CS International 2024

Novel high-power Laser Modules for Battery Manufacturing

Dr.-Ing. Roman Koerner | CTO TRUMPF Photonic Components

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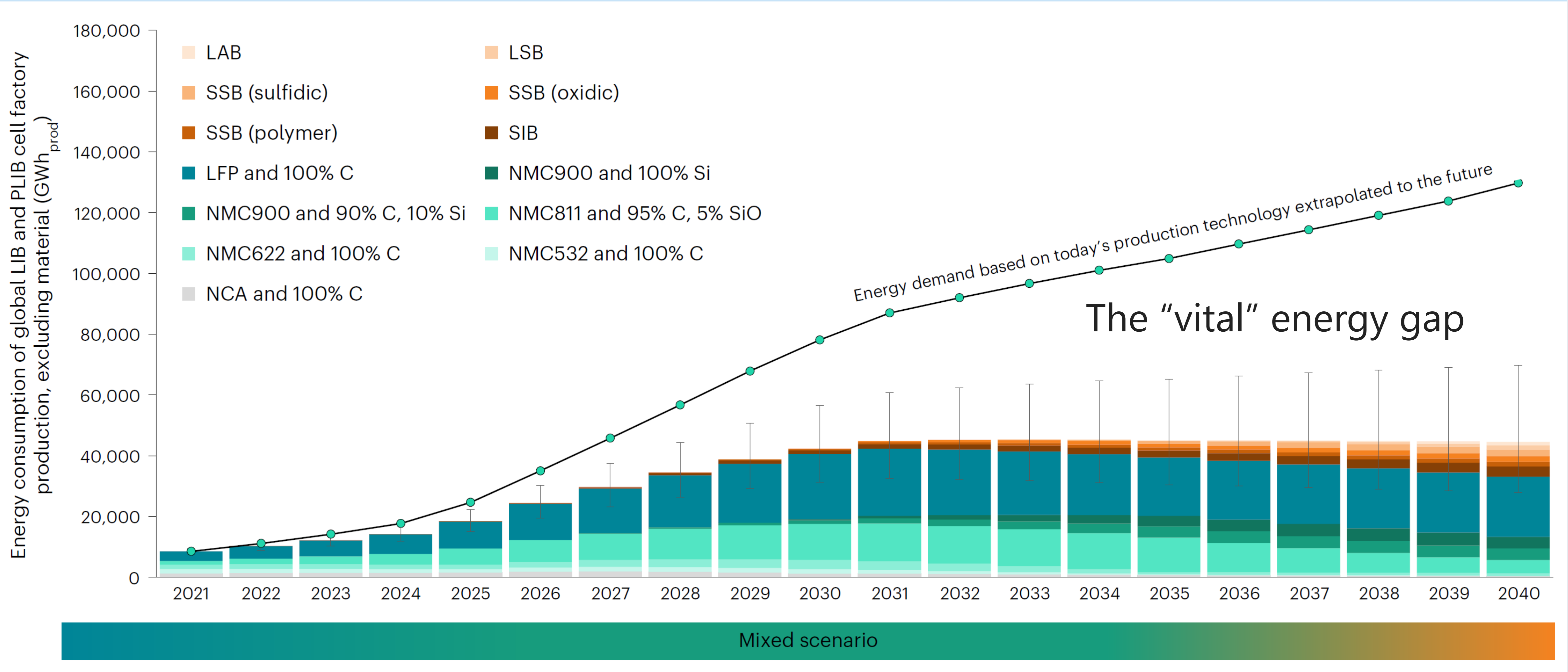
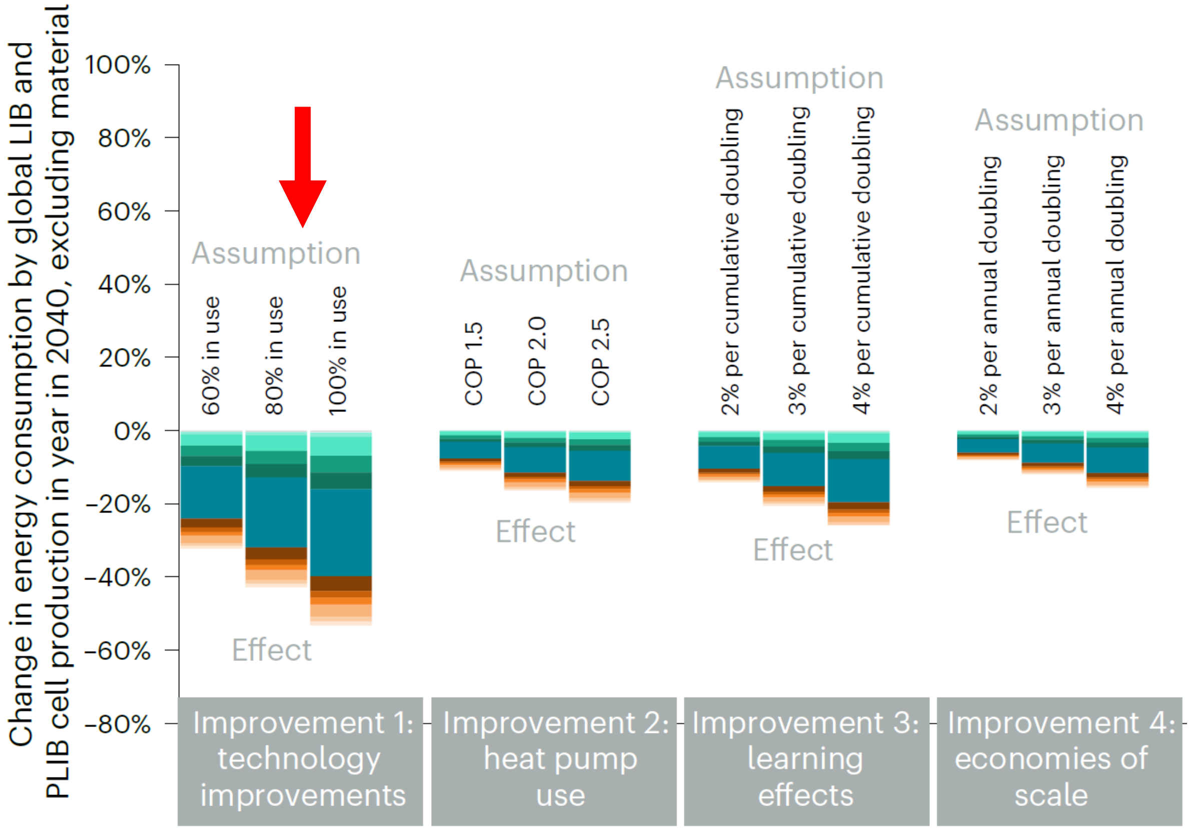
Agenda

Energy consumption of current and future production of battery cells



Degen, F., Winter, M., Bendig, D. *et al.* Energy consumption of current and future production of lithium-ion and post lithium-ion battery cells. *Nat Energy* **8**, 1284–1295 (2023). https://doi.org/10.1038/s41560-023-01355-z

A change of 66% in energy consumption is achievable up to 2040



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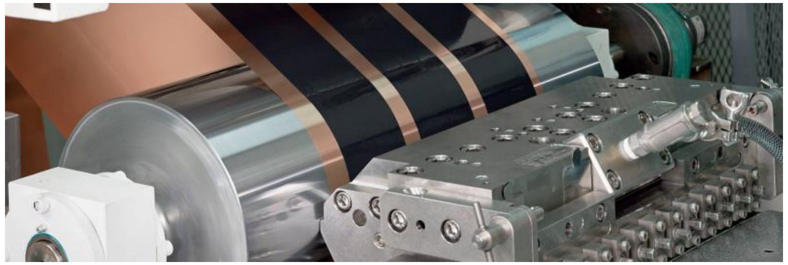

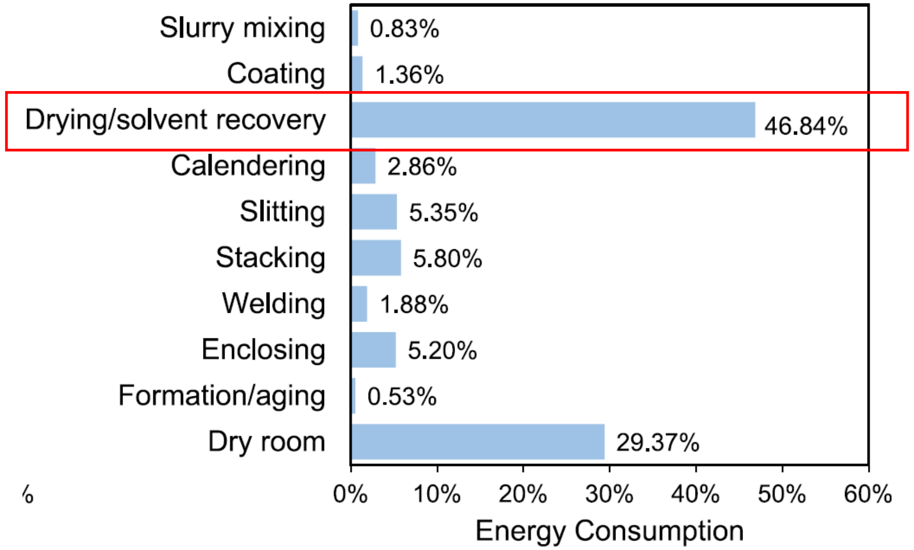

Liu, Yangtao & Zhang, Ruihan & Wang, Jun & Wang, Yan. (2021). Current and Future Lithium-Ion Battery Manufacturing. iScience. 24. 102332. 10.1016/j.isci.2021.102332.

Technology advancements in foil drying has an huge impact.

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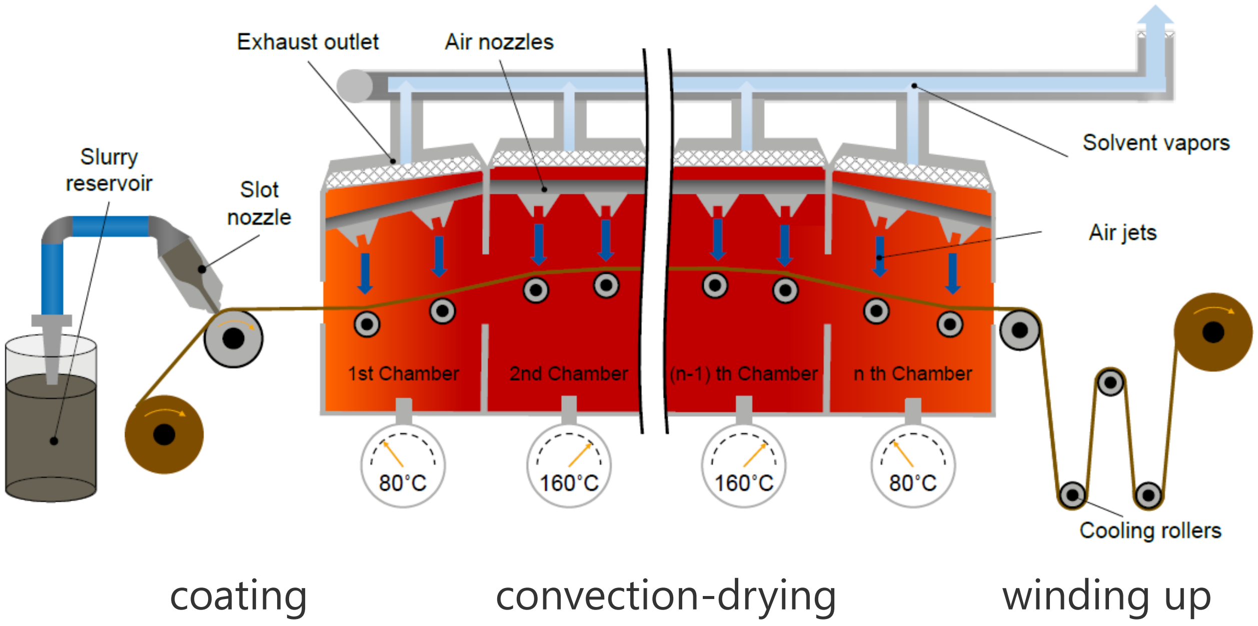
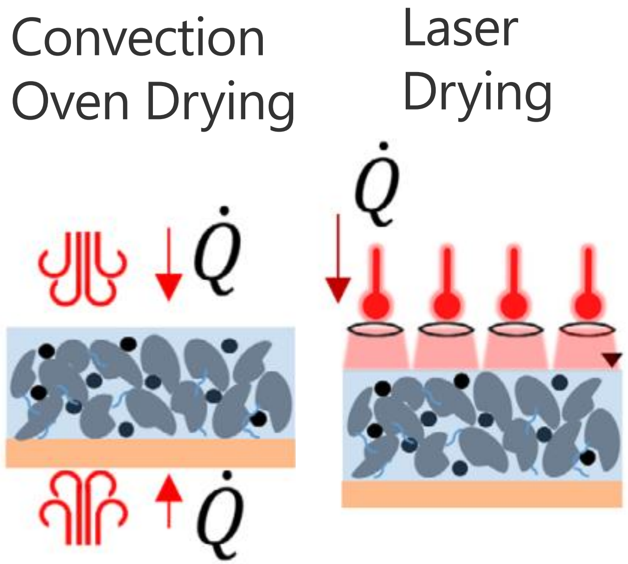
Drying of Li-Battery Electrode Foils

Technology Advancements



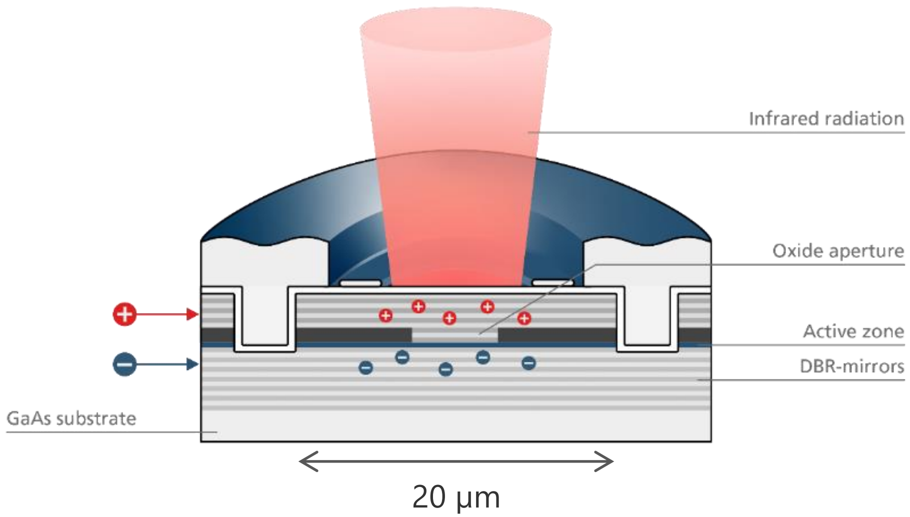


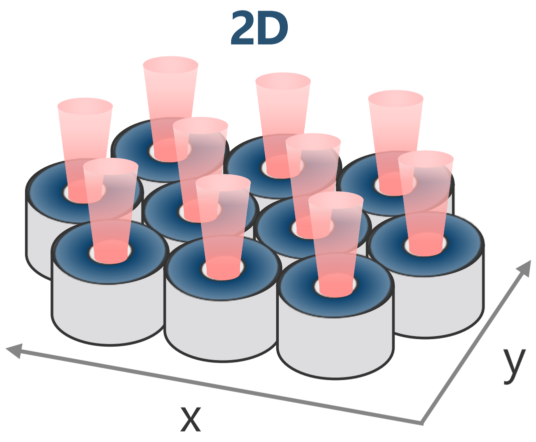
Efficiency	10-20%	> 40%
Complexity	simple	moderate but no optics needed
Regulation	limited	precise
Flexibility	limited	high
Compactness	~60 m	~10 m

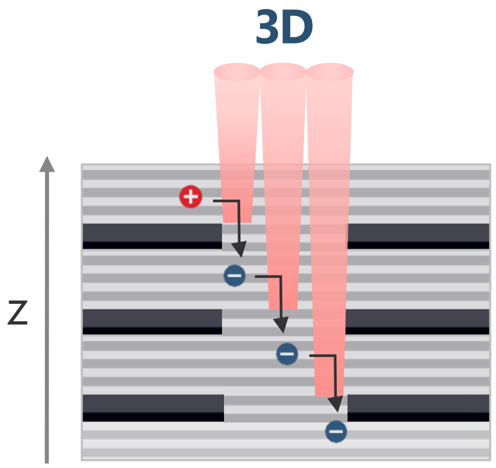
- Battery electrode foil = Li-containing coating on thin metal foil (Cu or Al)
- Coatings are thick and wet (slurry) and must be dried

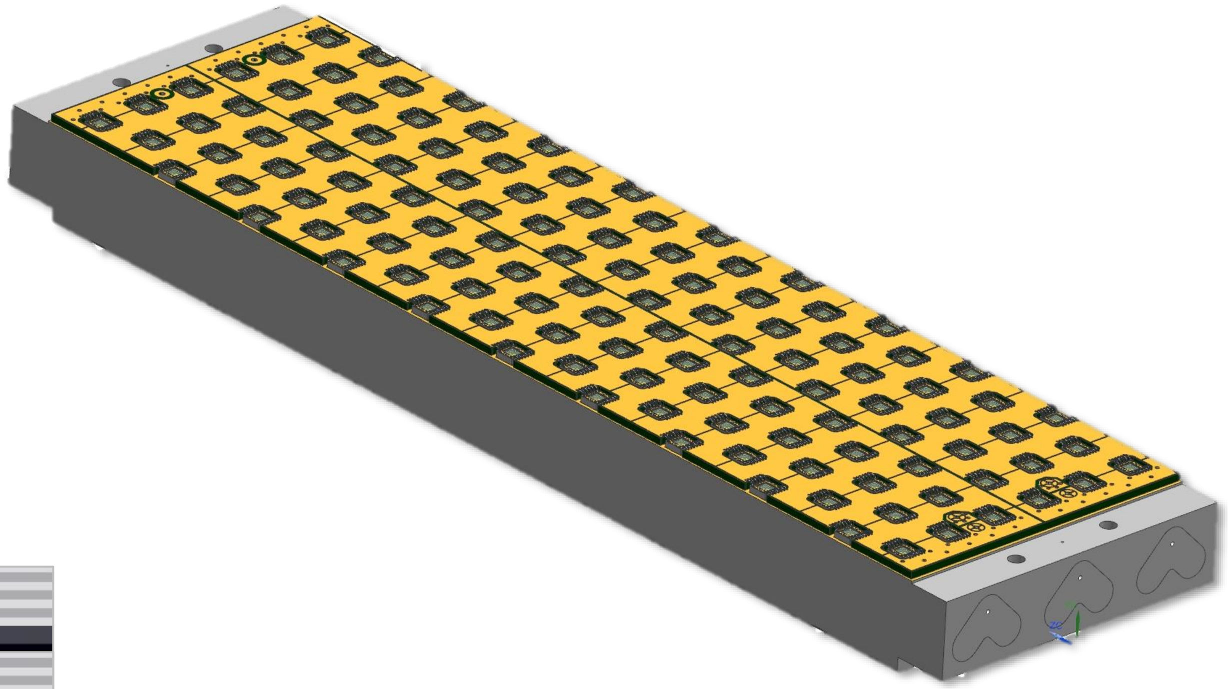
VCSEL Technology – Scaling in all Dimensions

Small device but big impact









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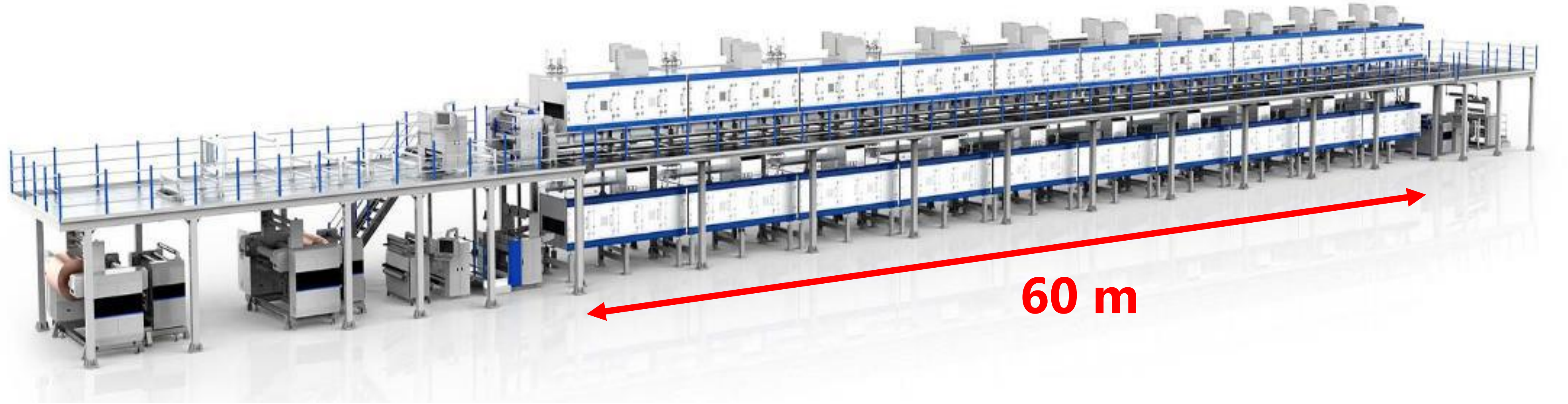
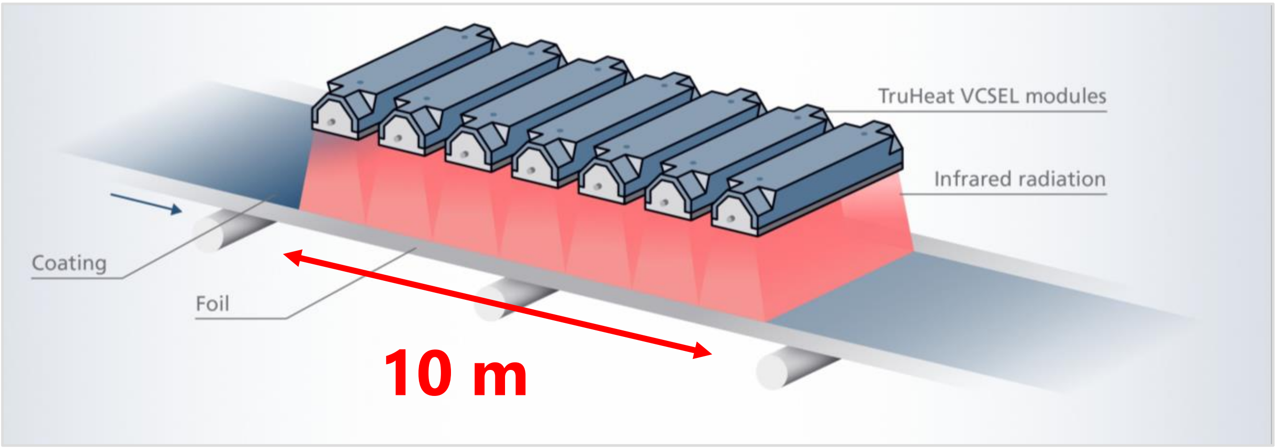
VCSEL Application: Battery foil drying

Direct laser drying without optics

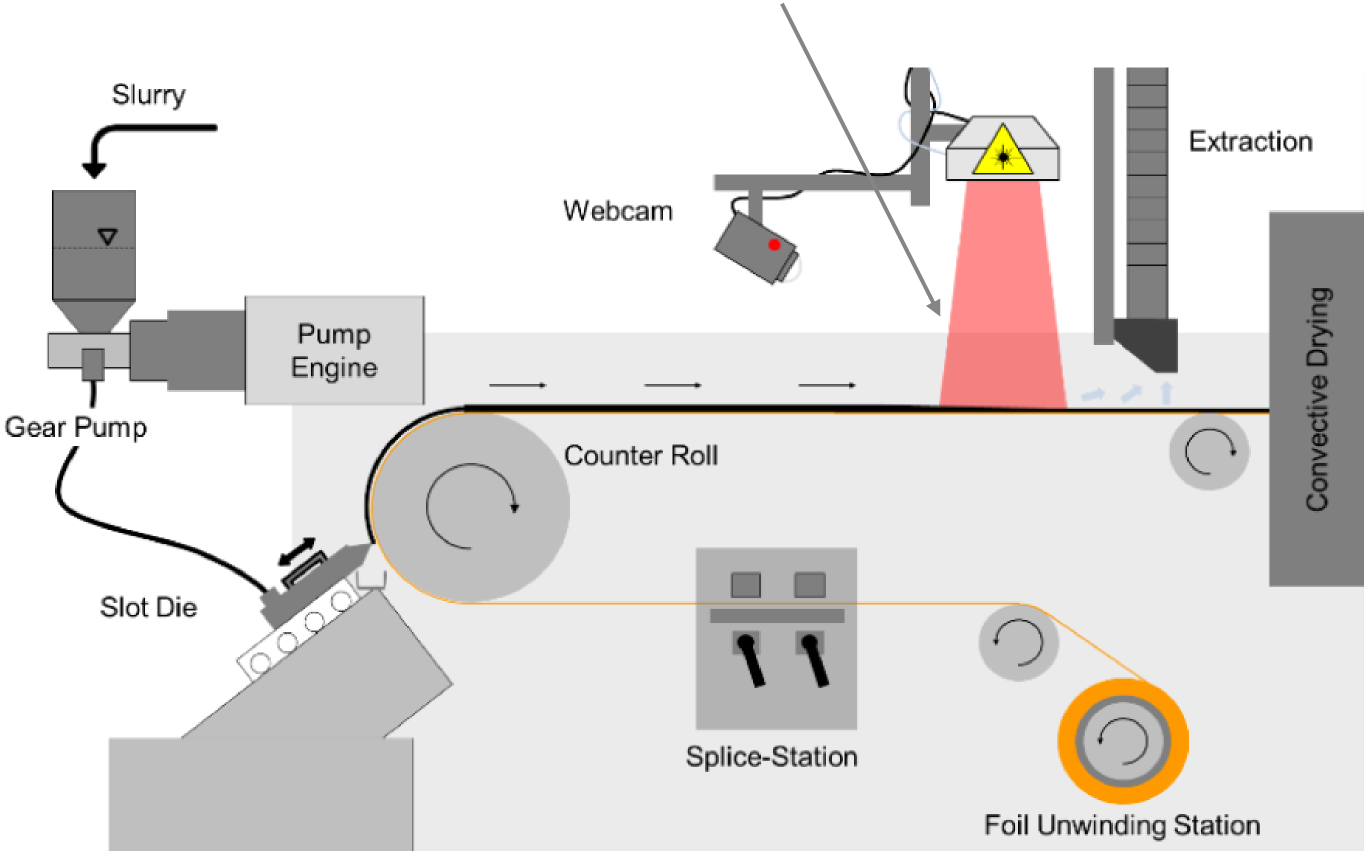




Verification Experiments

TruHeat VCSEL Module

150 – 300 mm working distance



Context: Subsidy project “ExLaLiB” 2016-2019

TrueHeat VCSEL Module:

- L x W on battery foil = 16.5 x 15 cm2
- Max. power density on foil ~ 8 W/cm2 (due to large spacing of emitters in module)

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Verification Experiments with 50 million VCSELs

- Good drying at 50% of maximum VCSEL power ~ 4 W/cm2 (still no damage of coating)
- Required exposure time at 1 m/min is = $\frac{15\text{ cm}}{100\text{ cm}}$ x 60 s = **9 s**

→ For 60 m/min belt speed, exposure length would be ~ 9 m (900 cm)

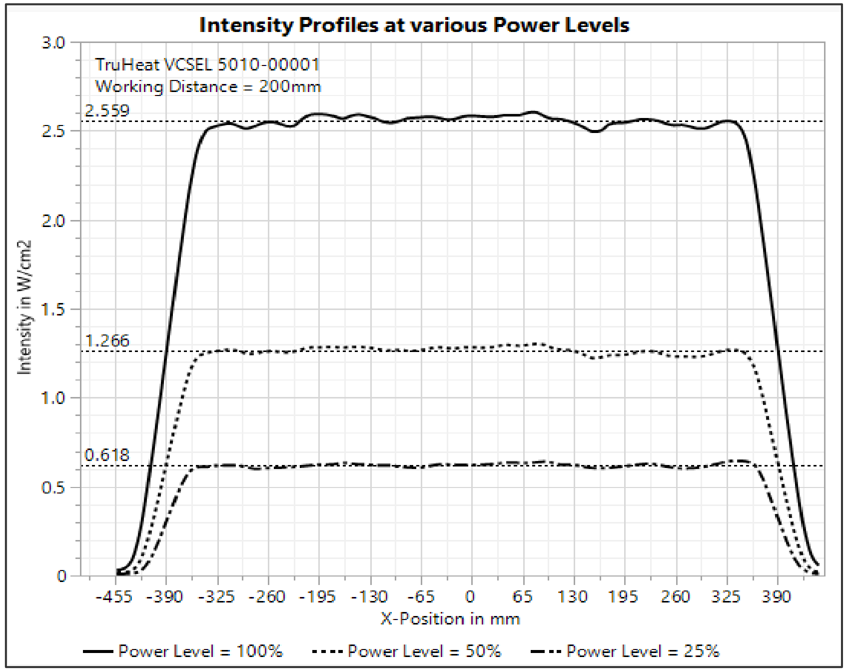
→ Total power needed for 140 cm belt width ~ 900 cm x 140 cm x 4 W/cm2 ~ 504 kW

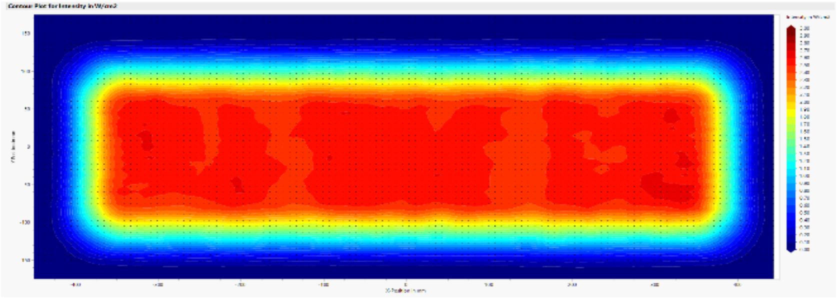
50 million VCSELs inside !

VCSEL TrueHeat - Uniformity

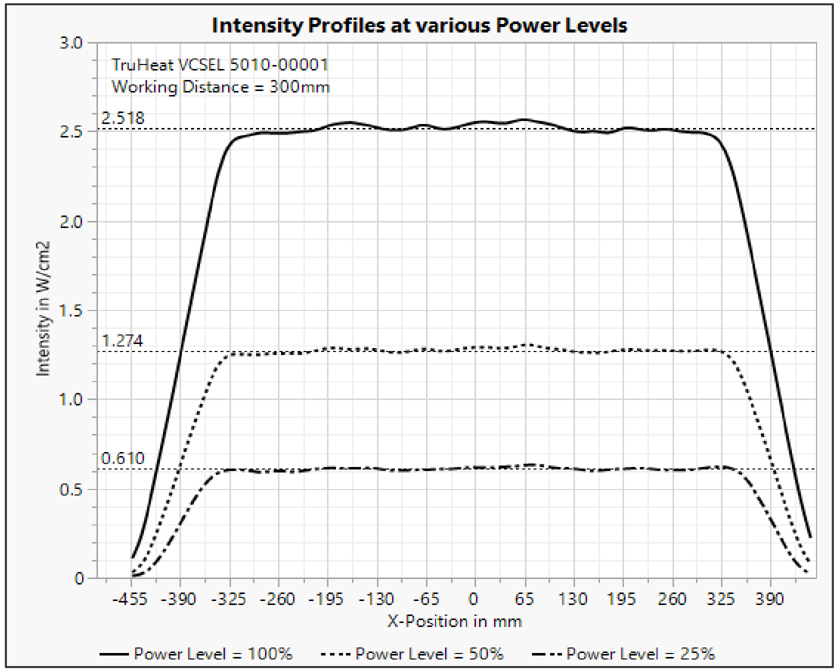
Intensity profiles **without any additional optics**

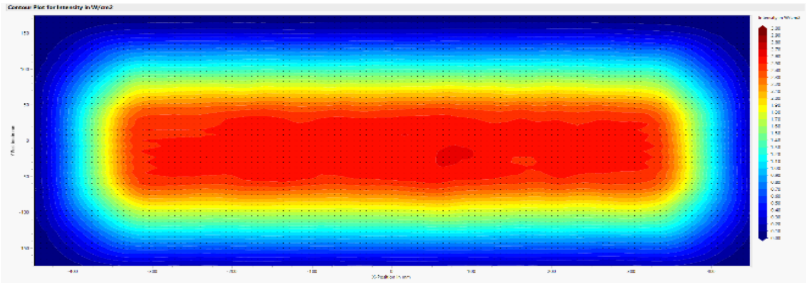
200 mm working distance





300 mm working distance





- > 2.5W/cm² average light intensity on 200/300 mm working distance
- Uncorrected intensity profile uniformity of **±2%**
- Laser spot intensity map as expected, no hot or cold spots

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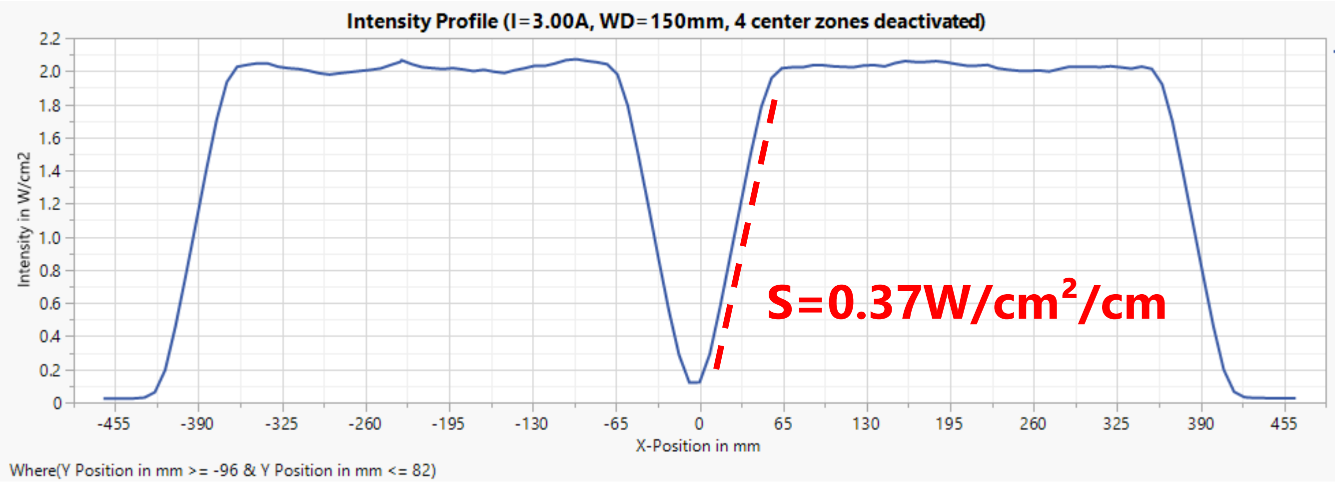
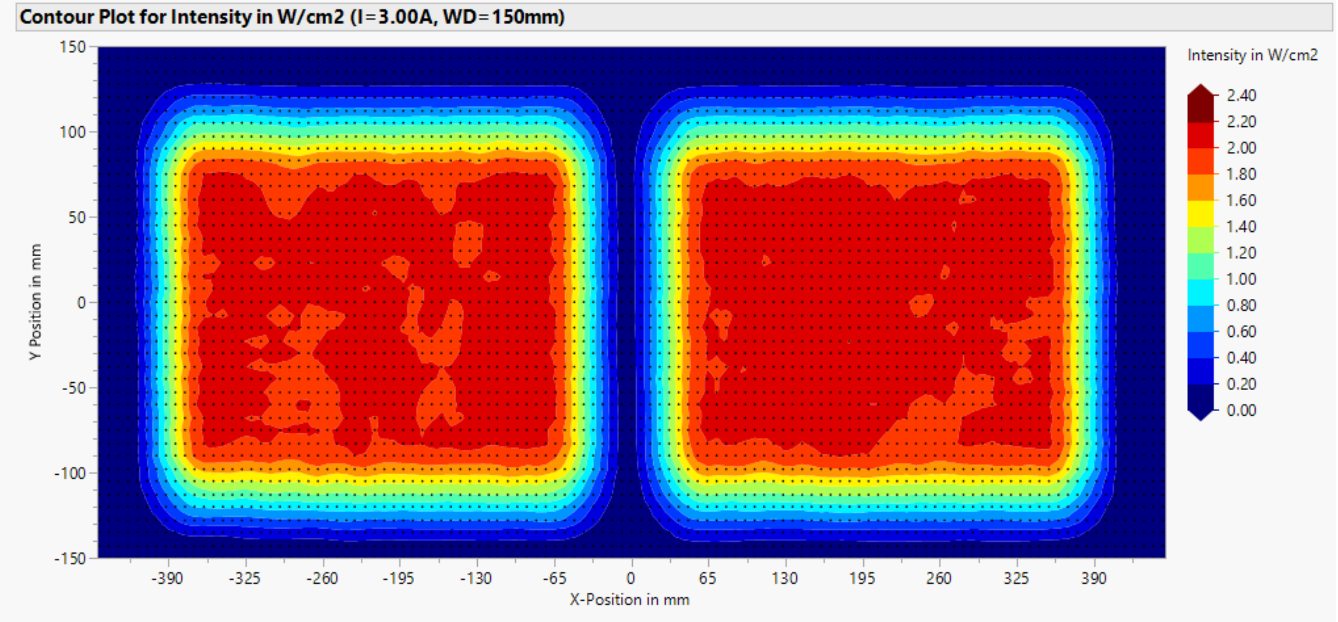
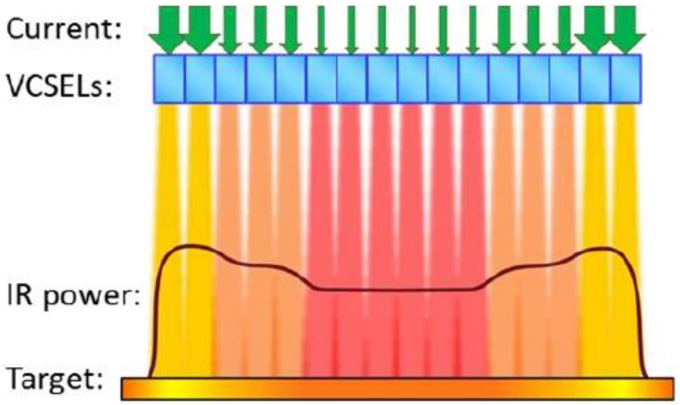
VCSEL TrueHeat - Zoning

Dynamic switching/diming of heating zones

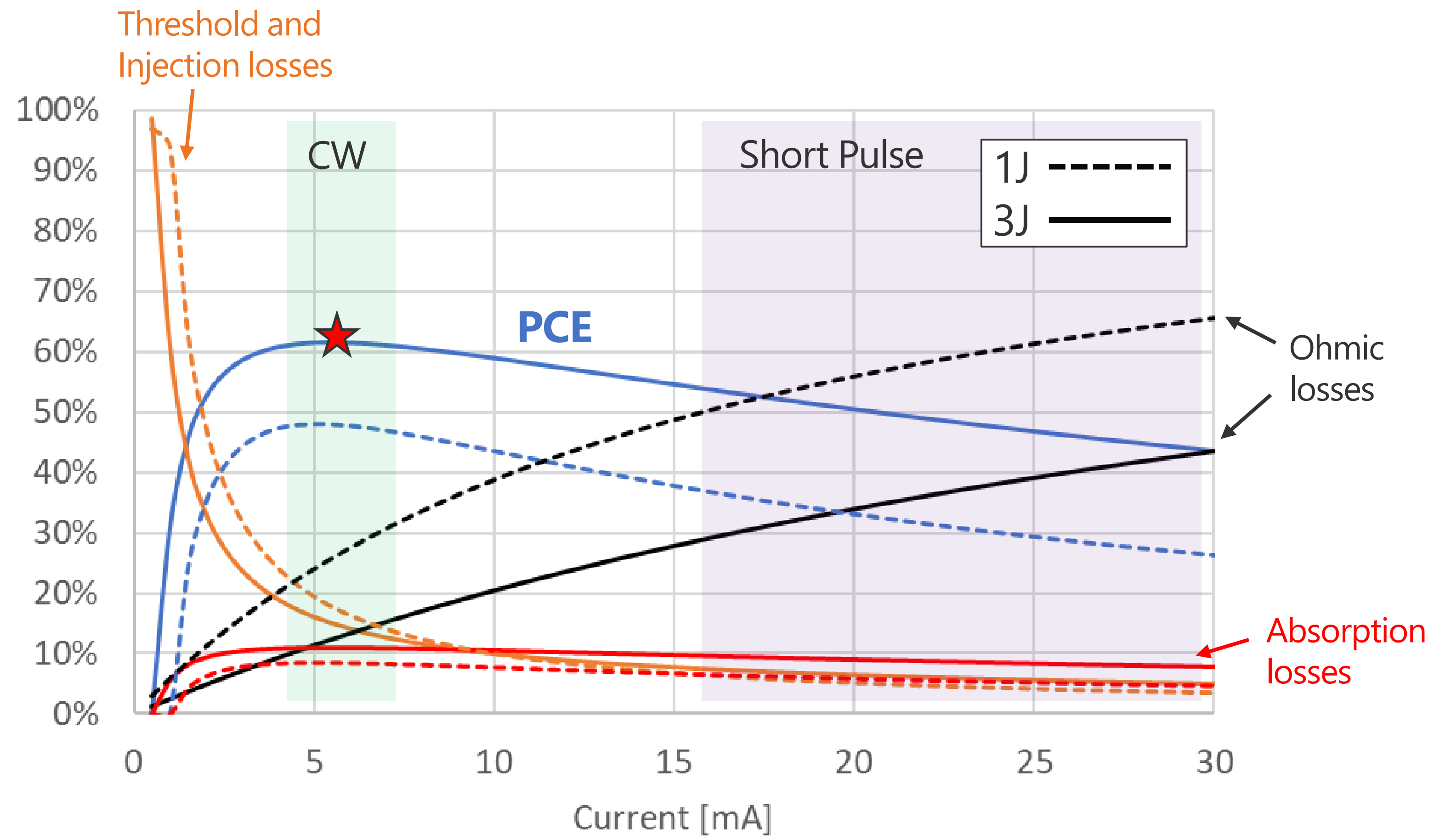
- Tailored intensity profile for flexible heating profiles
- Slope of profile S ~ 0.37W/cm²/cm
- 48 controllable zones with ~ 32 mm minimal width of each zone

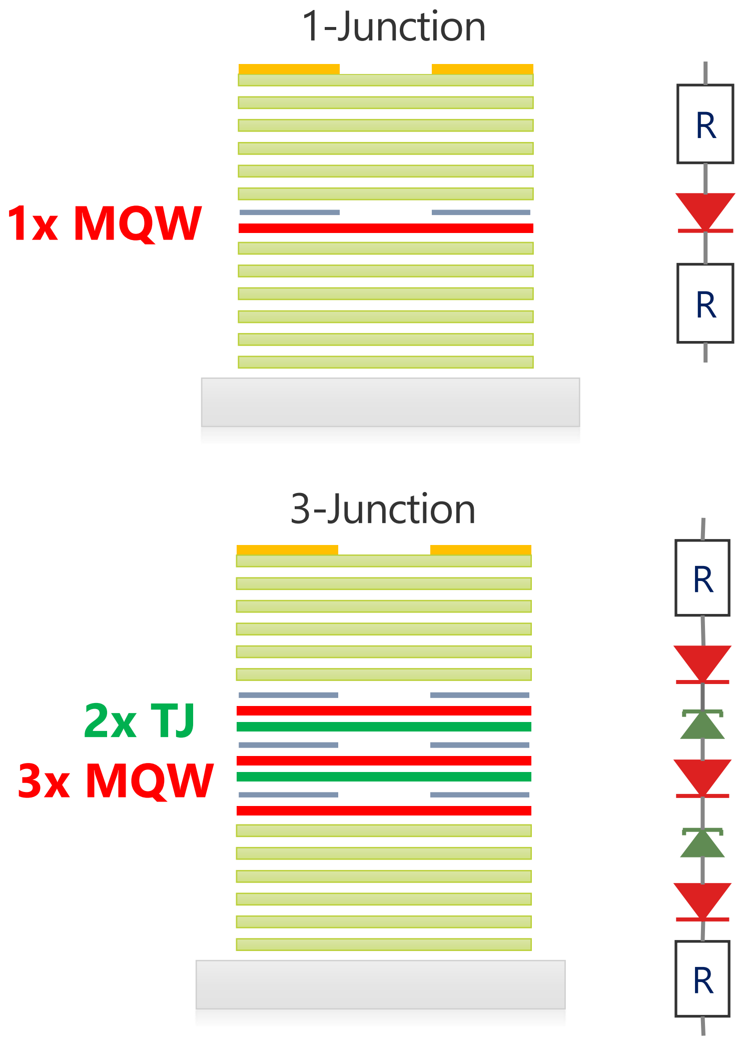






Relative Losses of Cascaded-Junction VCSELs





$$P_{tot} = \underbrace{I^2 \times \left(R_p + R_n\right)_{DBR} + 2 \times I^2 \times R_{TJ}}_{\text{ohmic}} + \underbrace{3 \times \left(I^*_{th} \times U_{th} + I \times U_{cap}\right)}_{\text{threshold + injection}} + \underbrace{\mathbf{3} \times (I - I^*_{th}) \times U_\gamma}_{P_\gamma}$$

Multiple photons per electron
→ More output power for
(almost) the same ohmic loss

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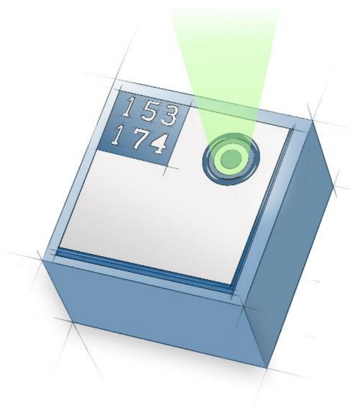
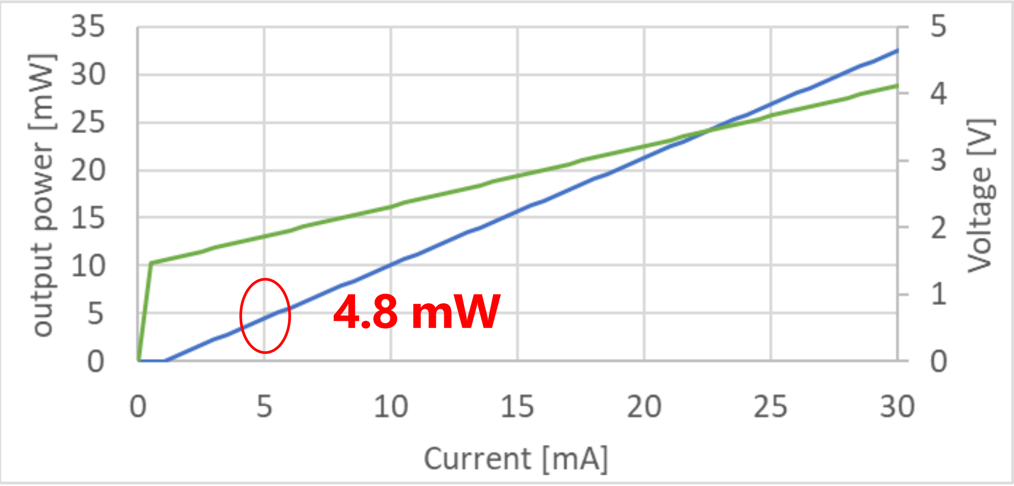
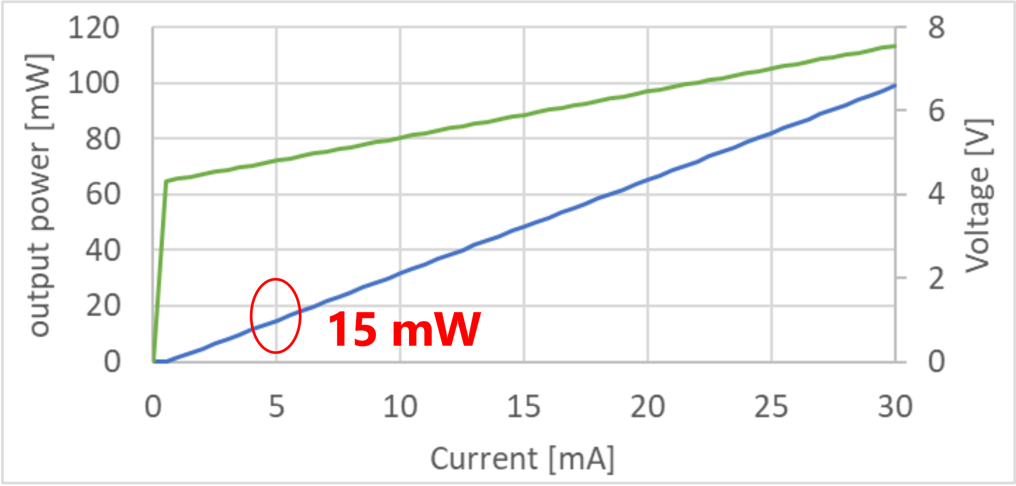
Single VCSEL performance benchmark (1J vs. 3J), CW



1-Junction



3-Junction



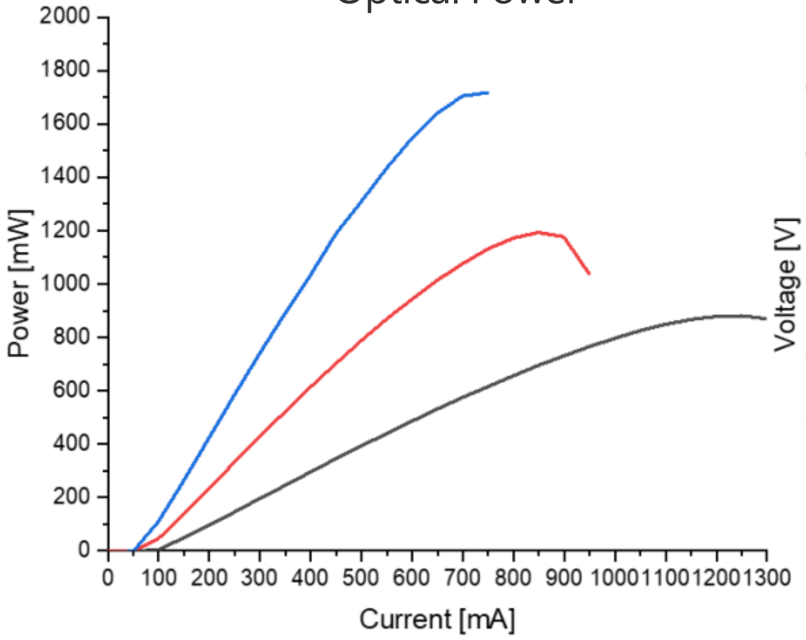
	1-Junction	3-Junction
Power Conversion Efficiency @5mA	49%	62.5%
Max Slope Efficiency	1.1 W/A	3.4 W/A
Power@5mA	4.8 mW	15 mW
Laser Threshold	1.1 mA	0.65 mA
Voltage @10mA	2.2 V	5.1 V

3x times higher slope efficiency and 75% more output power in CW

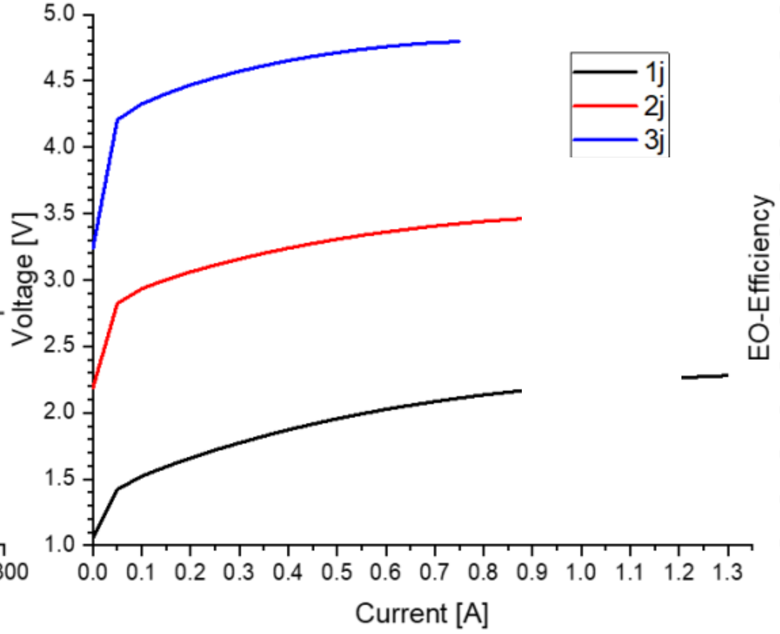
Results 3J Multi Emitter Arrays (Consisting of 99 VCSELs)

CW Operation on Heat Sink

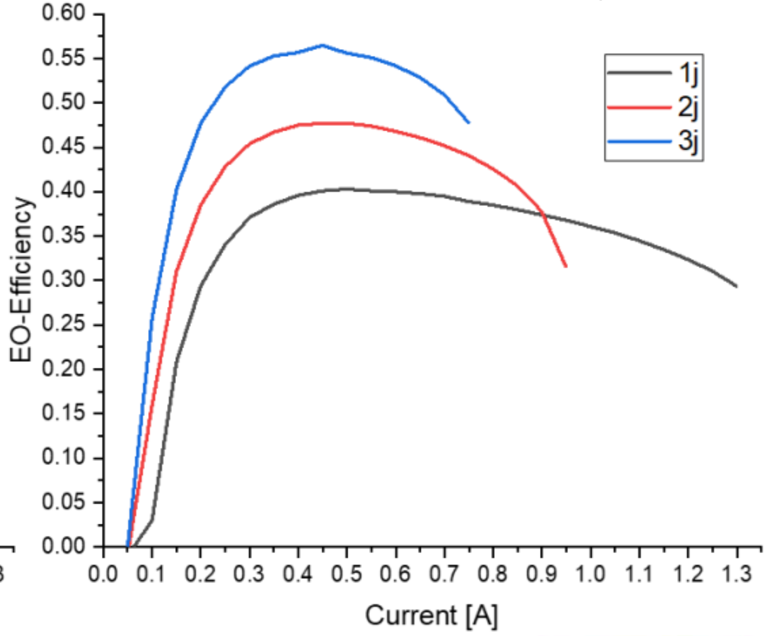
Optical Power



Voltage / Current

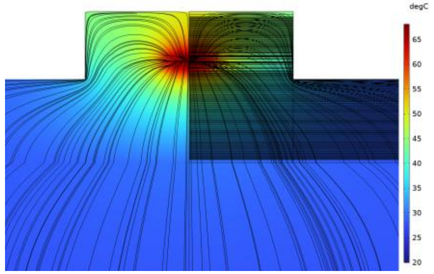


EO-Efficiency



- 56% VCSEL Array efficiency at 20°C with 4 – 5 mA per 3J-VCSEL
- 75% more output in CW operation (i.e. heat removal limited)

$$P_{out} \sim \frac{\eta}{1-\eta} \cdot P_{heat}$$



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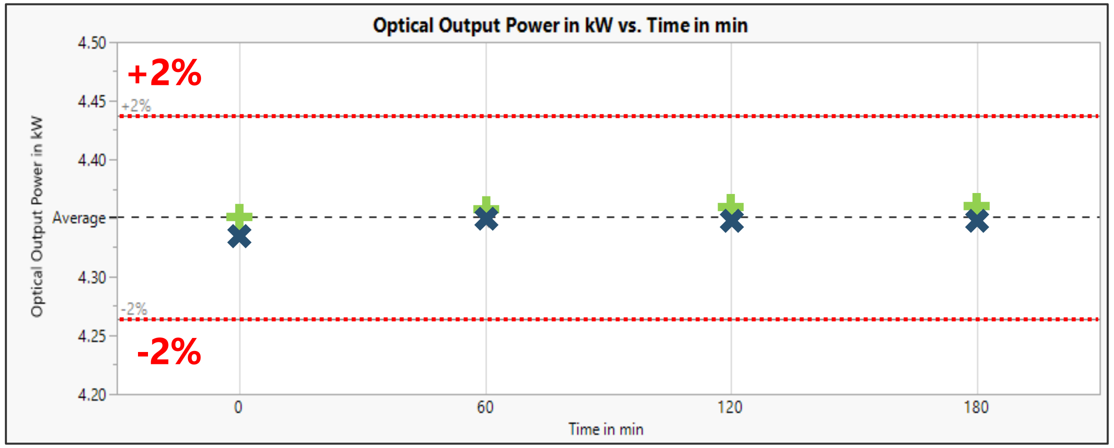
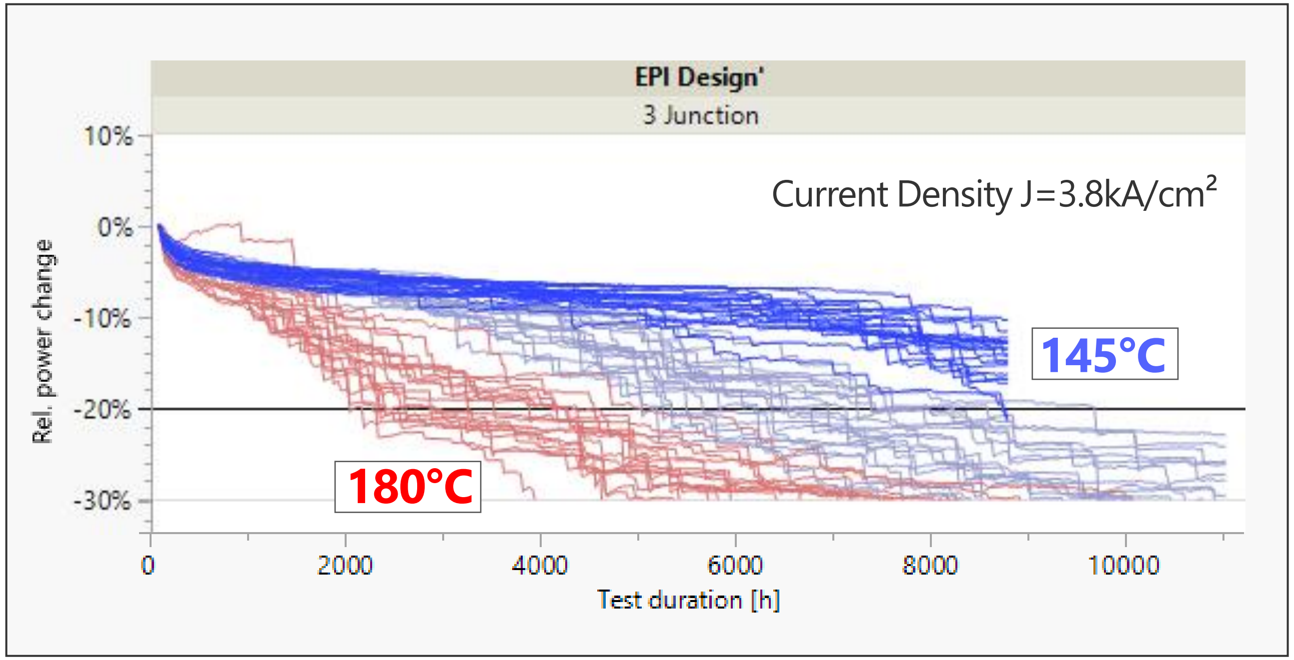
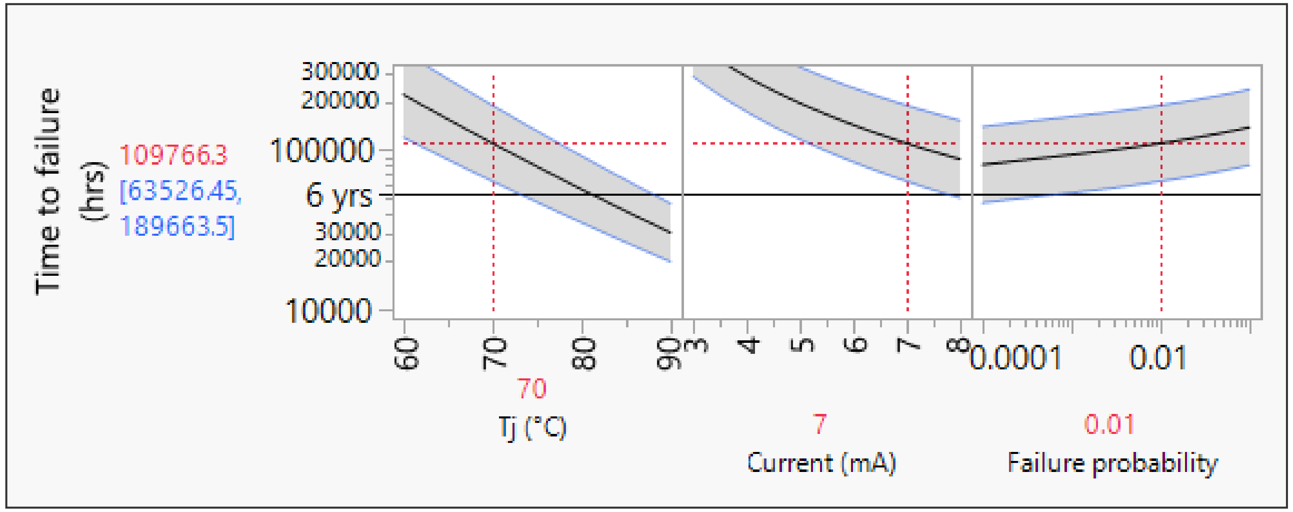
Accelerated Lifetime Tests





- During module operation, power drift of less than 0.04 % is observed during CW emission of ~ 4.3 kW
- Accelerated aging tests on 3J VCSEL chips showed > 8000h @145°C till 20% power drop
- For 70°C junction temperature and 7 mA max drive current, the MTTF is 109766 h **(>12.5 years)**



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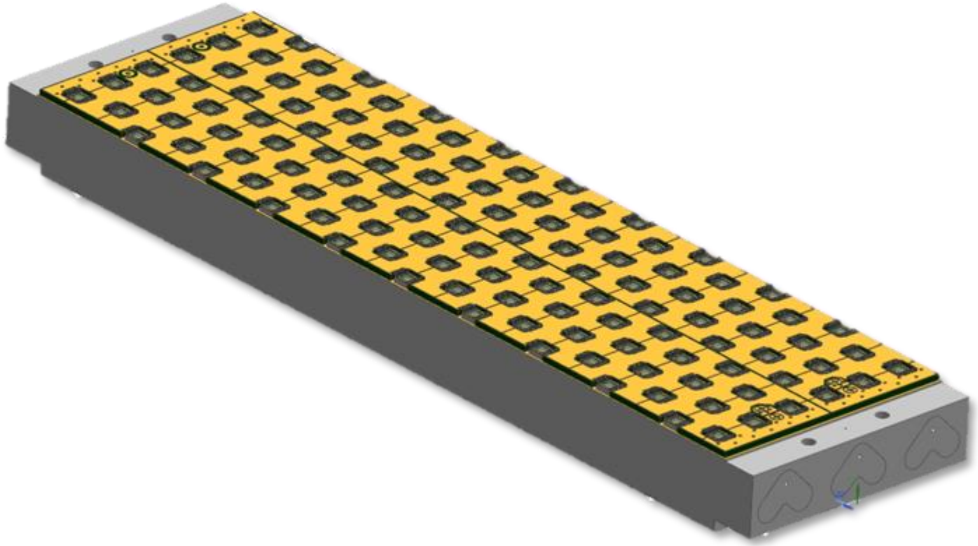
Conclusion and Outlook

VCSEL Heating provides

- Simplicity, redundancy, reliability
- Fast switching for energy saving and safety
- Uniform heating without additional optics
- Compact form factor and ease of integration



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Acknowledgement

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IPCEI Microelectronics and Communication Technologies

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Thank You.

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