Isolation Integration into Cold Plate and Thermal Densification of Liquid-Cooled Power Modules

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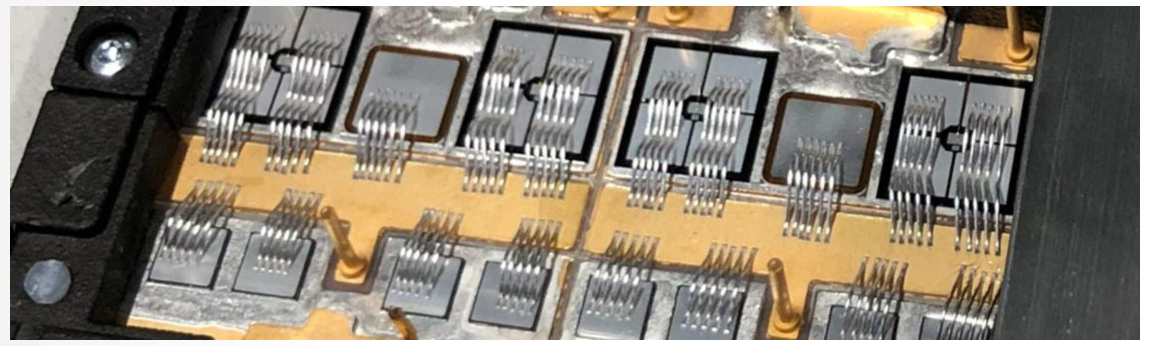
(Trumpf Photonics & Stellar Industries)

Company introduction

TRUMPF Photonics Inc.

Subsidiary of the TRUMPF Group

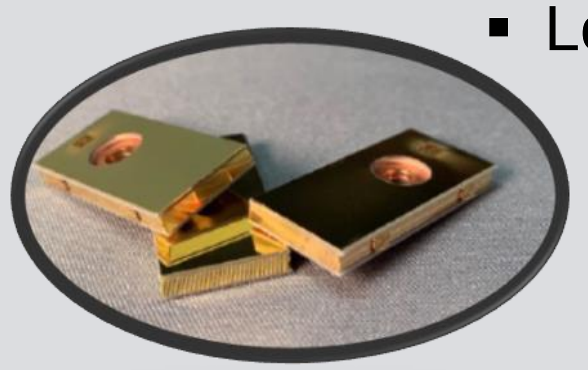
- Established in 2002
- Located in Cranbury, NJ (USA)
- Over 250 Employees
- $106 Mio. Sales (FY21/22)
- 110,000 sf facility with 35,000 sf clean room
- Integrated GaAs Diode Laser Fab: Epitaxy to Module
- Products: Laser Diode Chips
  Laser Diode Modules
  PE Components

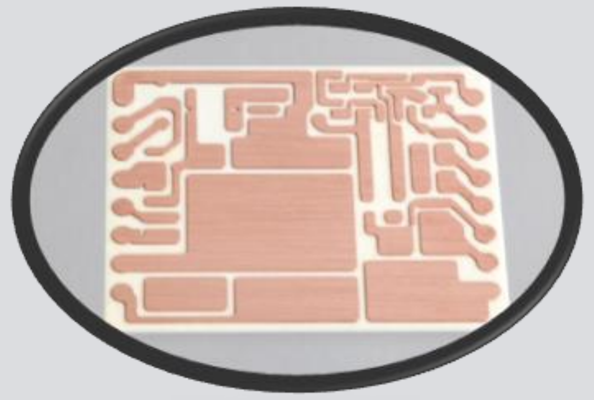


Stellar Industries Inc.

Subsidiary of the TRUMPF Group

- Located in Millbury, MA (USA)
- Over 50 Employees
- Capabilities: Direct Bond Copper, Thin Film Metallization, Thick Film Metallization, Precision Machining, Electroplating
- Products: Laser coolers, custom substrates
- Company Name: Stellar Industries Corp.
- Location: Millbury, Massachusetts, USA
- Facility: ~38,000 sf
- Founded: 1985



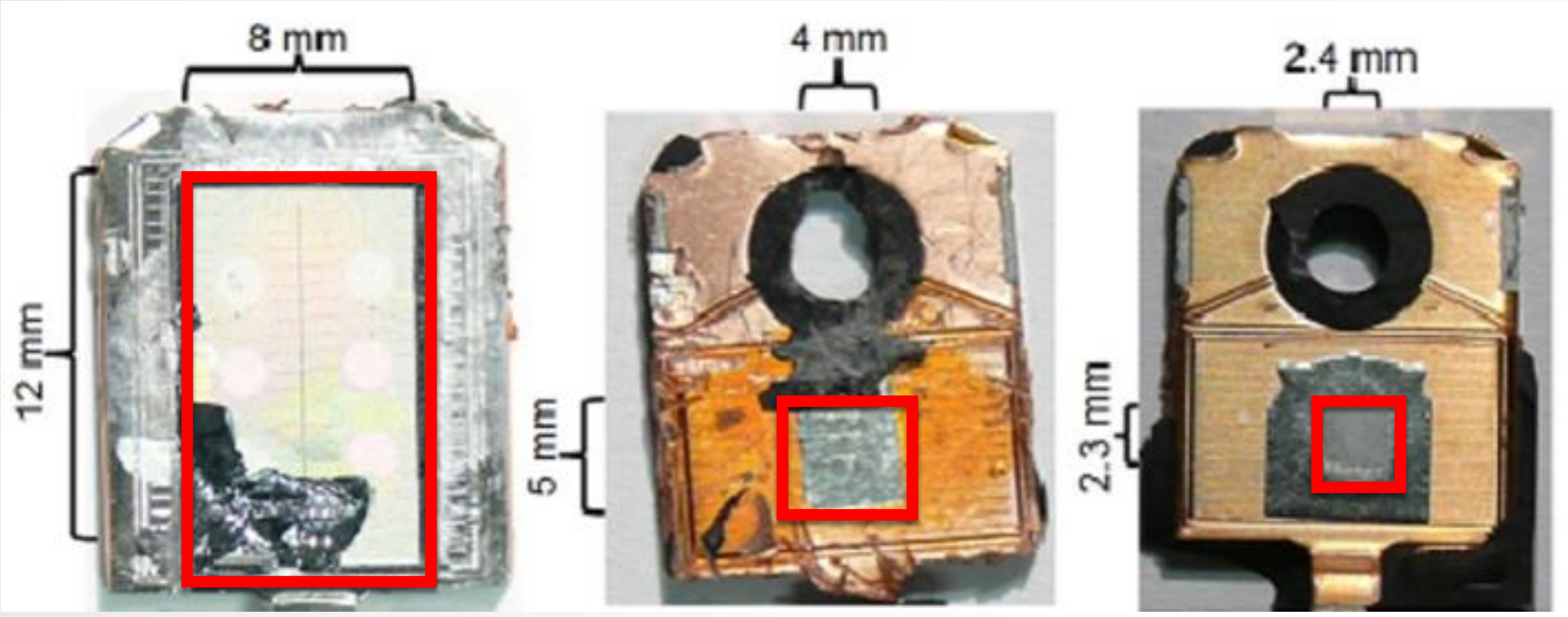


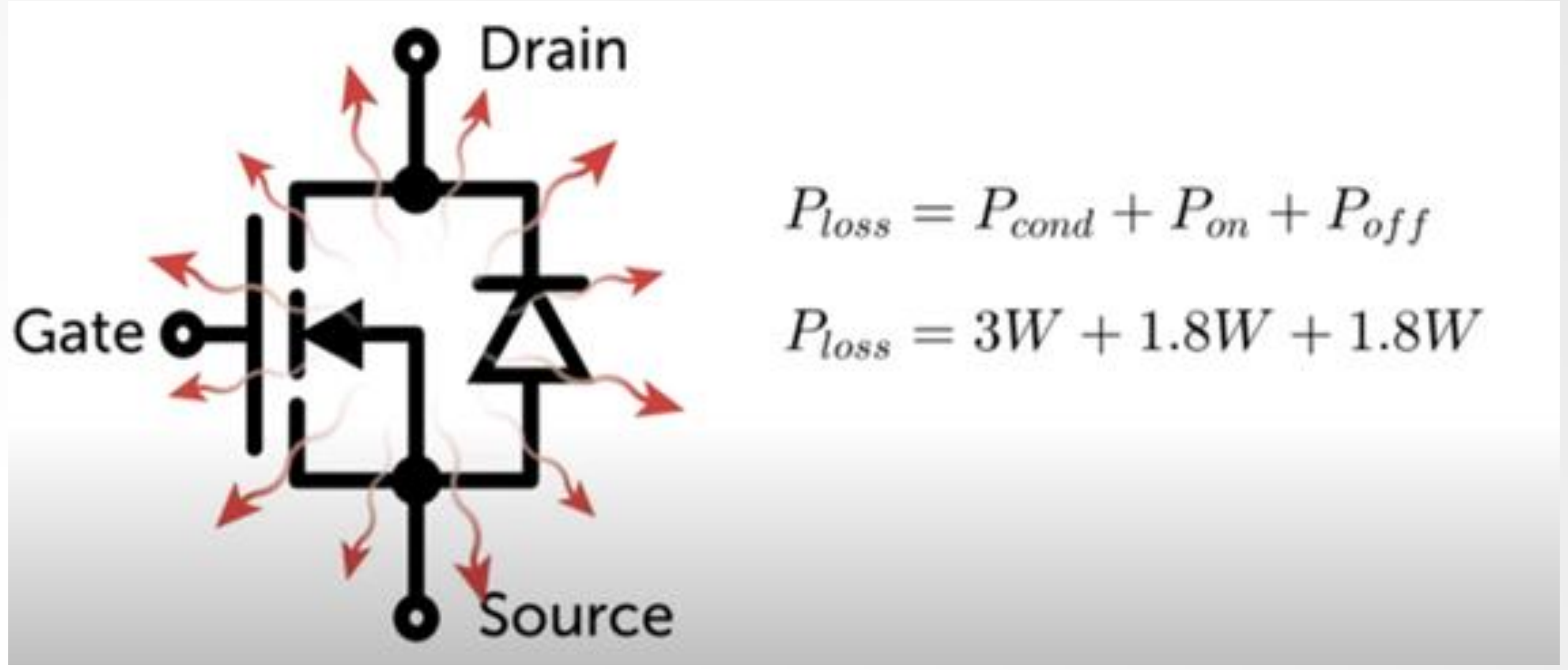
Business:

- Build-to-print manufacturer for metalized ceramic substrates
- Supplying to customers in Aerospace, Defense, Photonics, Telecom, Commercial and Industrial Electronics
- AS9100D/ISO9001 Certified
- **ITAR Registered**

Point of contact for defense customers

Motivation: Why is active cooling becoming more important?



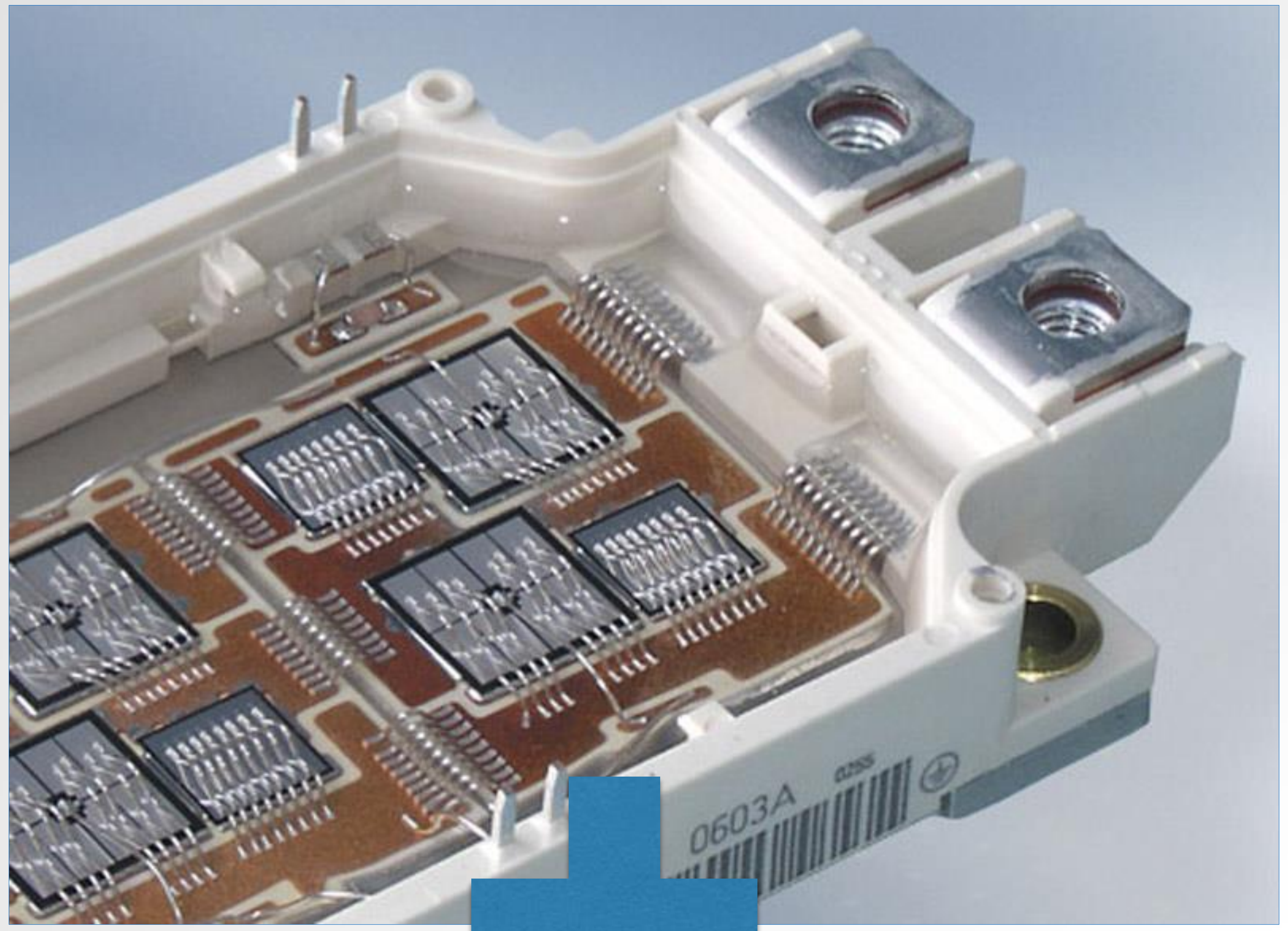


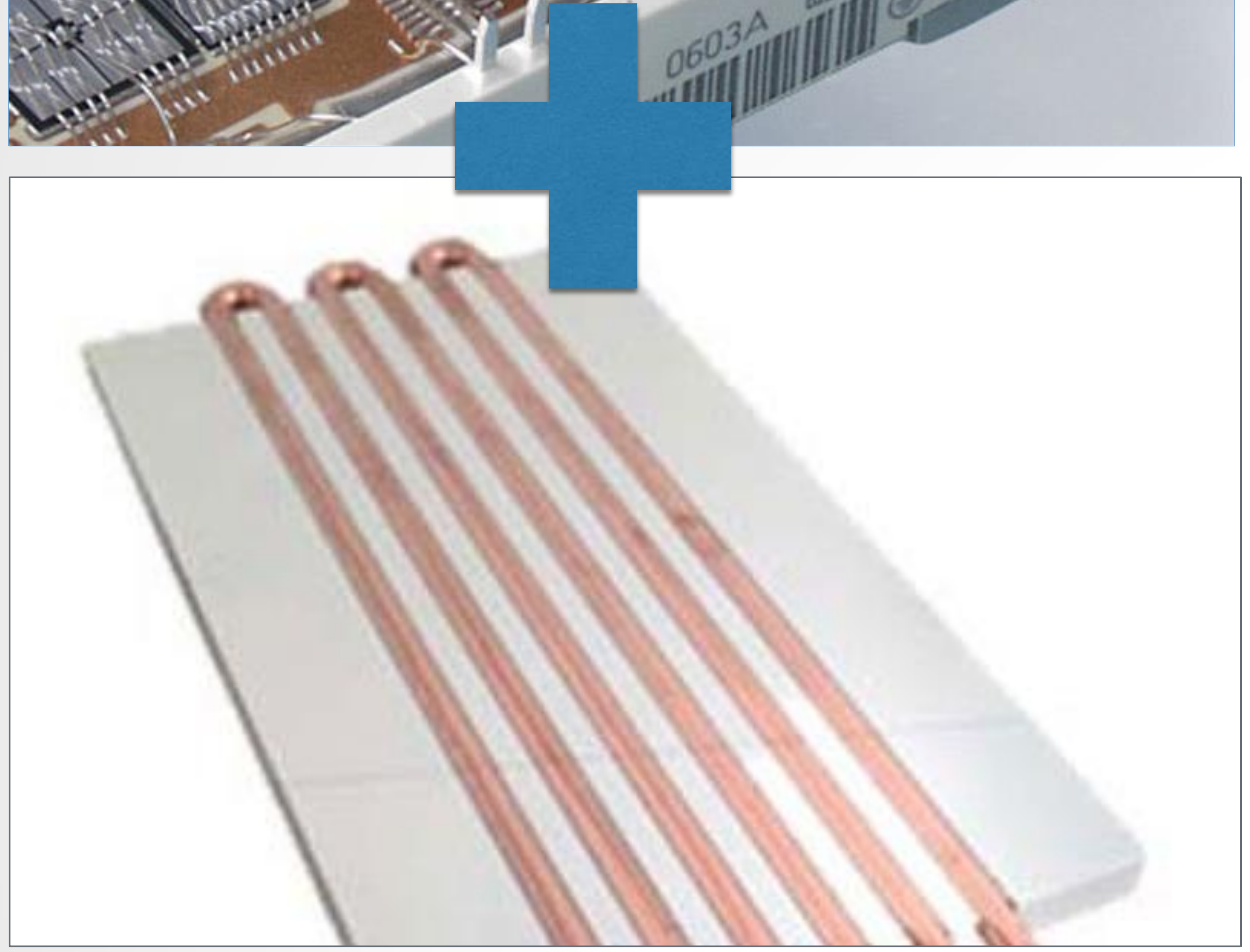
Smaller die size

Increased switching frequency

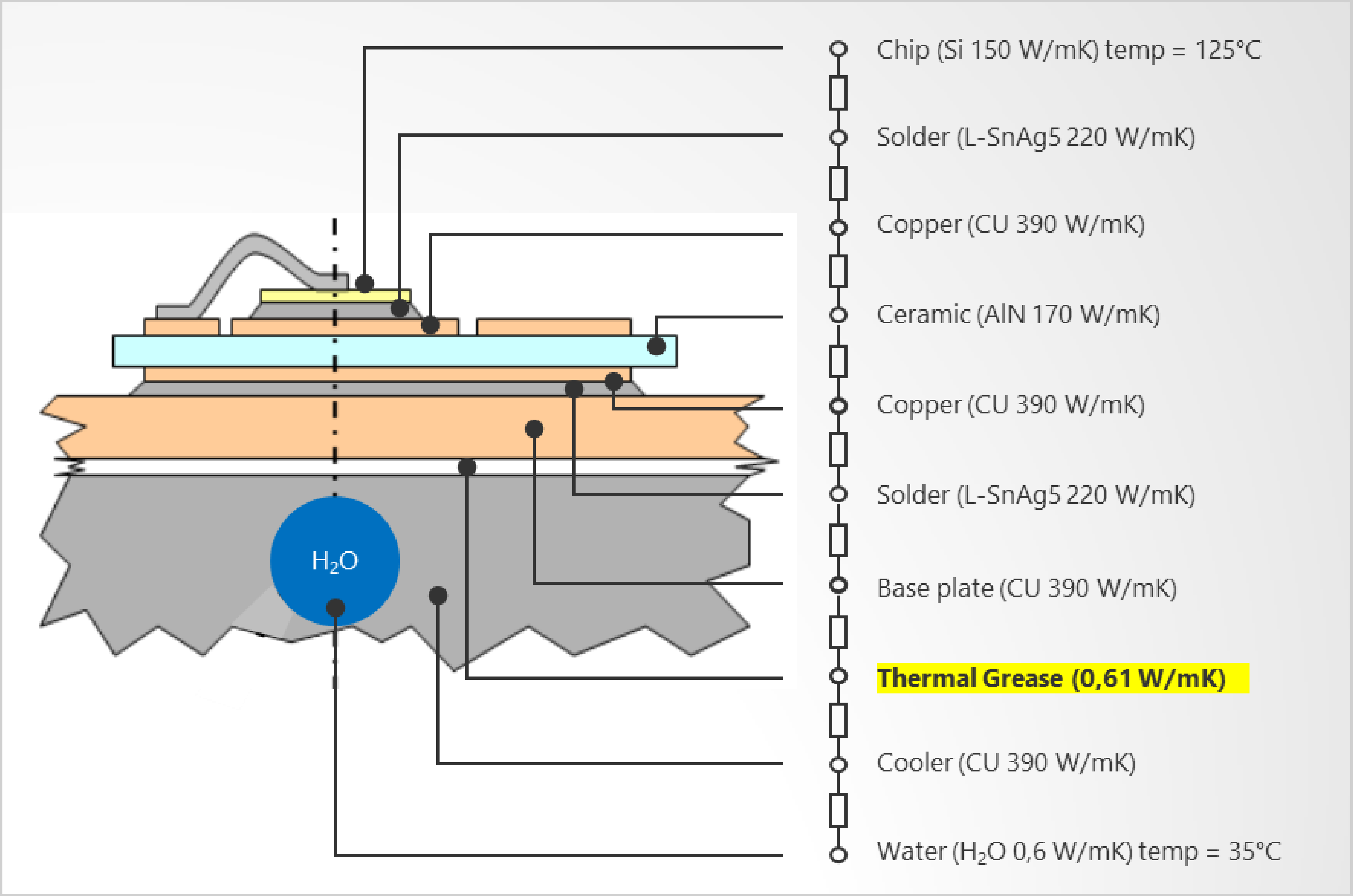
Cost savings by smaller packaging and densification

Typical packaging

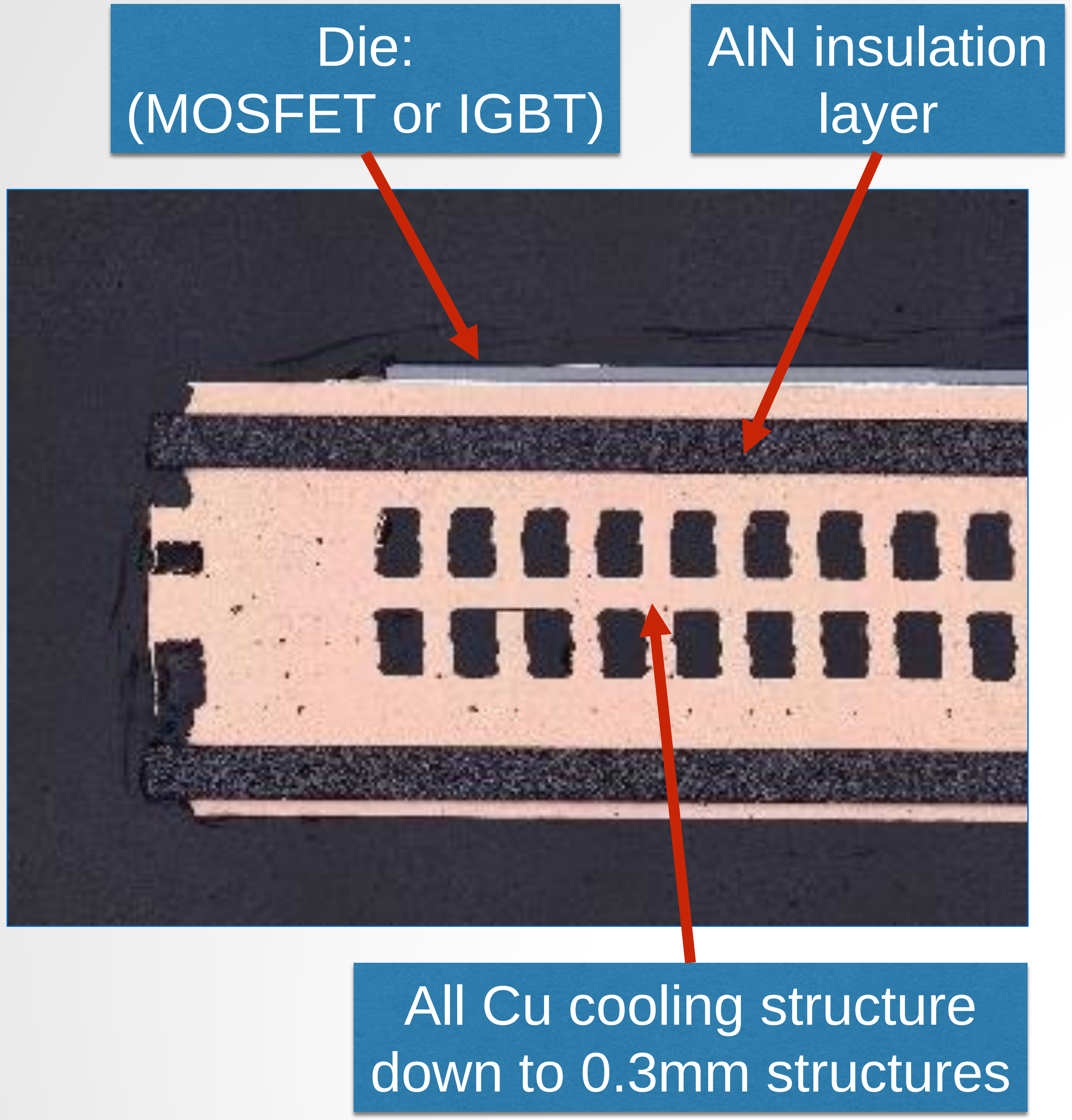




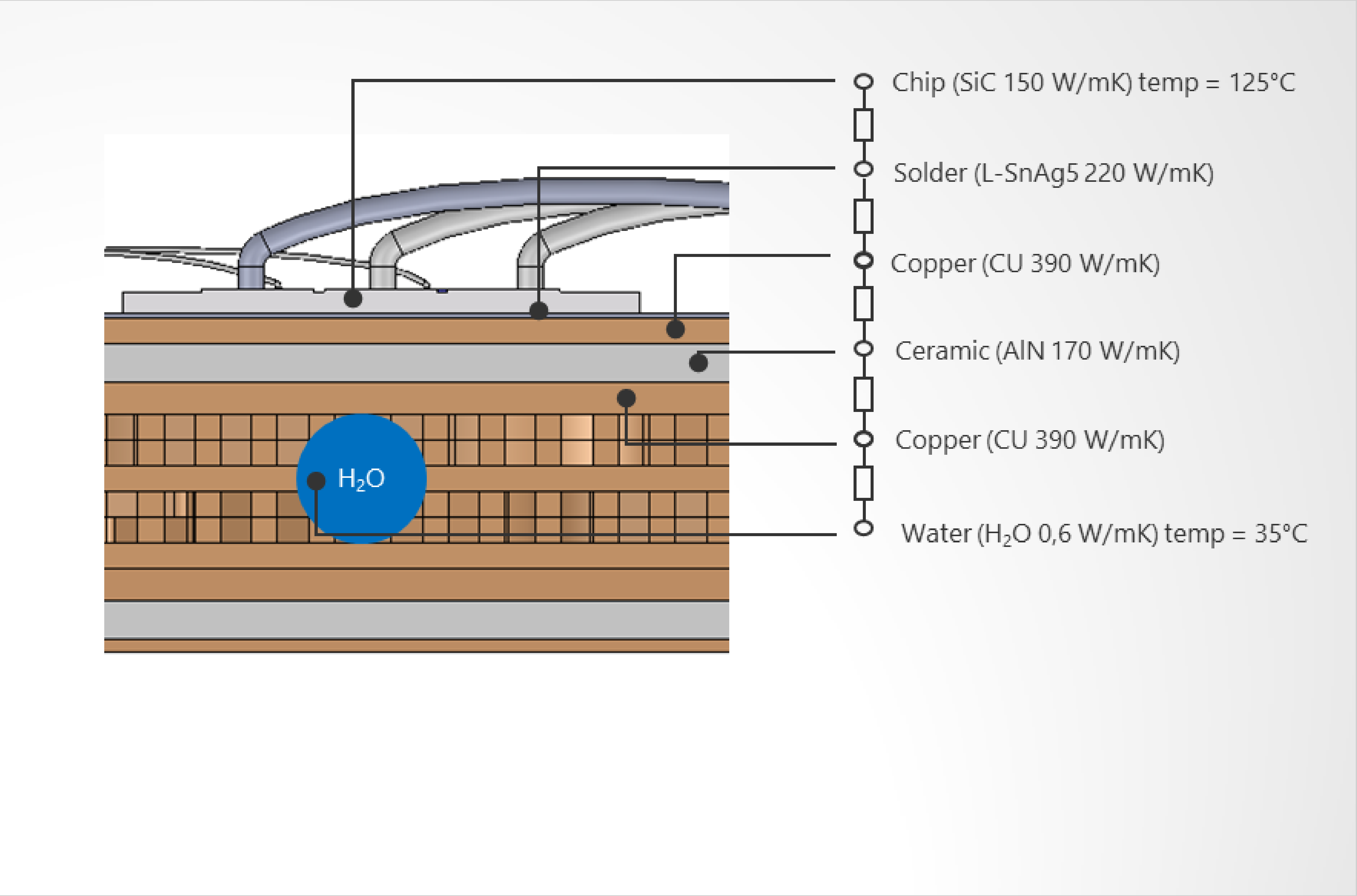
Standard setups introduce too many thermal resistances!



Integrated cold plate solution



DCB cooler thermal resistance



Reduction in Rth for integrated cold plates

$$R_{component} = \frac{L}{kA}$$

L = plane thickness
k = material conductivity
A = affected area

$$R_{th} = R_{chip} + R_{solder} + R_{copper} + \ \ldots..$$

Typical packaging:
Rth ~ 0.5

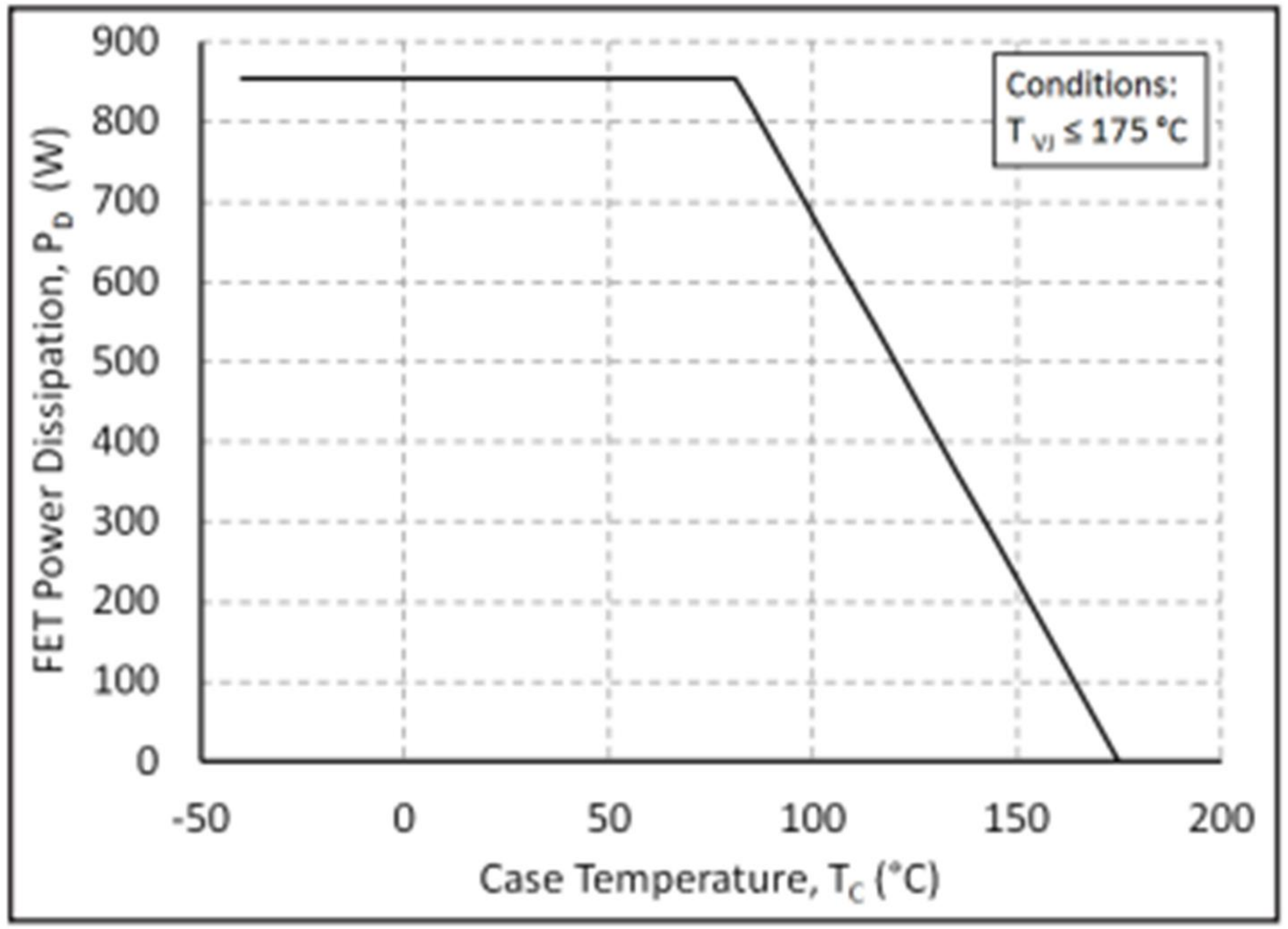
Factor 4-5 improvement by reducing thermal resistances and eliminating the thermal interface to cold plate (TIM 2)

Integrated cold plate packaging:
Rth ~ 0.15

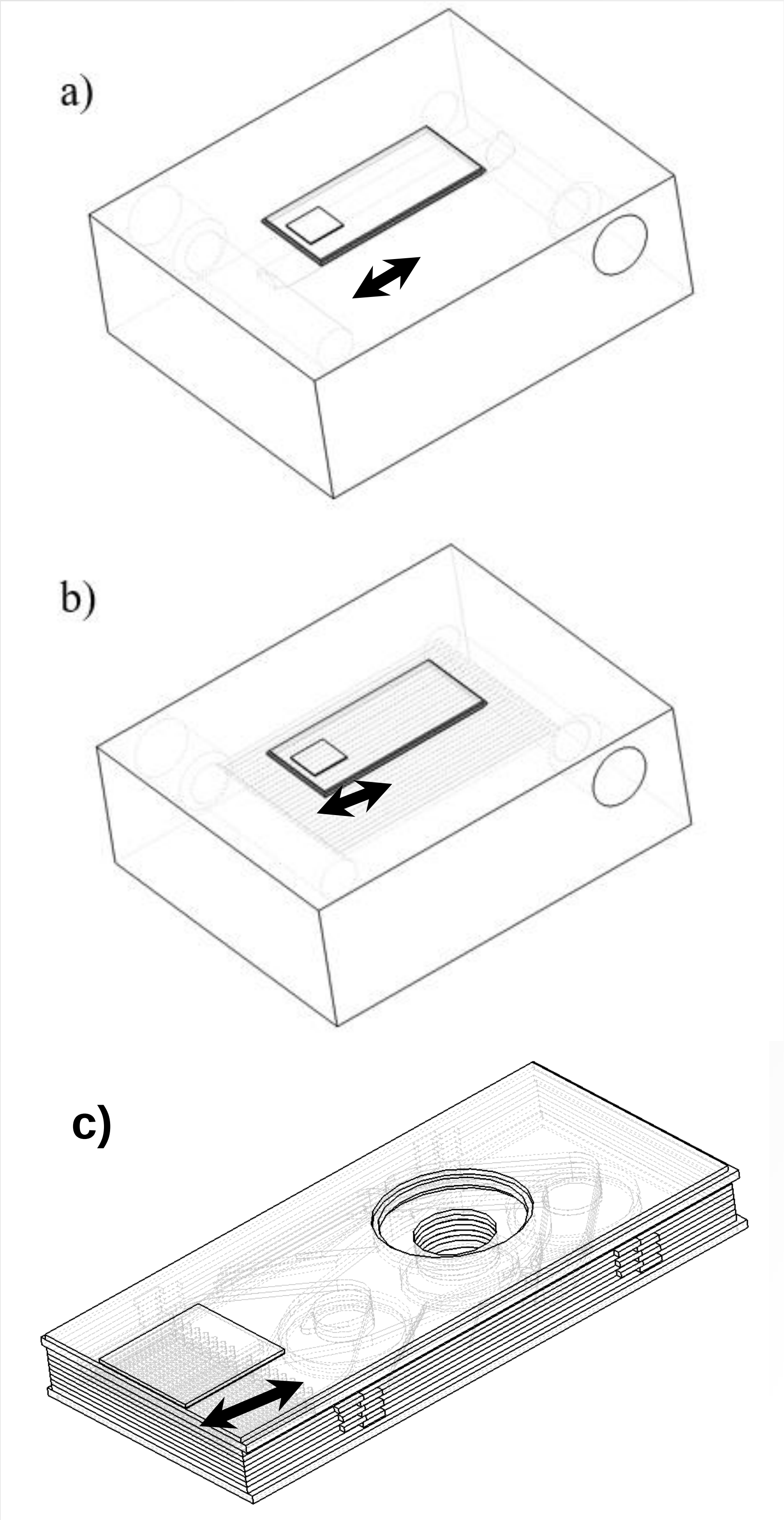
Design considerations for liquid cooling

- Module baseplate and cold plate surface flatness / roughness
- Module material characteristics and internal component design
- Cold plate material and coefficient of thermal expansion (CTE) and internal stresses
- Cold plate internal structure
- Single- or two-phase coolant, viscosity, and performance characteristics
- Coolant flow rate
- Coolant operating temperature
- Pressure drop (cold plates, heat exchangers, filters, quick disconnect fittings, meters, etc.)

Datasheet example: Conventional Power module case temperature dependance



Example: for a thermal densification



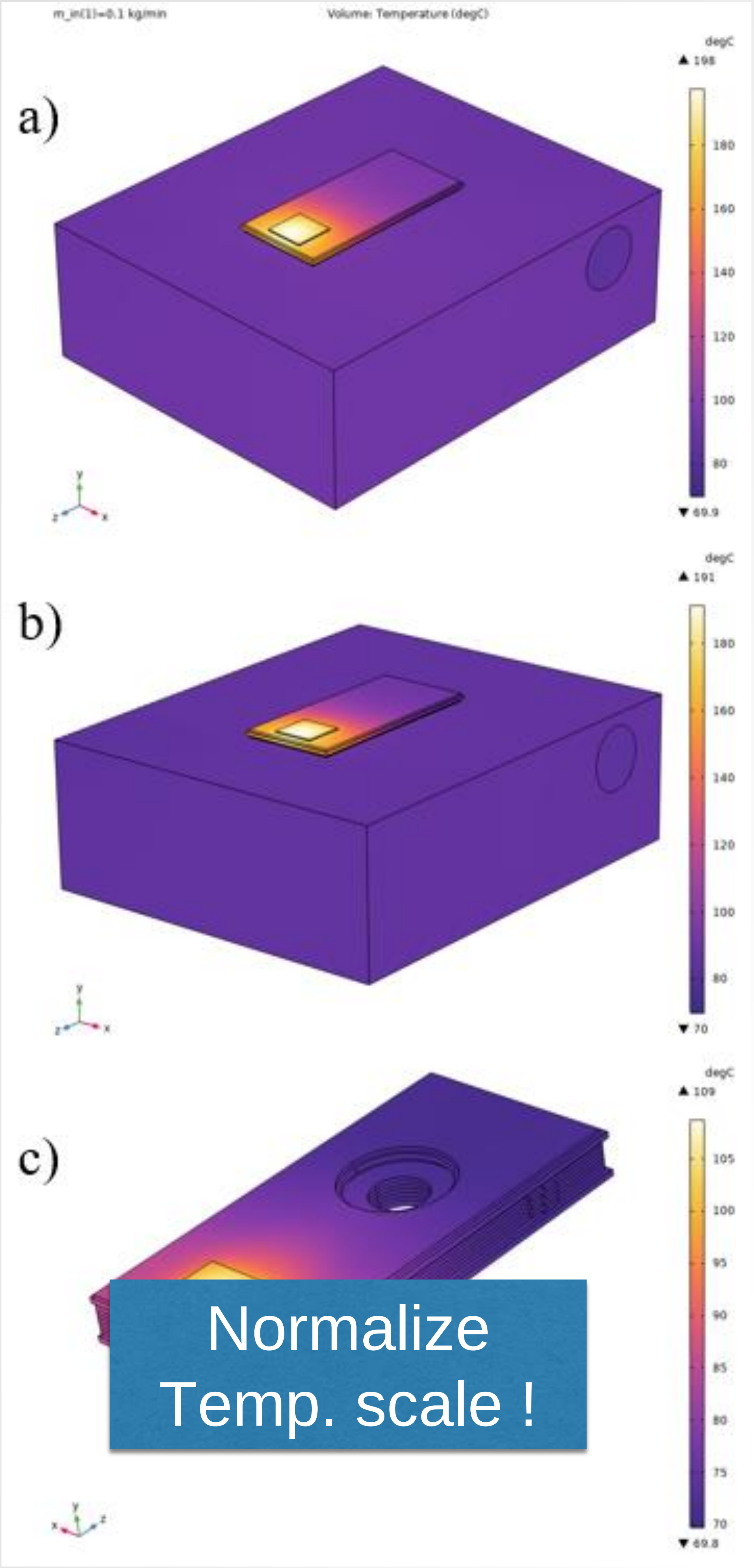
Die size: 5.45mm x 5.45mm

(a) Single hole (pipe) cold plate (60x50x20mm) as interior structure. Representing the technology used in many low-cost, readily available liquid cold plates.

(b) Structure with 1mm cooling channels in cold plate, for improved performance. This type of cooler requires more sophisticated manufacturing technologies like brazing or welding.

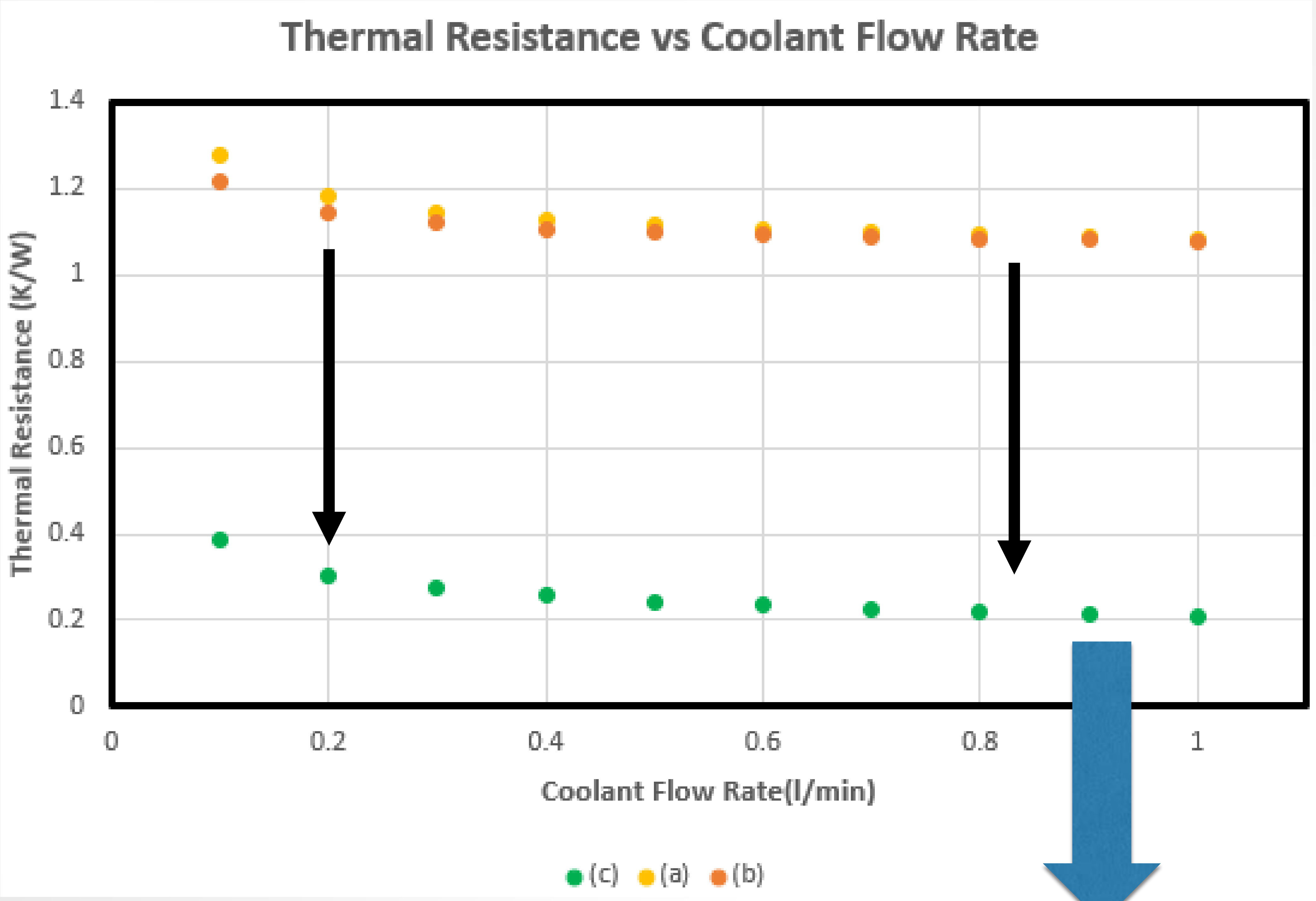
(c) Trumpf DBC integrated direct bond liquid cold plates with 300µm coolant channels.

Example: Simulation results



- Software: Comsol Multiphysics
- Comparable boundary conditions
  - 0.1 l/min to 1 l/min, increments of 0.1 l/min
    - Dissipated heat load (Ploss): 100W
- The thermal interface material to connect the DBC to the coolers in (a) and (b) has a thickness of 100µm and bulk thermal conductivity of 1 W/mK. Silver sintering film with a bulk thermal conductivity of 200 W/mK. Water is the coolant with an inlet temperature of 70°C.

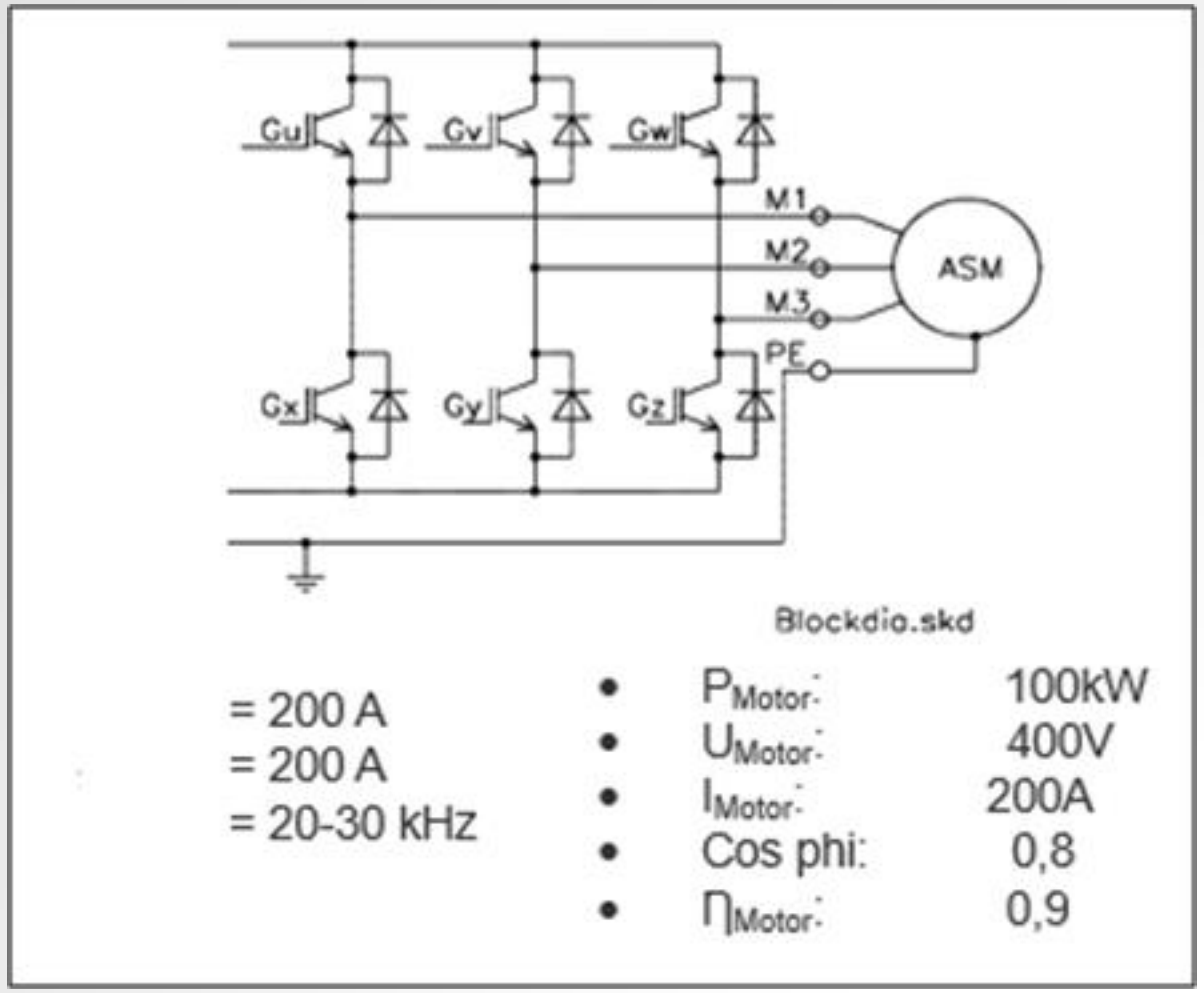
Proposed cooling technology

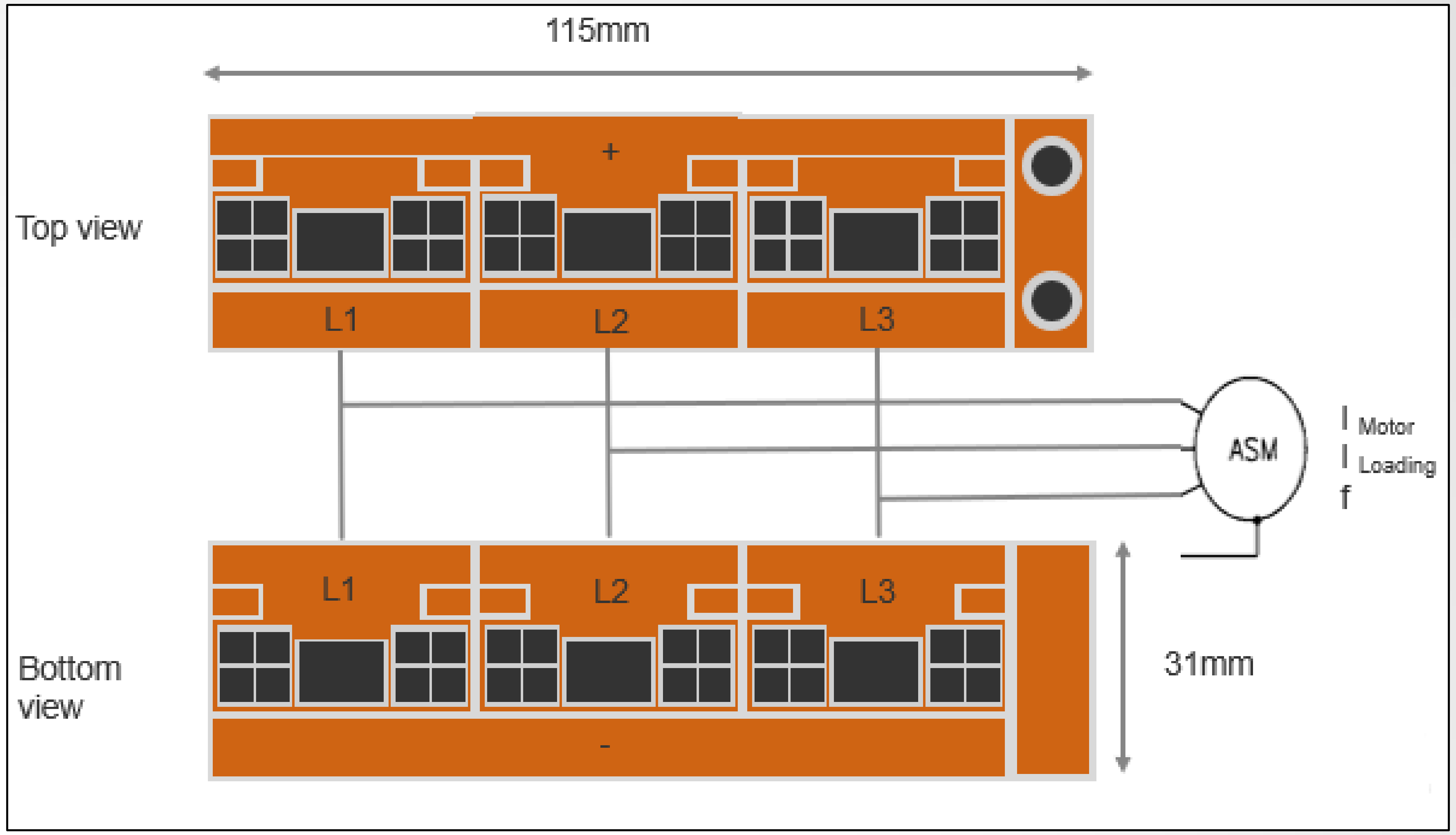


Die Size [mm]	Cooling Method	Flow per Liquid Cold Plate [l/min]	Thermal Resistance, Rth [K/W]
5x5	single	0.4	0.42
5x5	single	2	0.33
5x5	double	0.5	0.15
5x5	double	2	0.06
10x10	single	1	0.15

- A and B show little performance difference. This is due to the typically poor performance of TIM2. To increase packaging density for A and B the total heat load will increase and worsen the performance
- C, the integrated cold plate shows superior performance for Rth. Removal of TIM2 has a significant impact.
  Note: Dimensions of the cooler are significantly smaller. Tight packaging will be possible.
- Die size and water flow cause different values for Rth (see table).

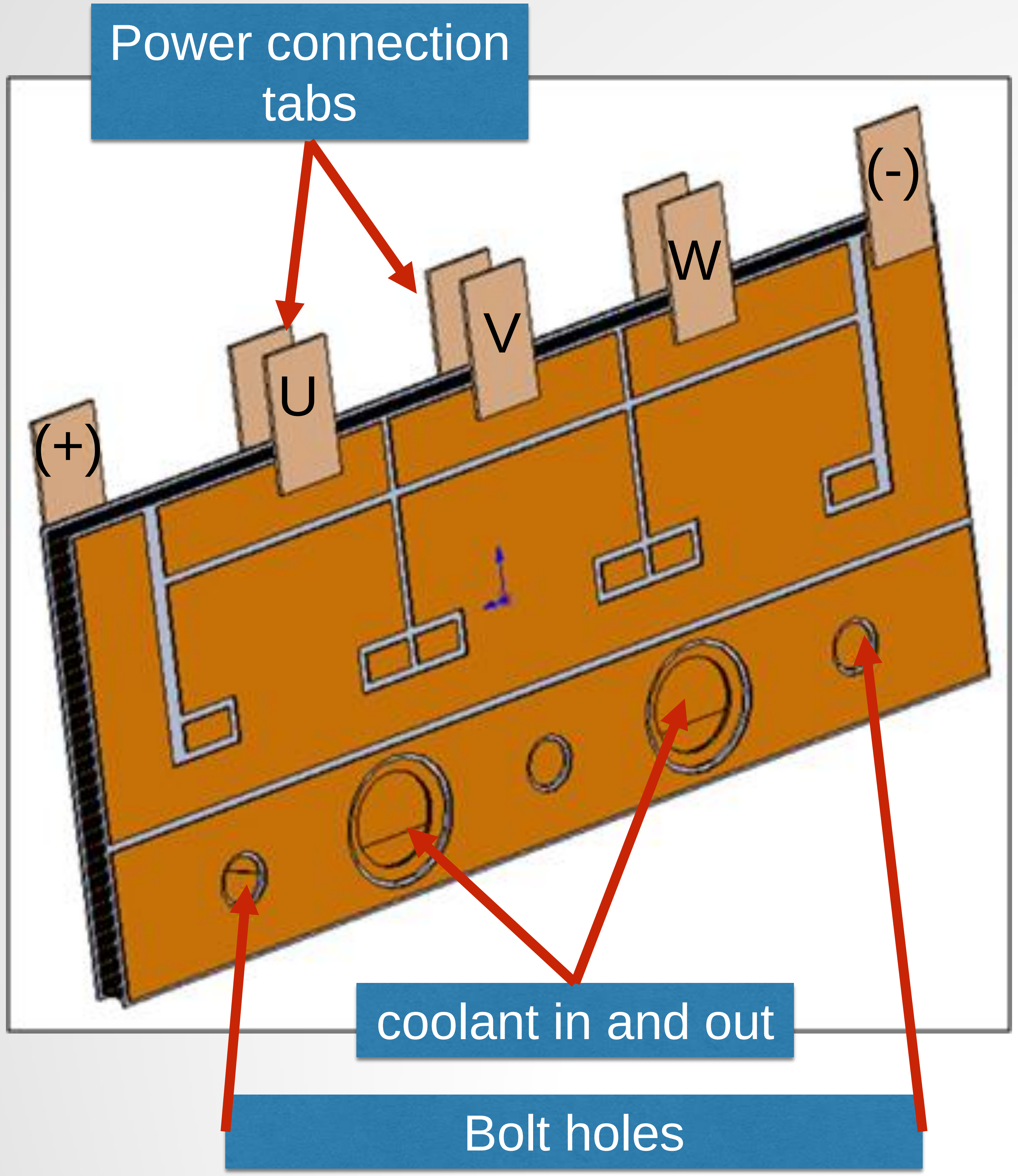
Application example: Traction inverter





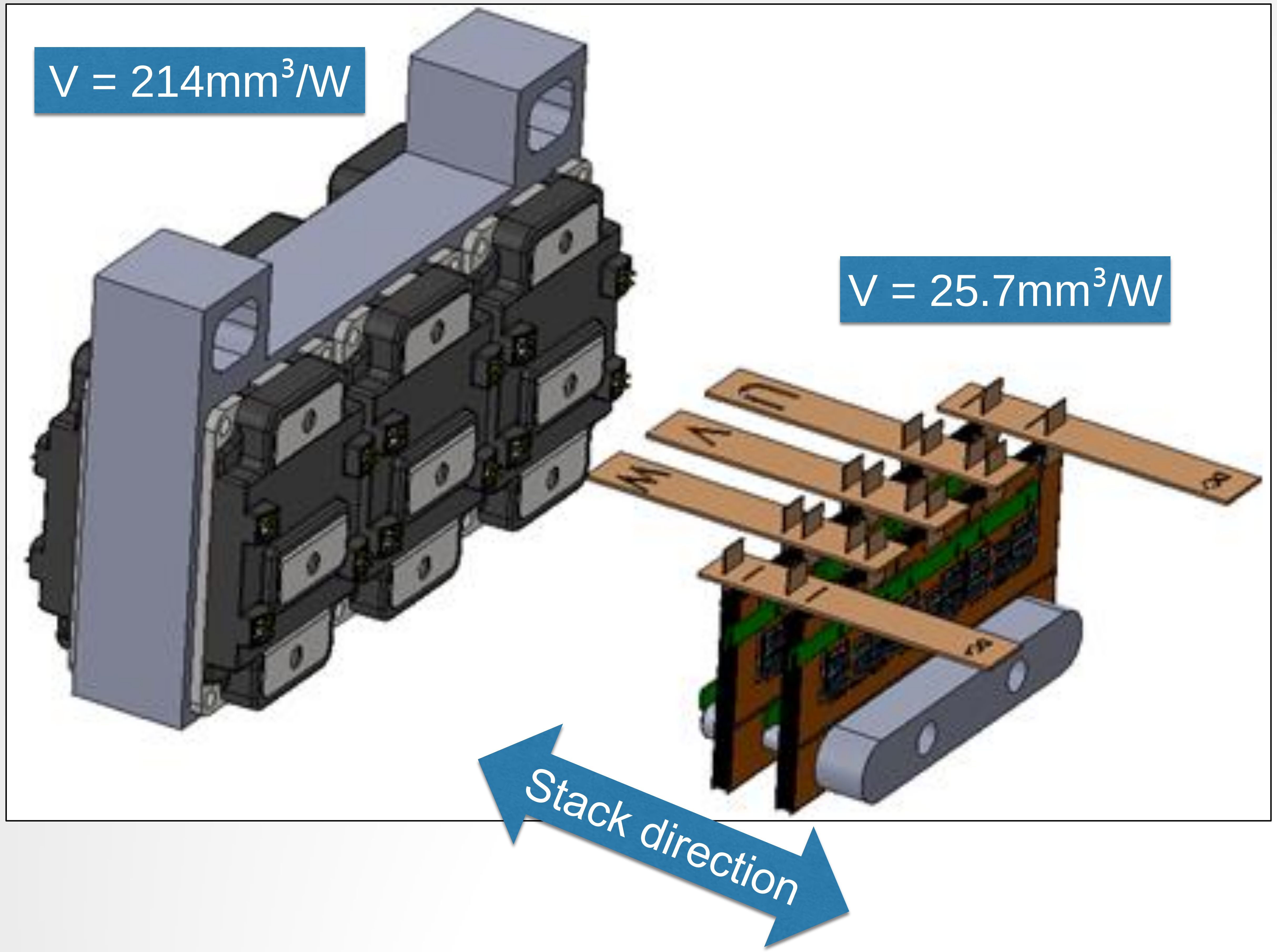
- Traction inverters use a 3-phase layout. Above numbers are used in this design
- The positive DC (+) layout is pictured on top
- The negative DC (-) layout is pictured on bottom

Example: Integrated cold plate for traction inverter



- Integrated micro-channel cooler based previous layout, stackable
- Custom internal cooling structures to remove heat: lamella or impingement
- Bolt holes for safe O-Ring compression, avoiding threads in copper
- Same cooler is being used for (+) and (-) boards. Sandwich structure reduces cost and increases density

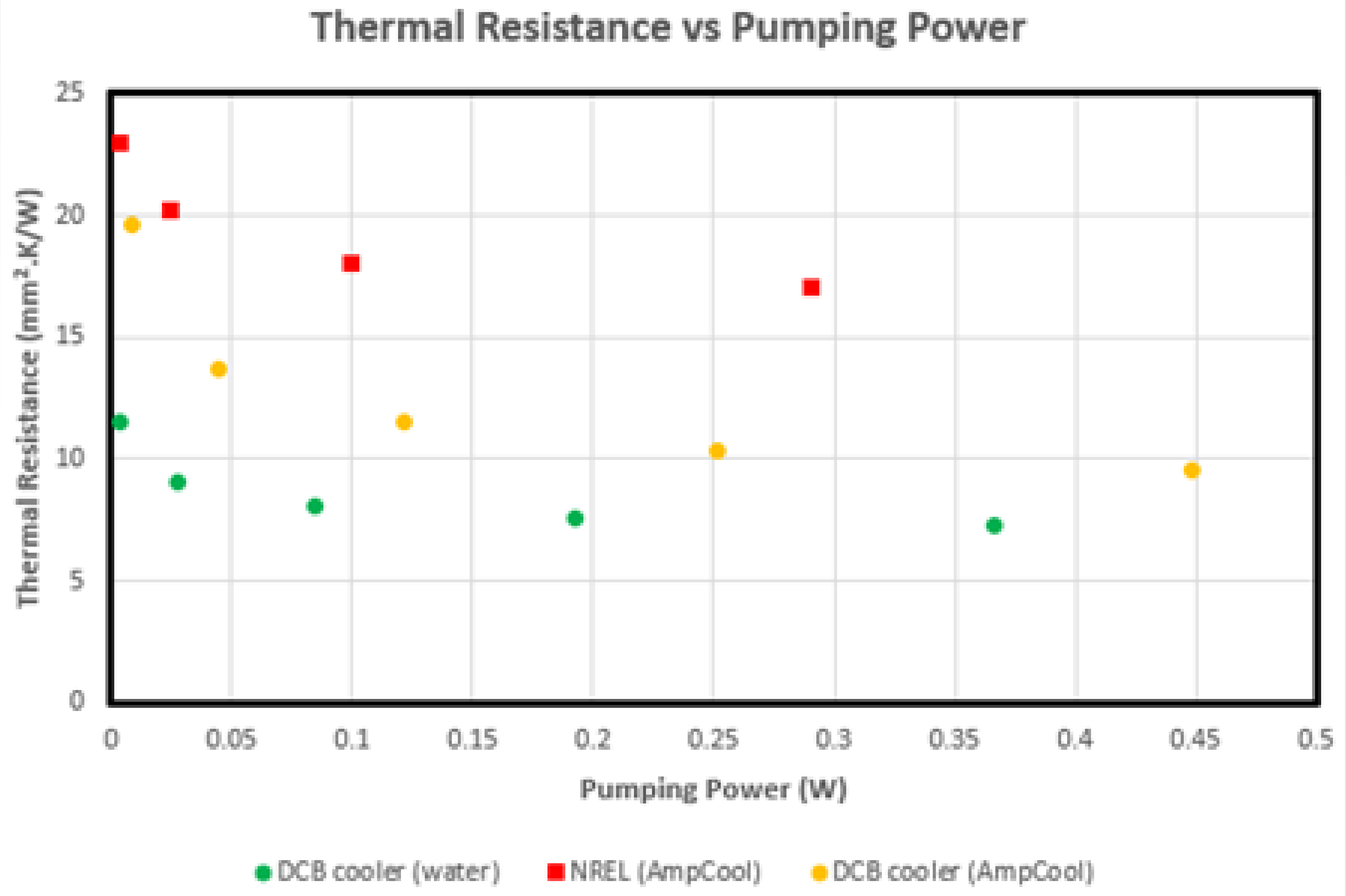
Application example



- Reduction in volume by ~ factor 10
- At the same time Rth improvements by factor 4-5
- Stackable design. Units can be added using the same concept
- Top access of electrical contacts allows Cu welding terminals
- Gate signals and temperature sensors supplied by PCBs

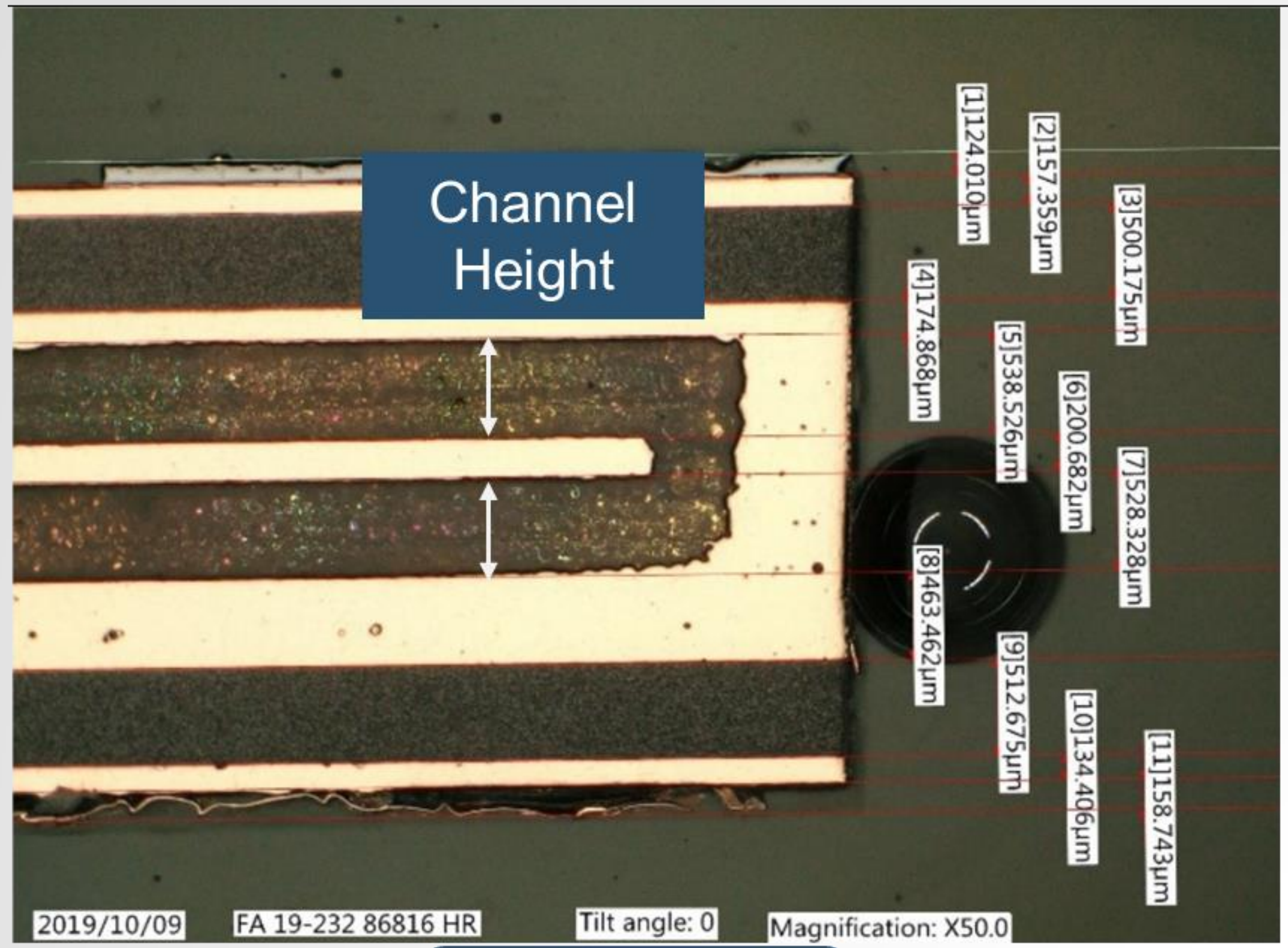
Rth vs Pumping power

- Small 0.3mm structures do not require excessive pump power due to their lower requirement in coolant volume
- Integrated cold plate technology delivers superior performance at all operation points.
- Integrated coolers can be used with dielectric coolants. The performance difference between water and AmpCool is expected due to different thermal capacity (4.186 J/g°C vs. 2.42 J/g°C)

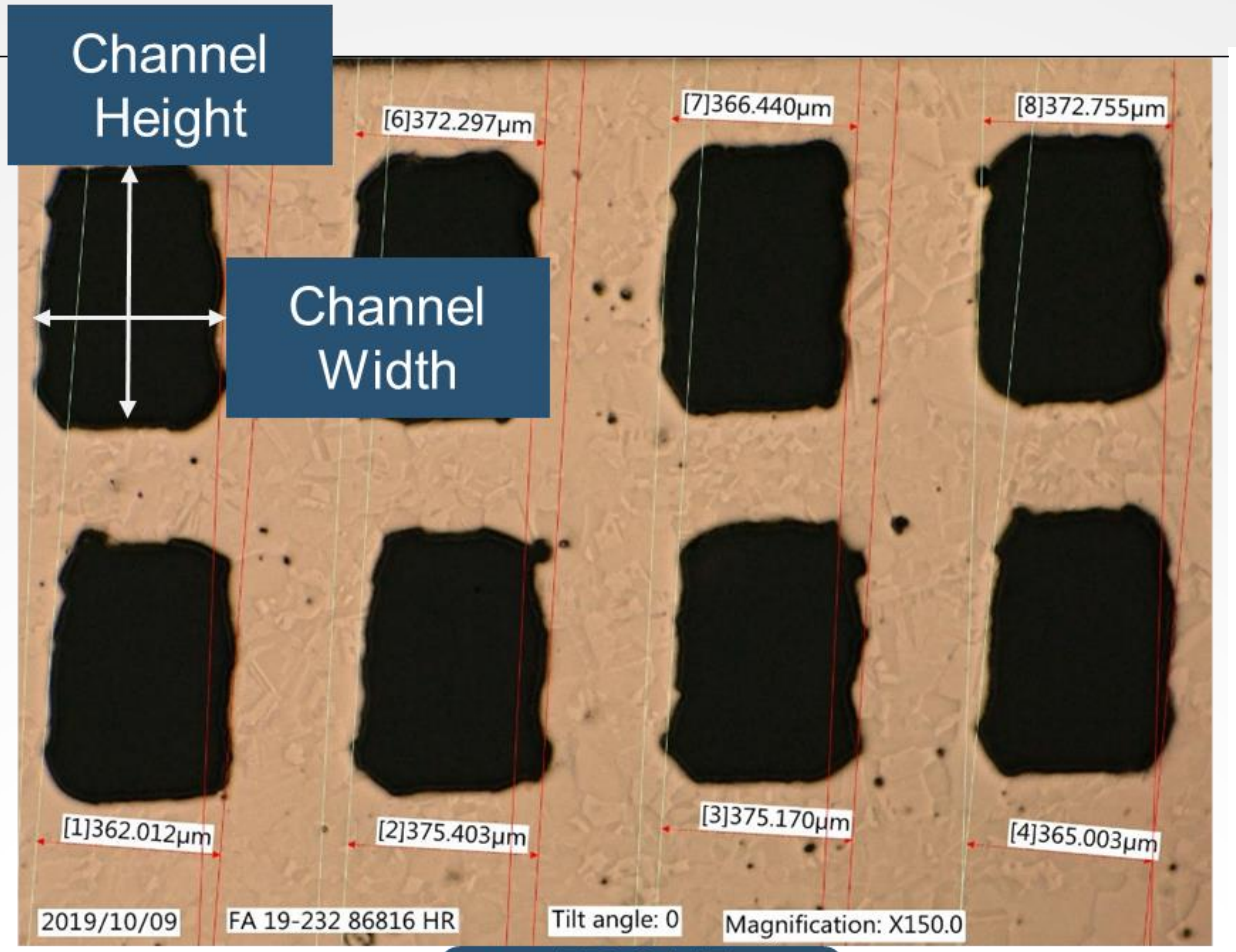


Based on NREL publication XXX

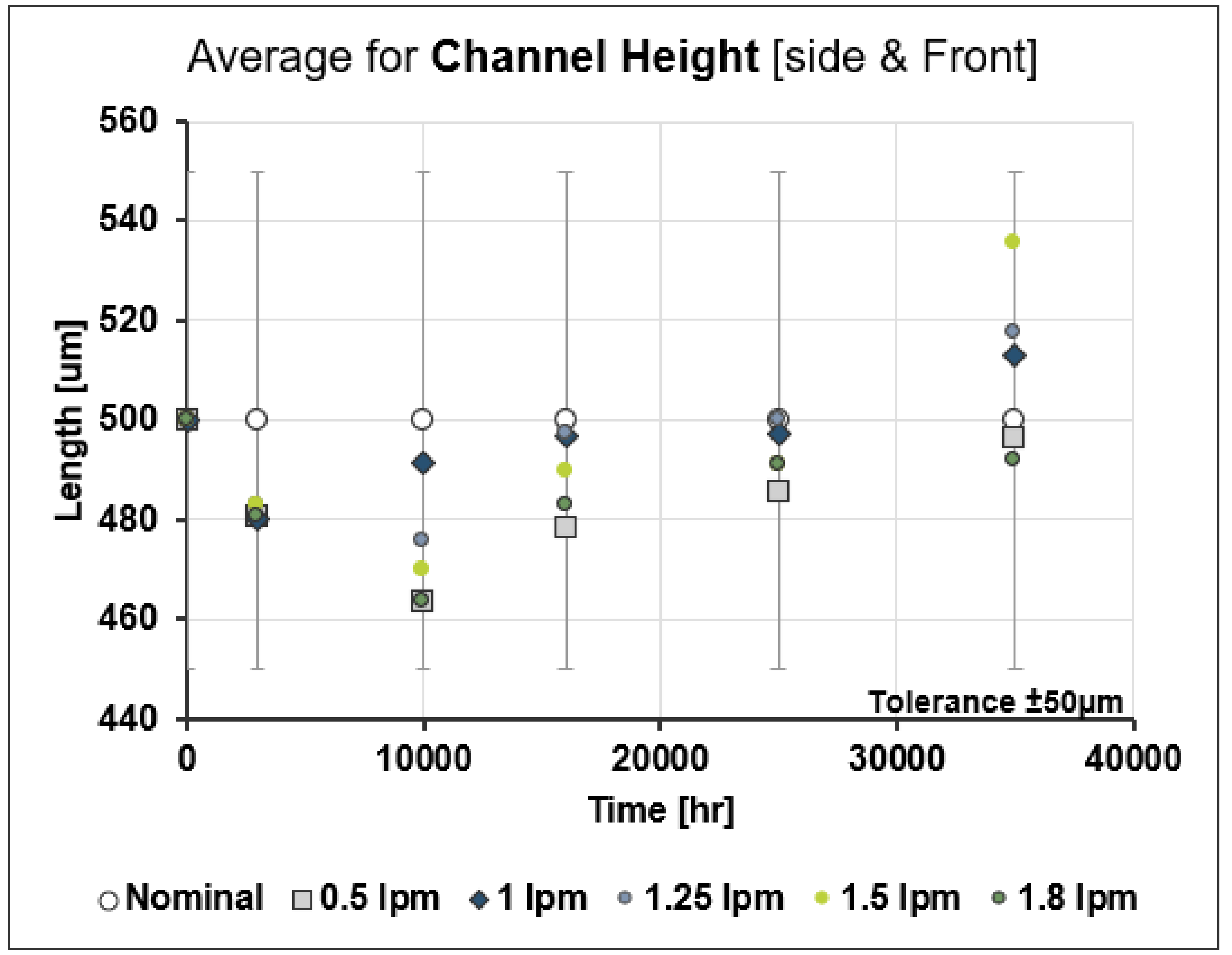
Lifetime and Reliability



SIDE
Cross Section



FRONT
Cross section



- Limited erosion of the channels can be observed: at the highest flow condition a widening of ~10% after 35,000 operational hours.
- + 1 Million in the field with very low field failure rate.
- Lifetime testing and power cycling with IGBT die is underway. Results are expected to be comparable to other DBC substrates

Your Contact

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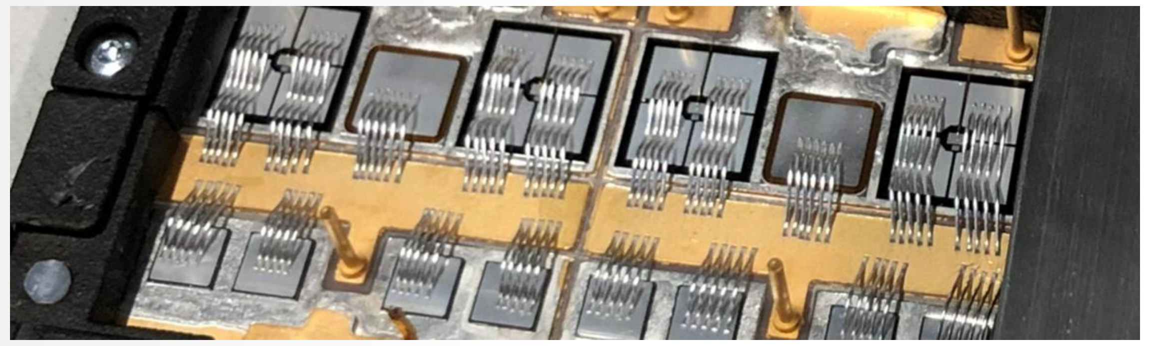

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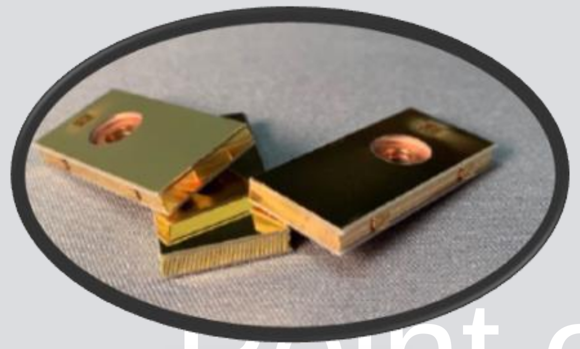

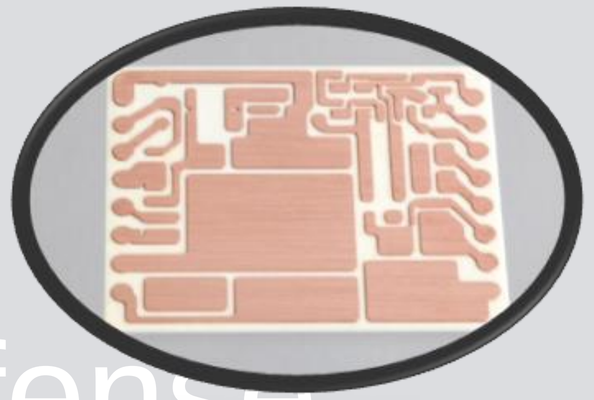

Point of contact for defense customers