Thermal studies of DEPFET cooling for Belle II

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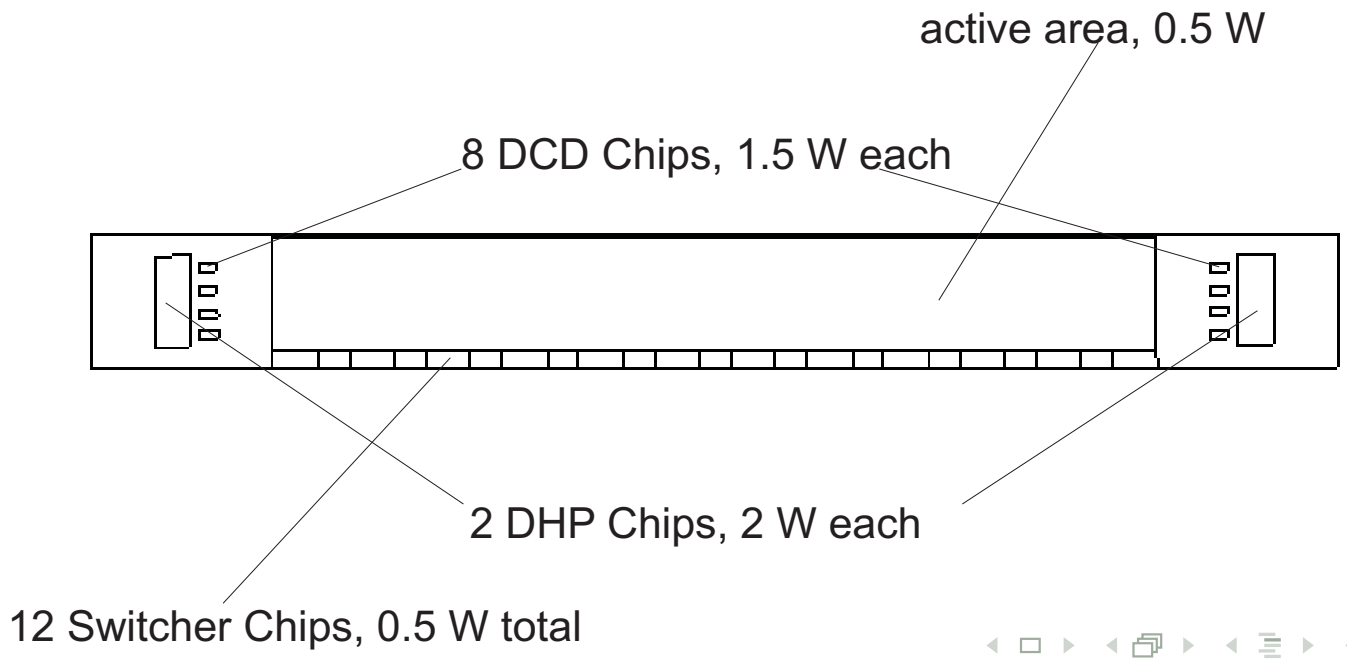
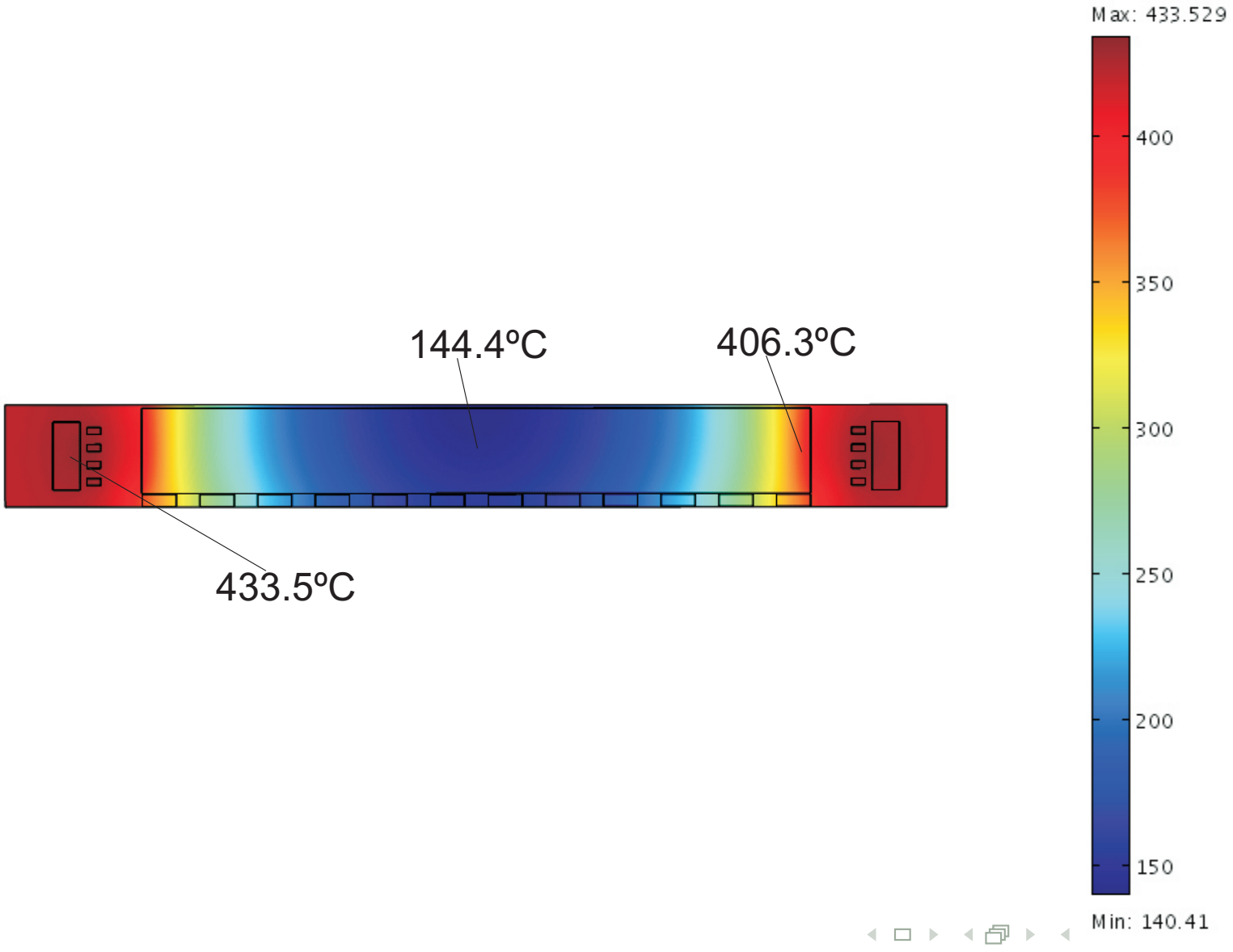
Outline

Assumptions

- 17 W total power dissipation (8 W at each module end)
- to simulate the bump bonding: a layer (50μm thickness) with λ=5 W/mK between the chips and the silicon
- 20°C ambient temperature

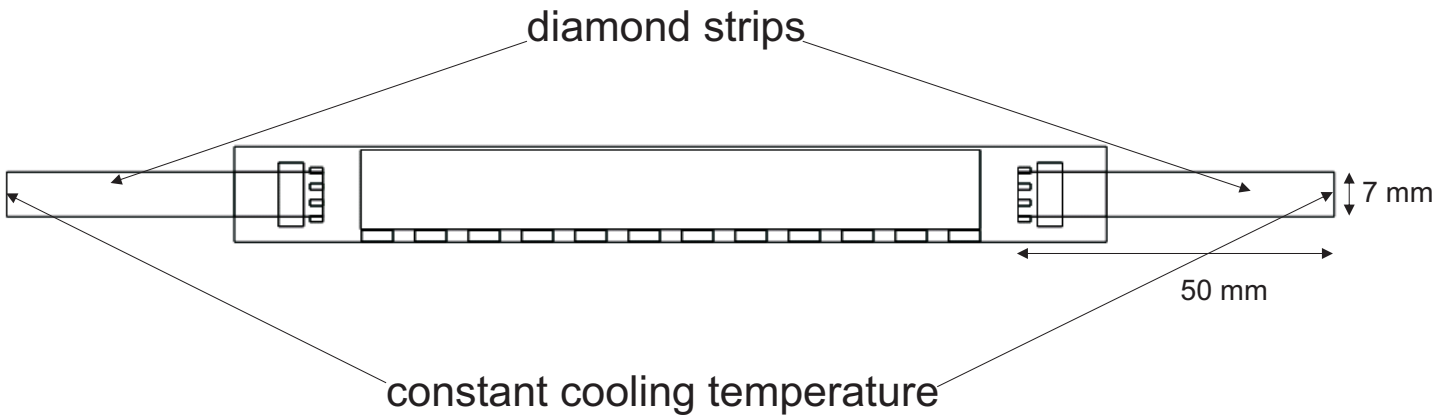


No contact cooling



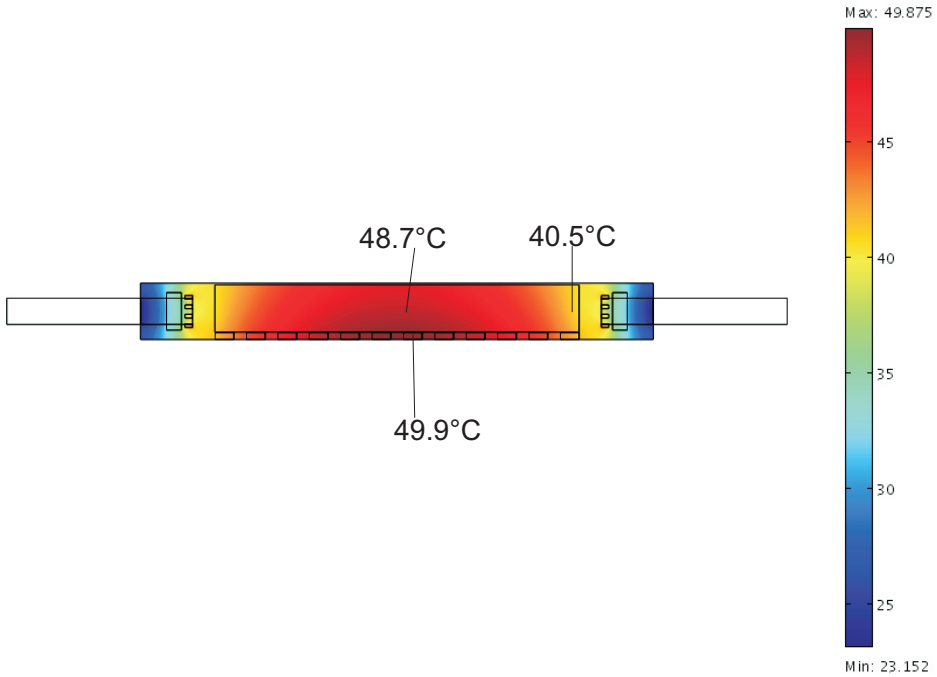
Contact cooling with diamond strips

- two diamond strips (7mm×0.4mm×50mm) glued on the both ends of the module
- adhesive layer: 50μm thick, thermal conductivity λ=5 W/mK
- -30°C cooling temperature



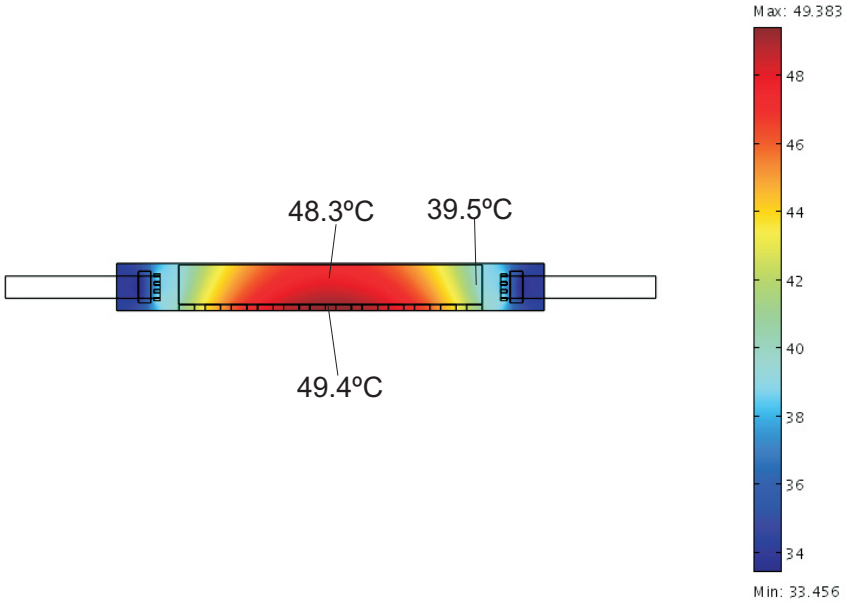
Cooling from below

- diamond strip glued on the underside of the silicon
- advantages: simple mounting, large contact area (98 mm^2)
- disadvantage: larger distance between the inner layer and the beam pipe



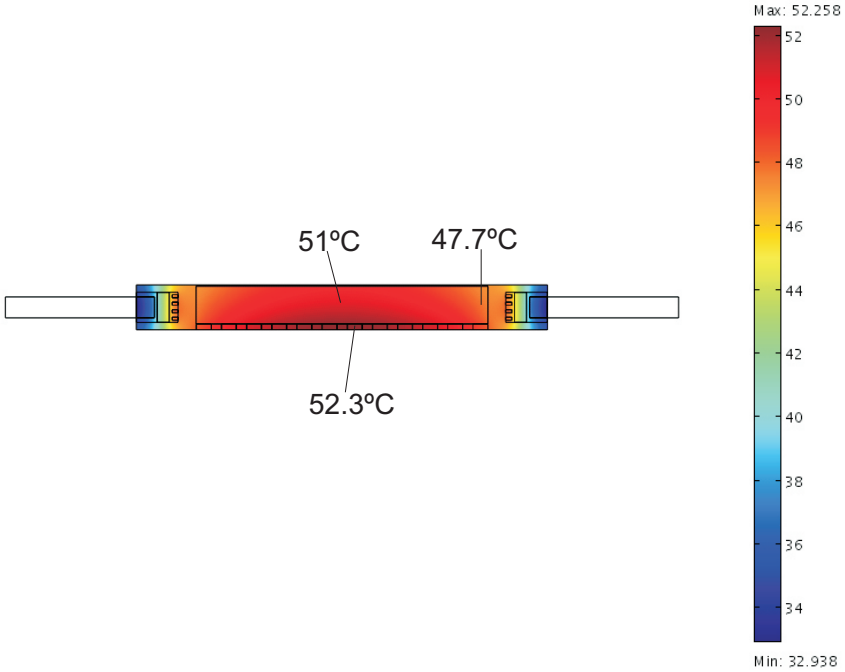
Cooling from above (directly on the chips)

- diamond strip glued on the chips
- advantages: no heat transfer through the silicon, heat is lead away directly from where it is produced
- disadvantage: chips have to be of the same height, mechanical stress to the bonds

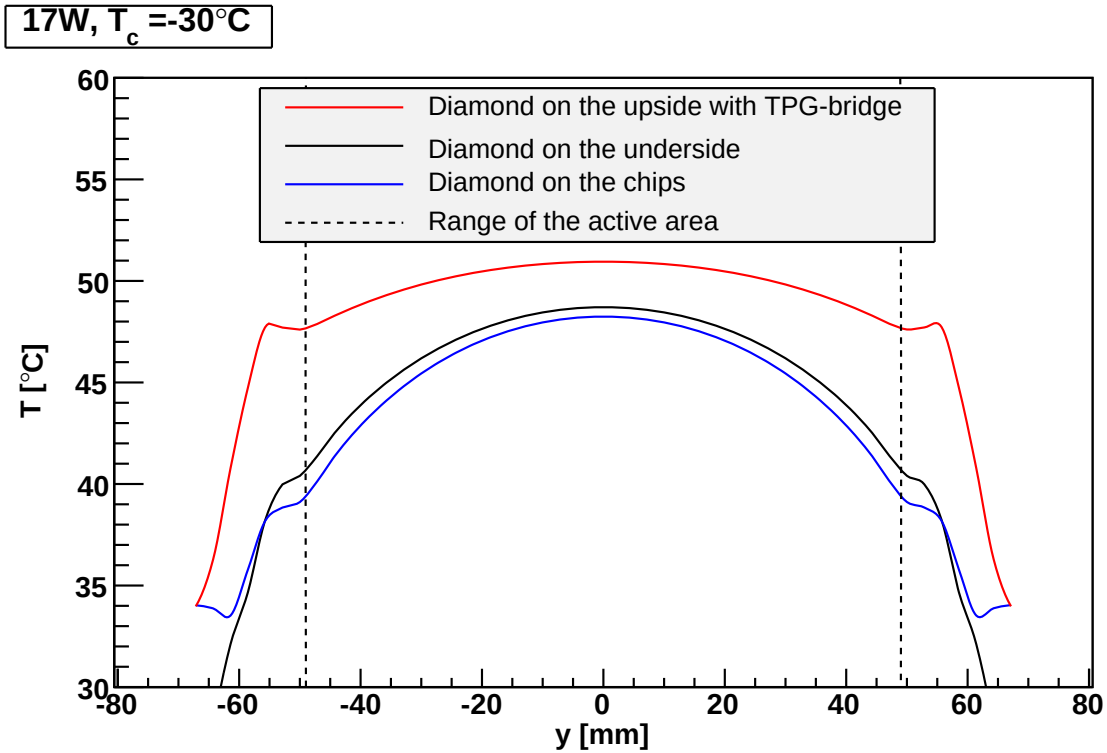


Cooling from above (with TPG-bridge)

- diamond strip glued on the upside of the silicon (42 mm^2 contact area)
- TPG-bridge (10mm$\times$0.2mm$\times$14mm) to connect the diamond directly to the chips
- $\sim 7 - 8^{\circ}C$ higher temperature



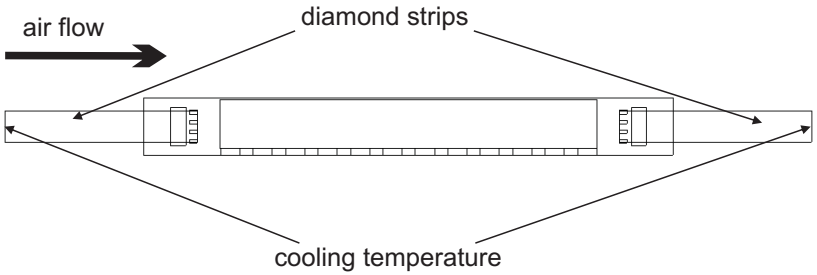
Comparison

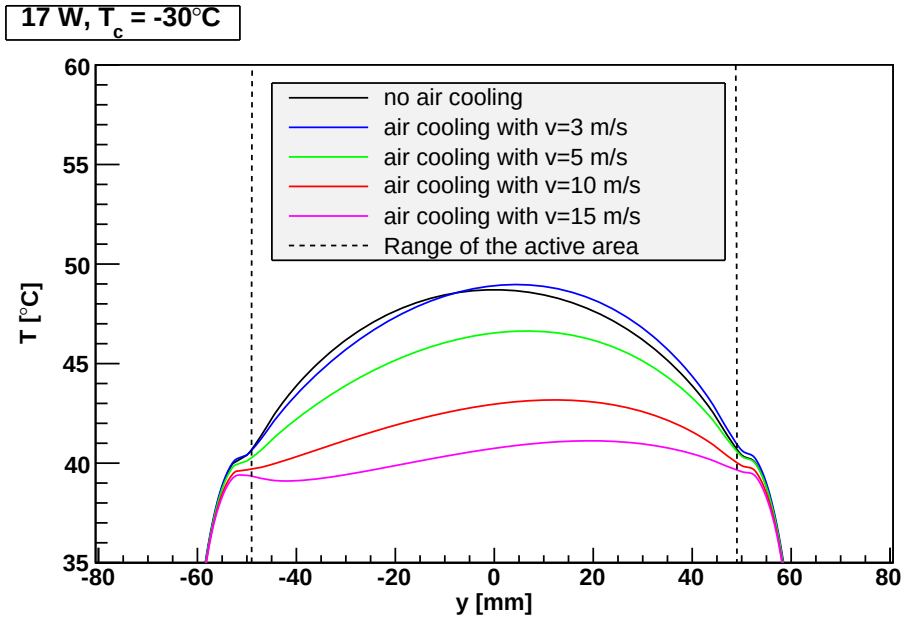


- best results from diamond glued directly on the chips
- nearly the same results from gluing the diamond on the underside
- ~8°C higher temperature on the edge of the active area with a TPG-bridge

Air flow

- cooling by diamond strips glued on the underside of the silicon
- $-30°C$ cooling temperature
- air flow along the module (air temperature $20°C$)

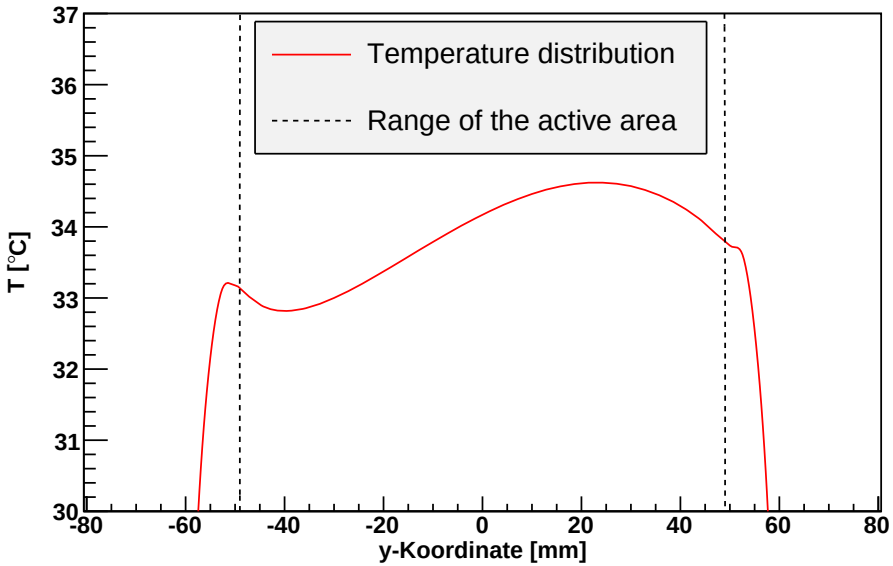


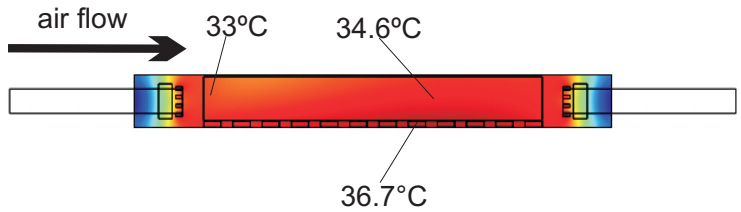


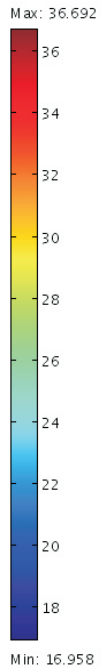
$\longrightarrow$ temperature at the center of the module decreases significantly with higher air velocity (nearly no change on the edges of the active area)

Possible solution

- −35°C cooling temperature
- 5°C air temperature, 5 m/s air velocity







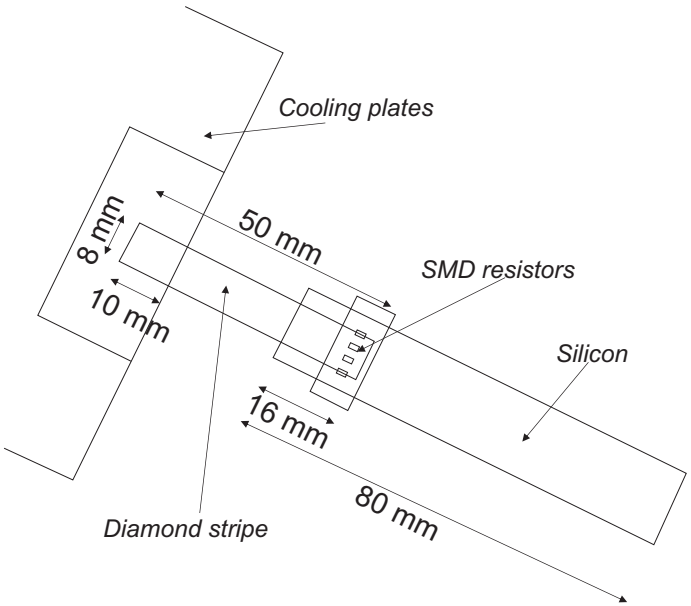
Conclusions

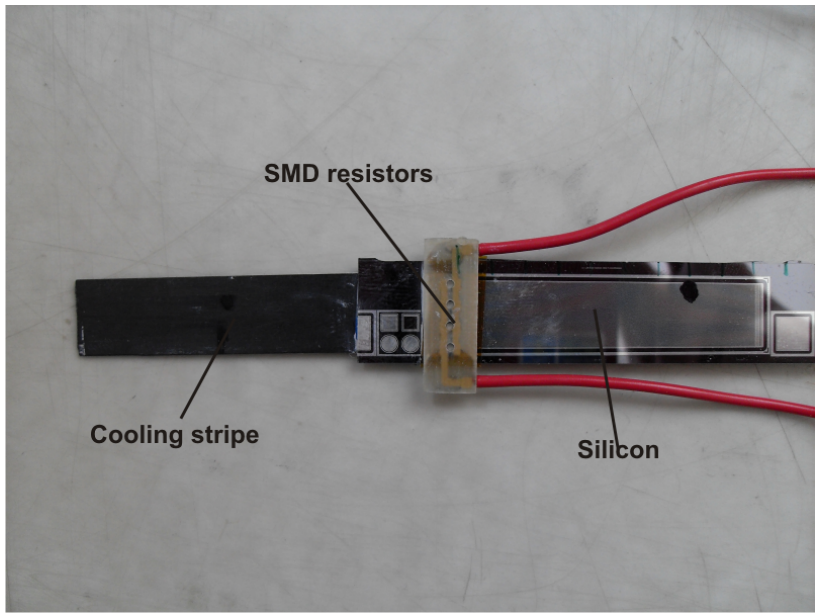
- A cooling temperature of $-30°C$ or lower is needed (if the diamond ist 7 mm wide and 0.4 mm thick)
- Slightly higher cooling temperature may be enough with a wider/thicker diamond strip and/or lower ambient temperature
- Similar results for all three possible diamond positions
- DEPFET temperature is $7°C$ higher when cooled with the TPG-bridge as by cooling from below, has to be verified experimentally
- Air flow is needed to cool down the center of the module

Experimental setup

Piece of silicon (15mm×80mm×0.5mm = half ladder) heated by SMD-resistors and cooled through a diamond strip (8mm×50mm×0.4mm)

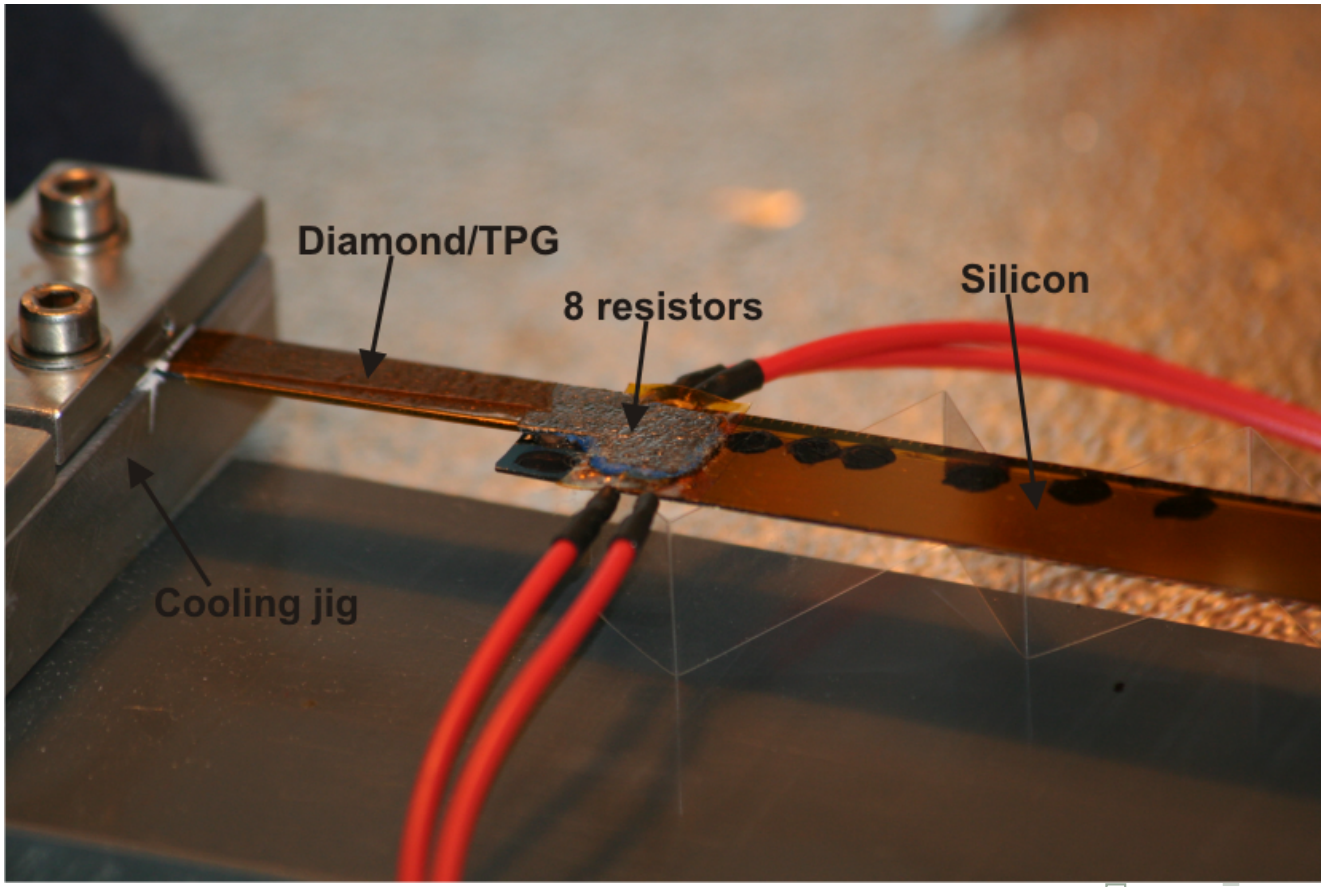
- First setup: diamond glued on the underside of the silicon (below the resistors)





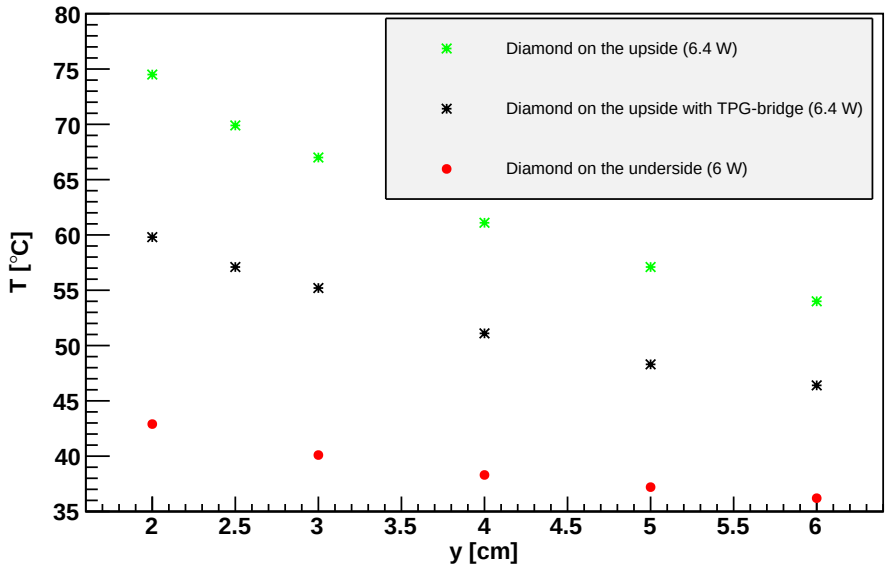
New setup

- New setup: diamond glued on the upside of the silicon. For the connection with the heat source a TPG stripe (0.3 mm thick) was glued on the resistors and on the diamond

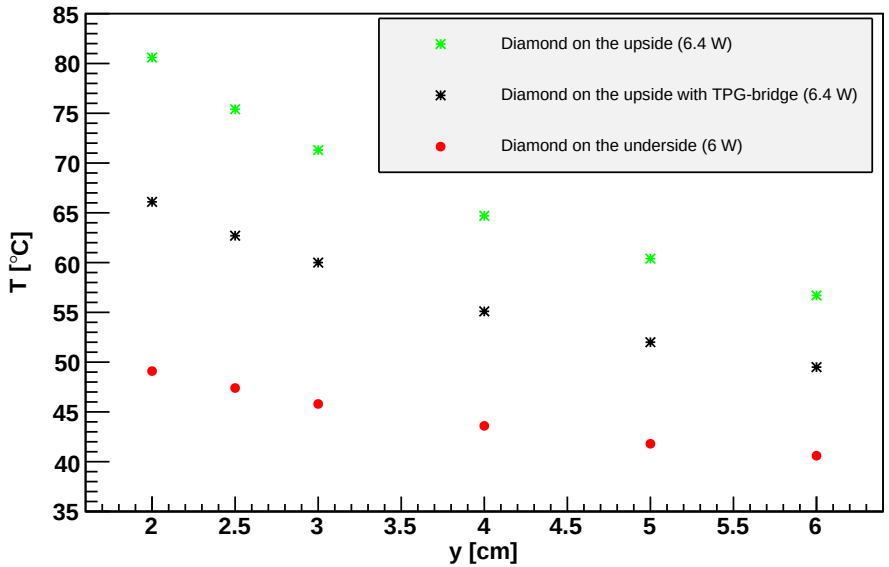


Results

≈ 6W, 10°C



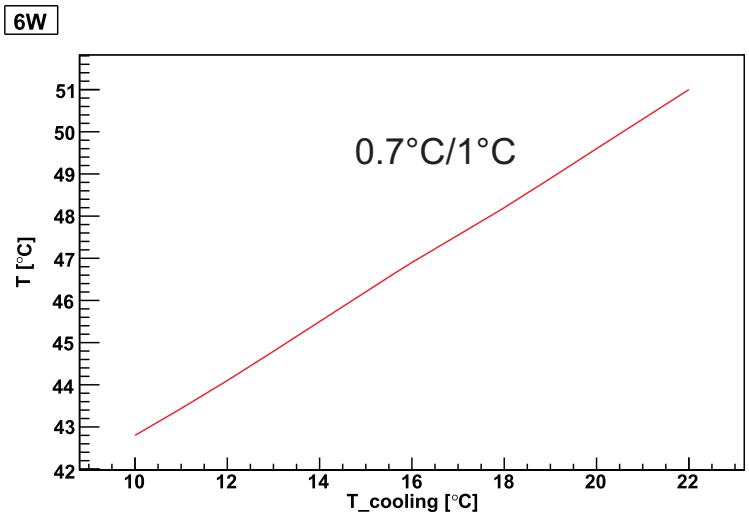
≈ 6 W, 20°C



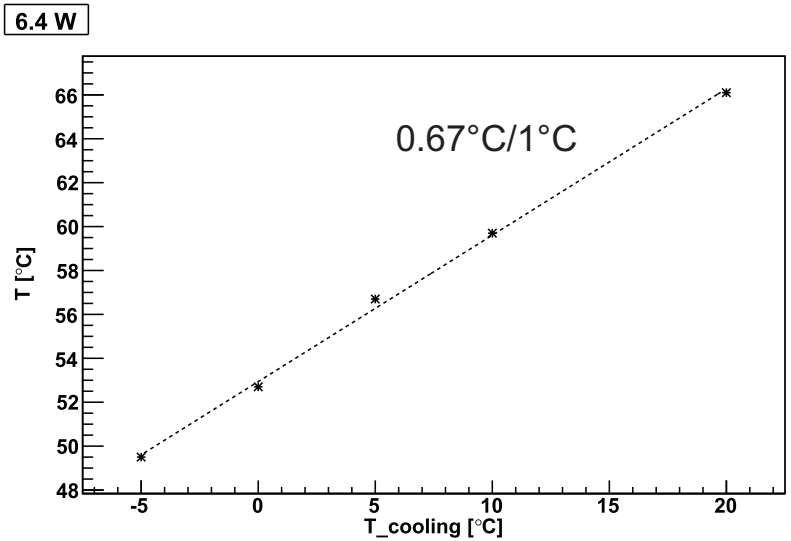
- 15°C temperature gain when using the TPG-strip
- even with the TPG-strip the temperature is 17°C higher than by cooling from below

Cooling temperature

- Simulation (diamond on the underside)



- Measurements (TPG-bridge)



→ good agreement, 1°C lower cooling temperature reduces the silicon temperature by ∼0.7°C

First conclusions

- Cooling only through a diamond glued on the upside of the silicon is not effective
- Setup with TPG-strip is very sensitive to mechanical stress and gluing, results are not exactly reproducible (preliminary) $\rightarrow$ more tests necessary
- Relatively high temperature already with 300μm thick TPG-strip $\rightarrow$ is it reasonable to test thinner TPG-strips?
- For cooling temperature higher than -5°C: 1°C lower cooling temperature leads to 0.7°C lower silicon temperature $\rightarrow$ -32°C cooling temperature needed to reduce silicon temperature to 30°C (for 6 W)

Thank you