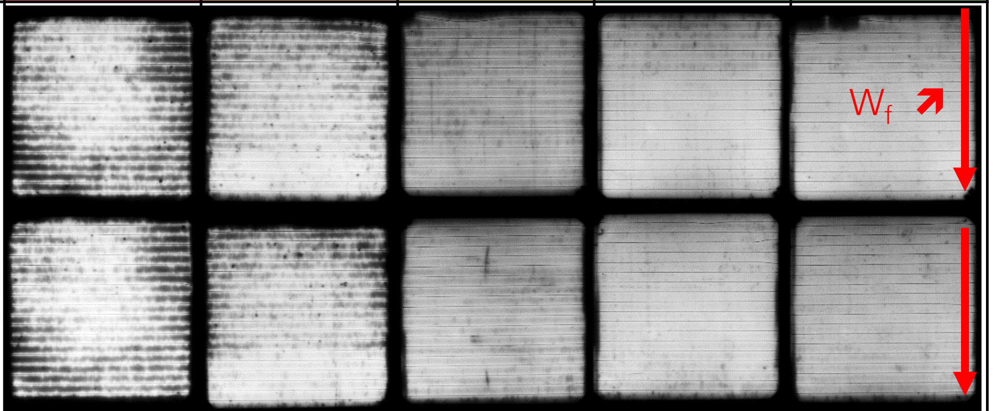
Test Form Screening

SWCT Module Results

M2+ FC TF
$pitch_{FS}$ = 1.32mm
$pitch_{RS}$ = 0.66mm

- **Reasonable η of 21%** (sim. 22.1% active area) **for ~ 8 mg LTP FS-laydown and w_f 20-24 µm**
- FC + additional R_S in module / cell periphery
  → low module FF: ~72.5%



Group	1	2	**3**	4	5
FS Laydown	6.7 mg	7.2 mg	**8.3 mg**	22.0 mg	30.1 mg
η_{STC}	19.4%	20.3%	**20.9%**	21.3%	21.3%
EL					
η_{STC}	19.4%	20.4%	**21.0%**	21.4%	21.3%

Module size: 28 x 25 x 0.3 cm³, float glass (no AR) + white backsheet
η active cell area 246 cm², IV not masked, module R_S losses included

Test Form Screening

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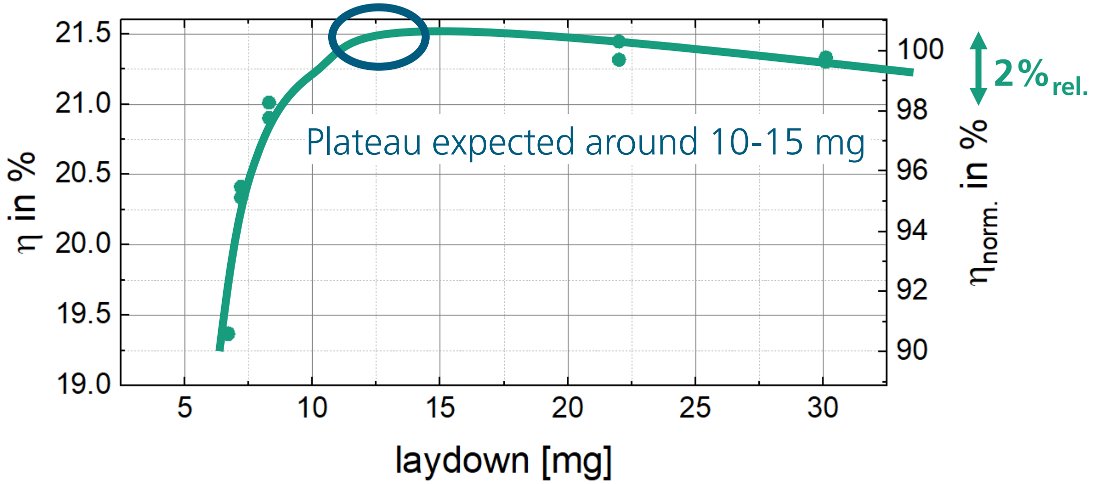

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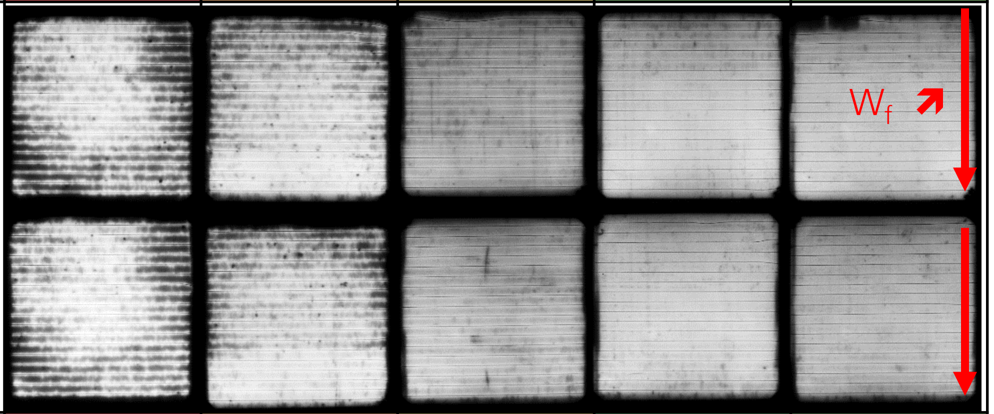
EL					
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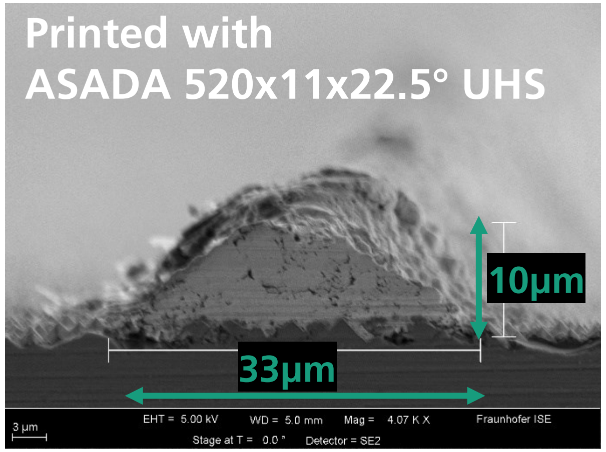
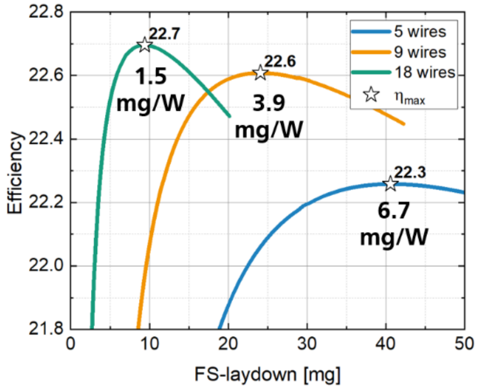
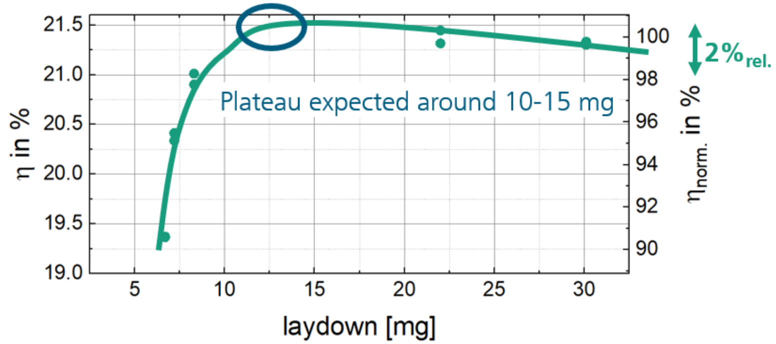
Summary

Progress on the Reduction of Silver Consumption in Metallization of SHJ Solar Cells

- High Ag paste consumption for SHJ (~ 15-35 mg/W)
  Target: **long-term 2 mg/W (mid: 15 mg/W)[2]**
- **Finer ASADA mesh** (380x14 → 520x11) with uniform printing → reduction in R_{LINE} and shading
  → **η* ➚ 0.08%$_{abs}$ laydown ➘ 15%**
- Cell / module layout (# wires) VIP to reduce Ag
  Sim.: η*>22.6% with **FS 3.9 (#9)** / **1.5 mg/W (#18)**
- "Fine-line test-form cells" in **SWCT mini modules**
  η = 21.0% → FS: 1.6 mg/W**
  η** = 21.4% → FS: 4.2 mg/W
- Mid-term Ag-targets clearly passed with
  advanced mesh, screens, paste and module







*η string level, da **η active module area

[2]Y. Zhang, EES 2021, https://doi.org/10.1039/D1EE01814K

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Outlook

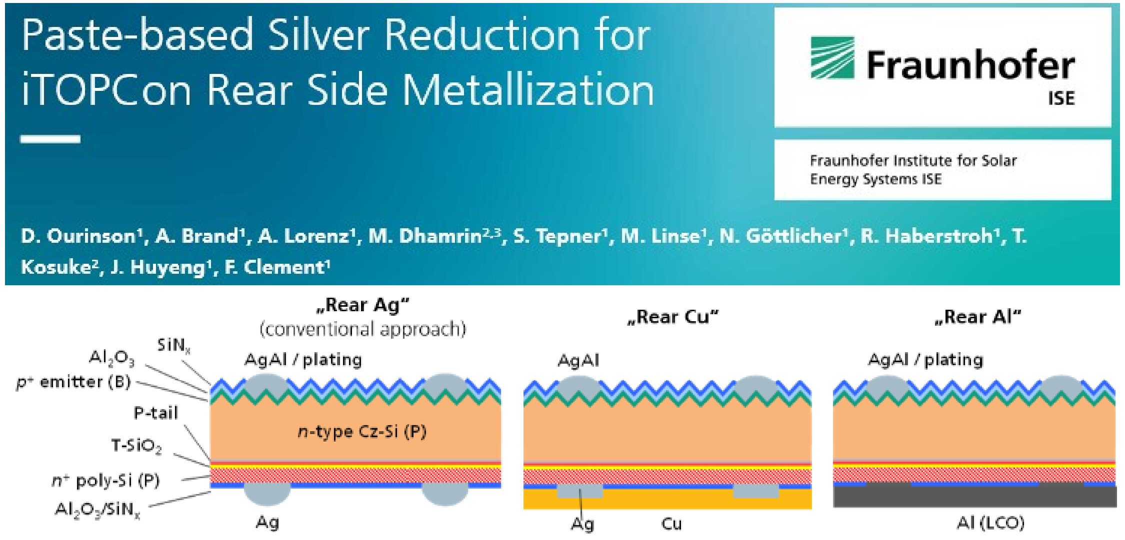
- Optimization of fine-line printing for **mass-production**

- Lower **FS + RS Ag-laydown**
  - **Fine-line Ag LTP**
  - **AgCu LTP** as a promising, already industry proven approach. Here fine-line printability was already investigated[14], further tests are planned
  - **Cu-LTP,** apply TOPCon learnings[9], enable screen printed **Ag-free SHJ**

Improve η_{module}

- **Integration of large wafer HC**
- **Application of** automated stringing

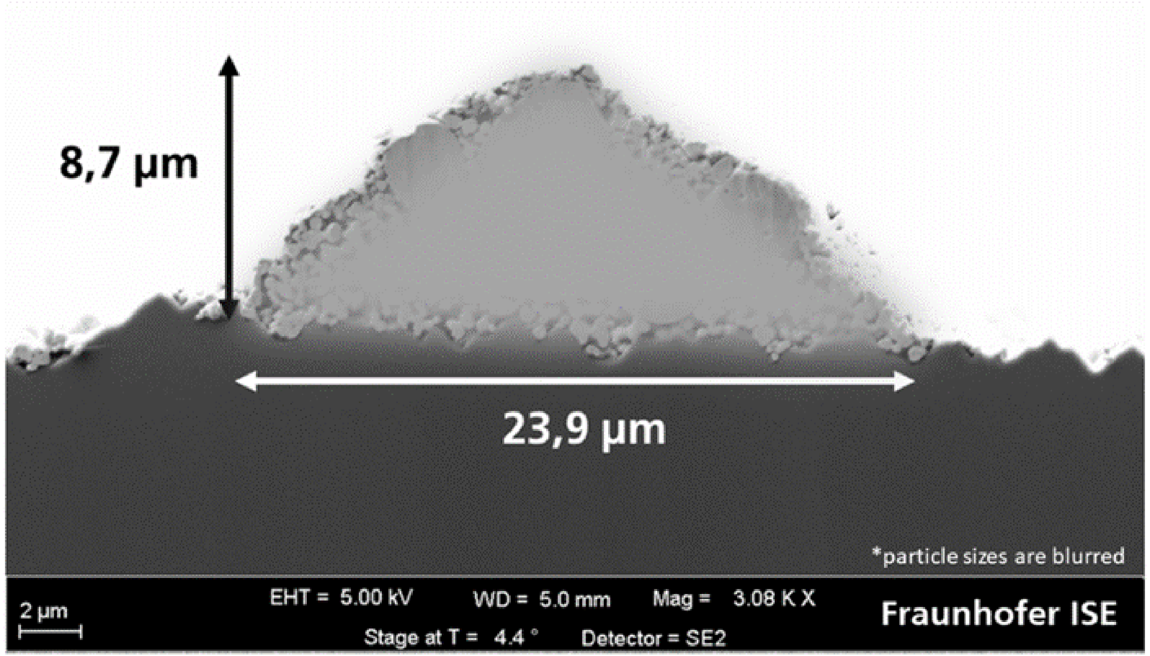
- **Long-term reliability testing**



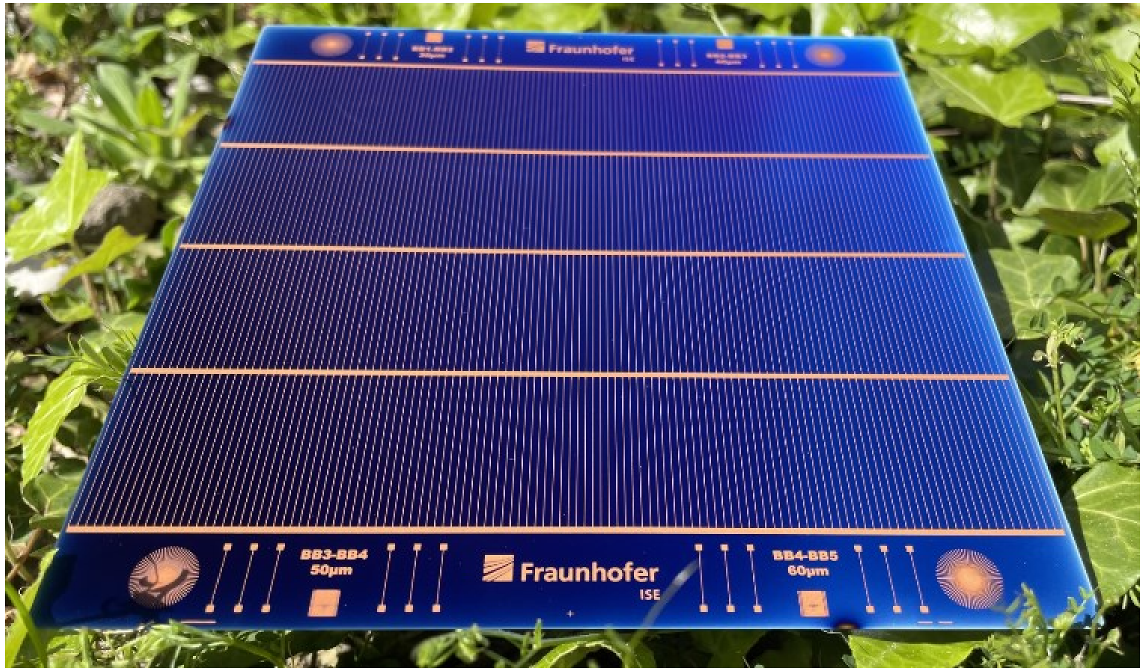
[14] S.Tepner: „Progress and current challenges with saving silver in screen printed metallization of Si solar cells", PVSEC-33 Nagoya 2022
[9]D. Ourinson, 2023, this workshop.

Outlook

Fine-line AgCu-LTP finger



Test form printed with Cu-LTP



Thank You for Your Attention!

Thanks to ASADA MESH for providing material for testing