SELF-CALIBRATION OF PHOTODIODES

USING THE DUAL-MODE METHOD

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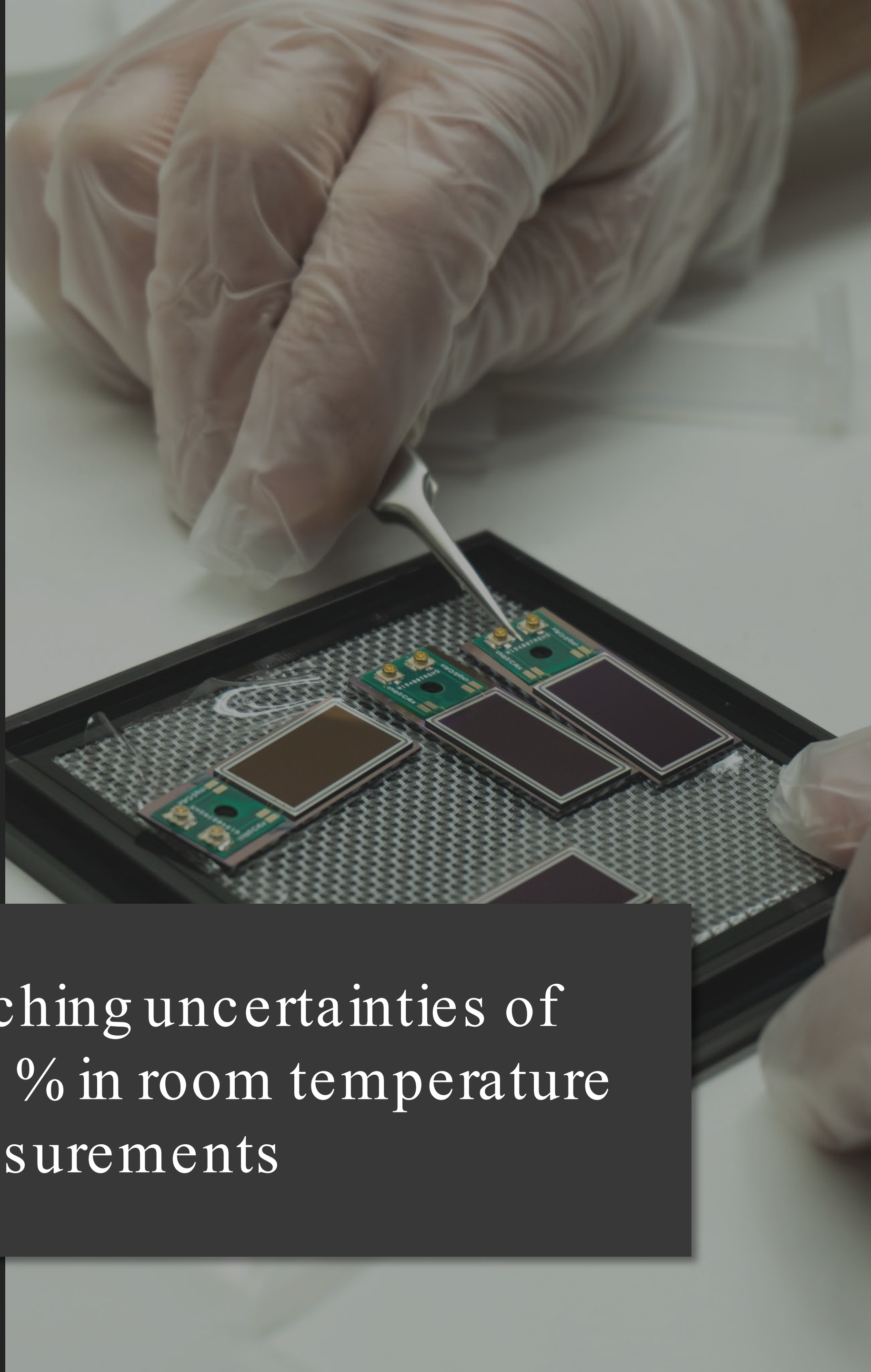
CALCON 2024
Logan – June 10



Reaching uncertainties of 0.03 % in room temperature measurements

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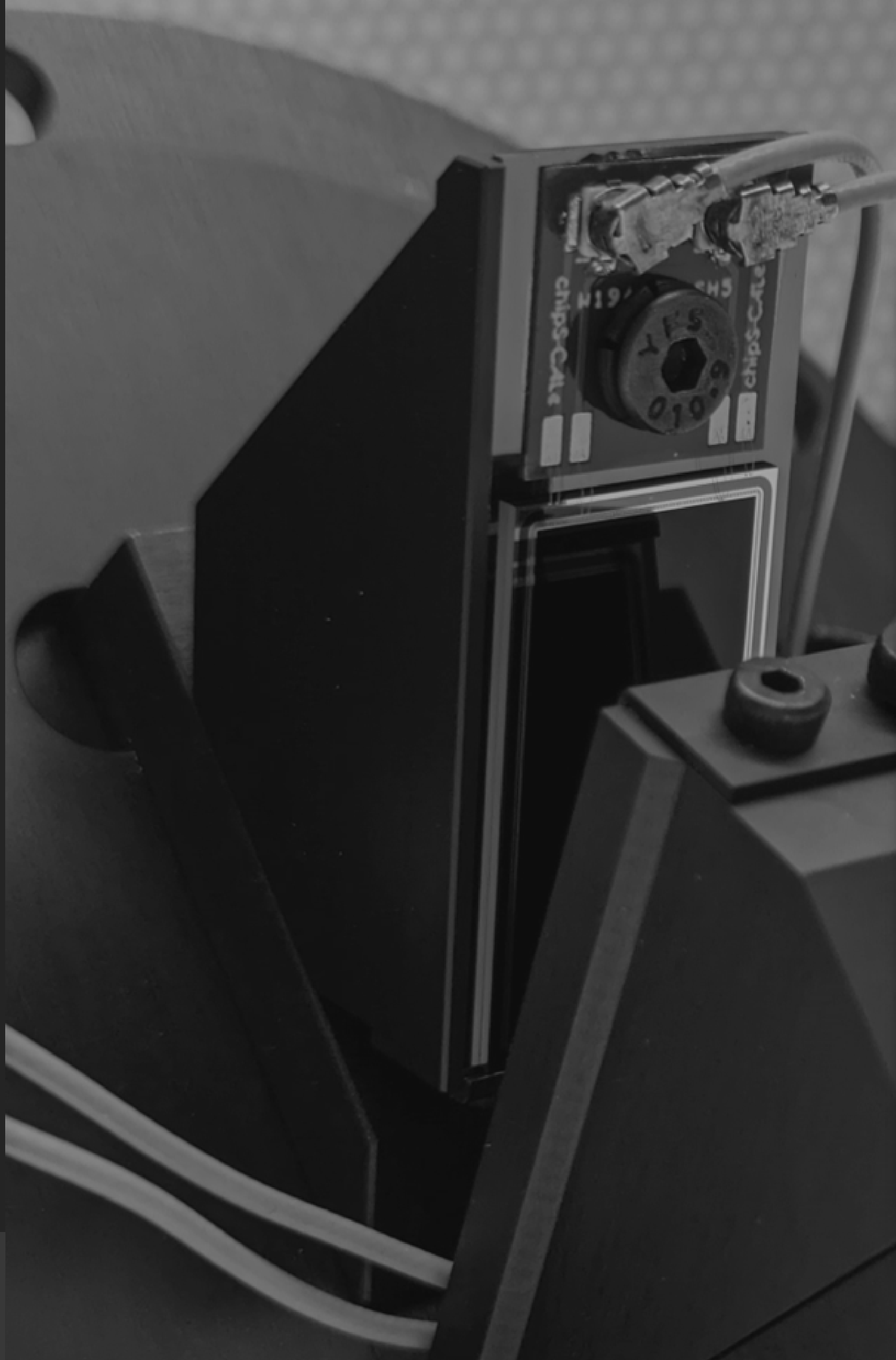

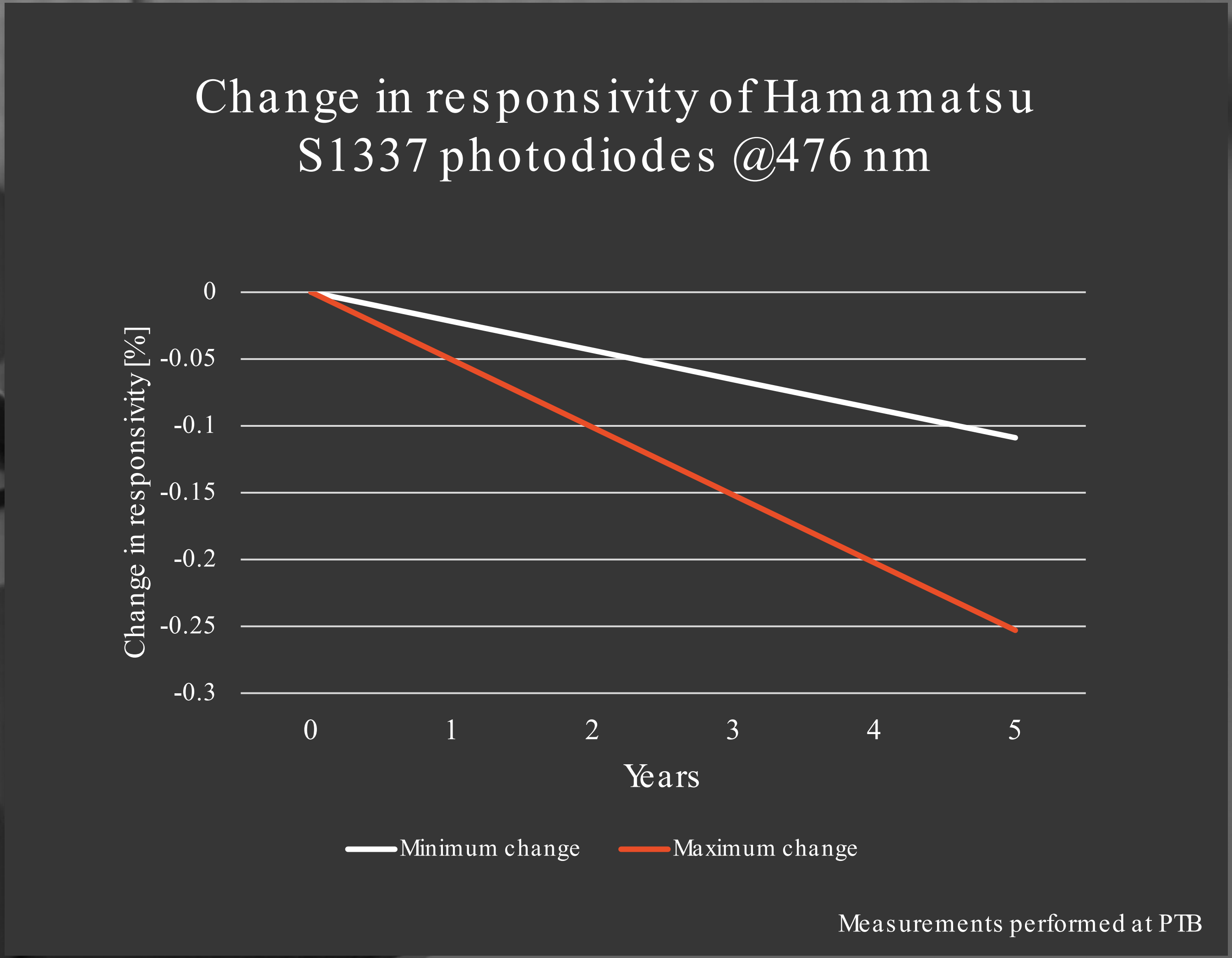
Change in responsivity of Hamamatsu S1337 photodiodes @476 nm
Change in responsivity [%]
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
0
1
2
3
4
5
Years
Minimum change
Maximum change
Measurements performed at PTB


WHERE DO WE NEED
SELF-CALIBRATION?

ACCURATE MEASUREMENTS IN REMOTE LOCATIONS

Reduce need for bringing the instrument to the lab for calibration. Example: space.

INTEGRATION INTO INSTRUMENTS

Shorter traceability chain.
Examples: spectrometers, power meters.

ACCURATE MEASUREMENTS IN REMOTE LOCATIONS

Reduce need for bringing the instrument to the lab for calibration.
Example: space.

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DUAL-MODE METHOD

Calibrating photodiodes: quantify internal losses.

We define the internal quantum deficiency (IQD):

$$\delta = 1 - \frac{P_{opt,pc}}{P_{opt,es}}$$

THE

DUAL-MODE METHOD

$$\delta = 1 - \frac{P_{opt,pc}}{P_{opt,es}}$$

Optical power assuming ideal photodiode

$$P_{opt,pc} = \frac{i_{photo}hc}{e\lambda}$$

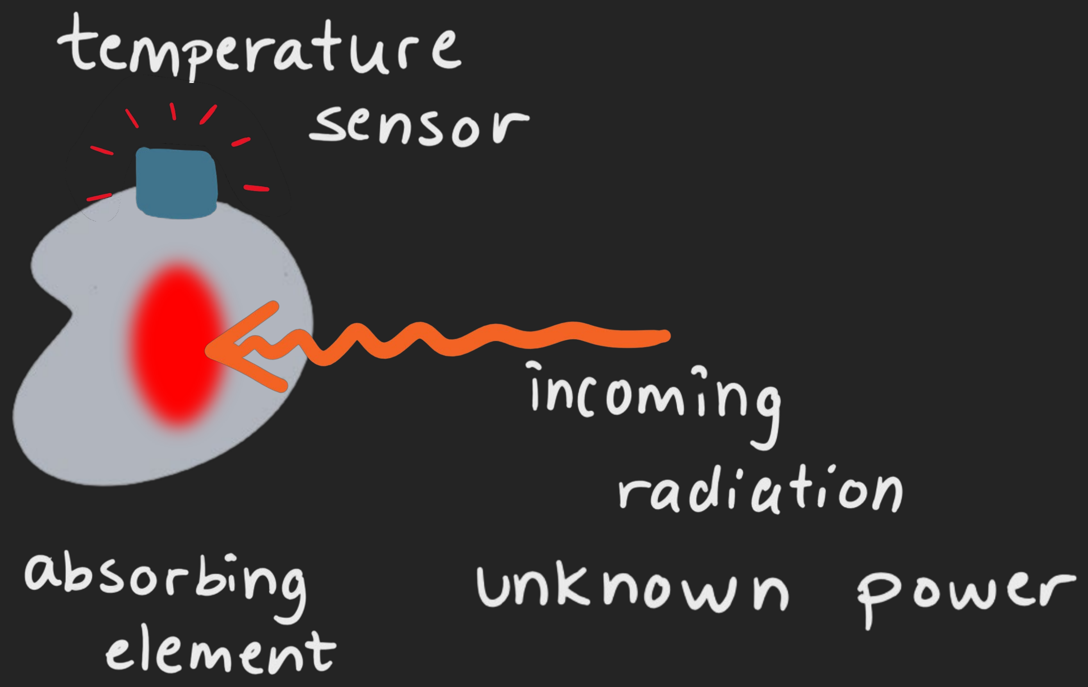
THE

DUAL-MODE METHOD

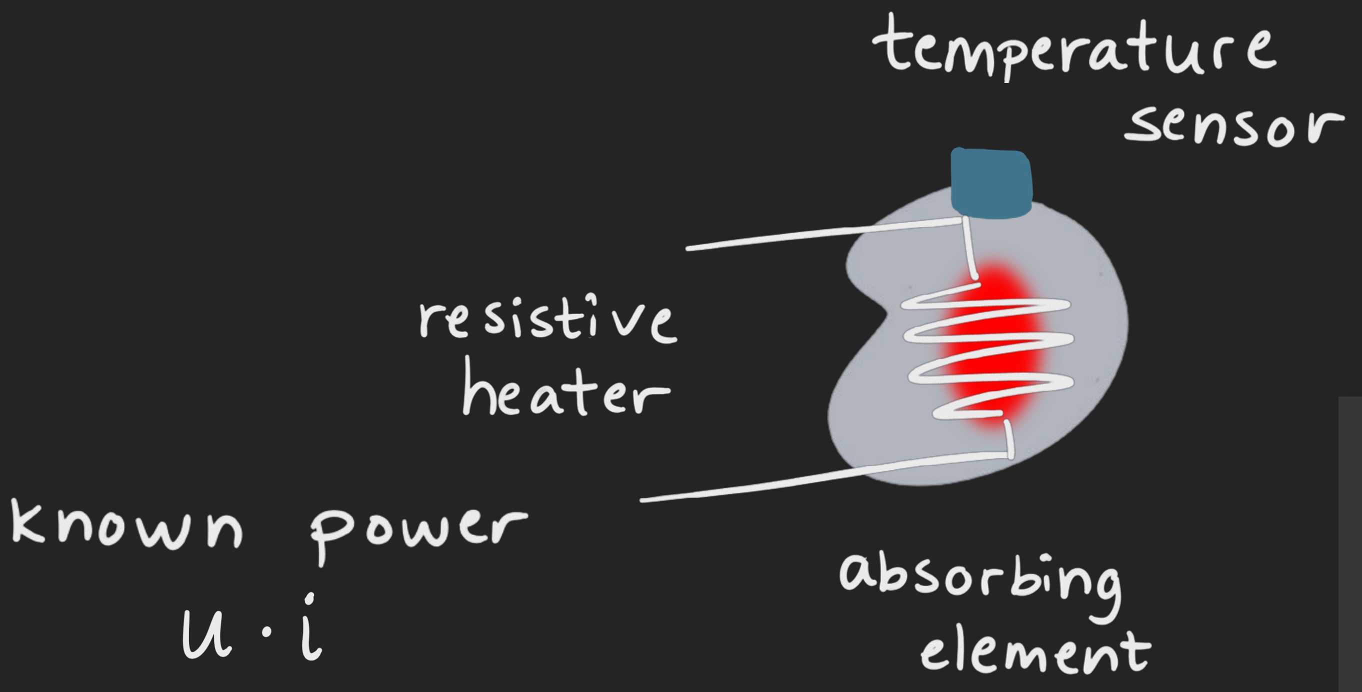
$$\delta = 1 - \frac{P_{opt,pc}}{P_{opt,es}}$$

Reference optical power found through electrical substitution

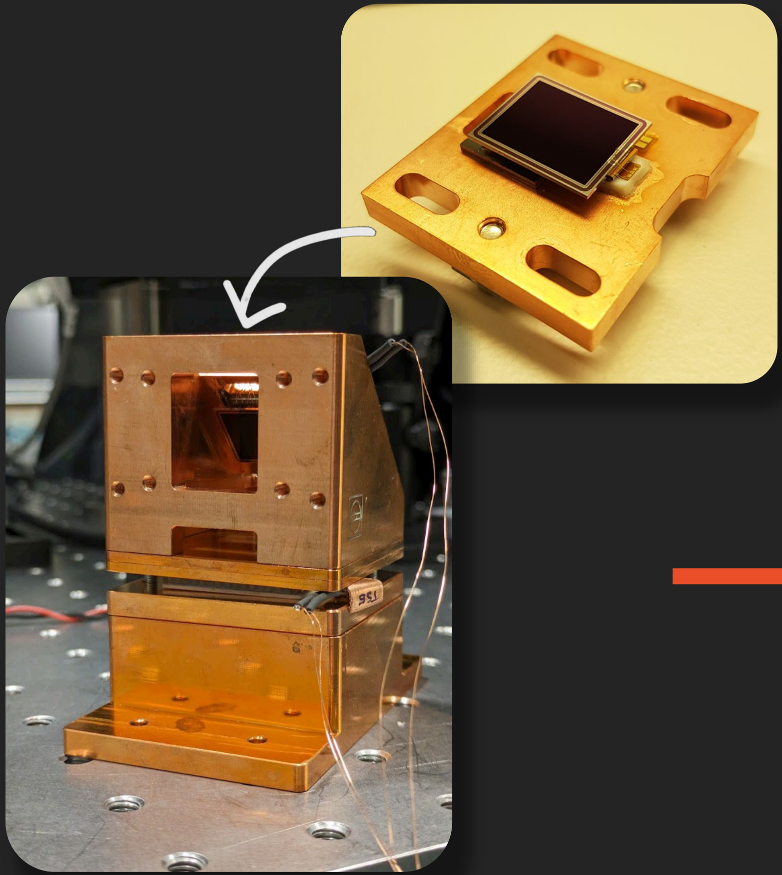
ELECTRICAL SUBSTITUTION

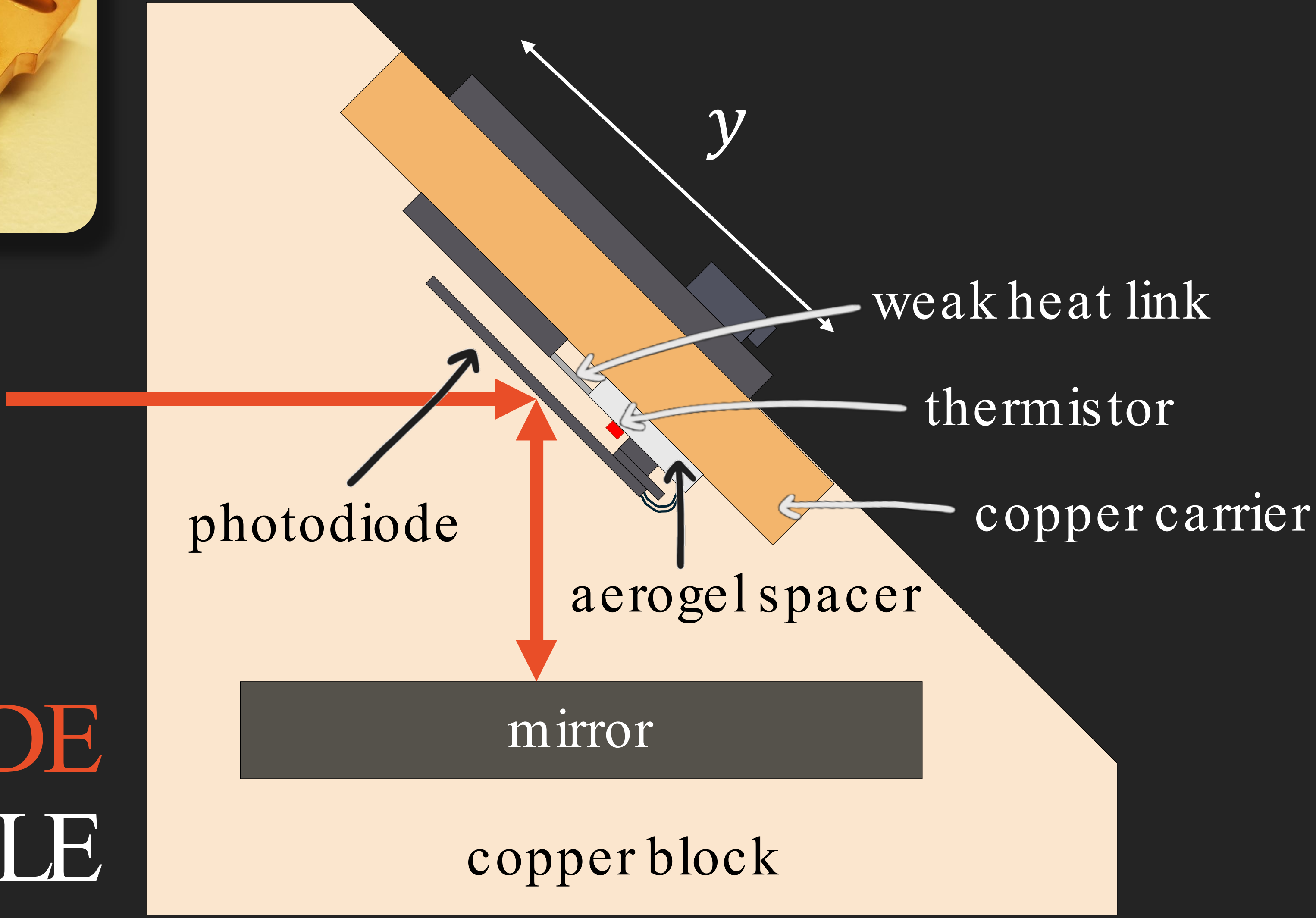


ELECTRICAL SUBSTITUTION

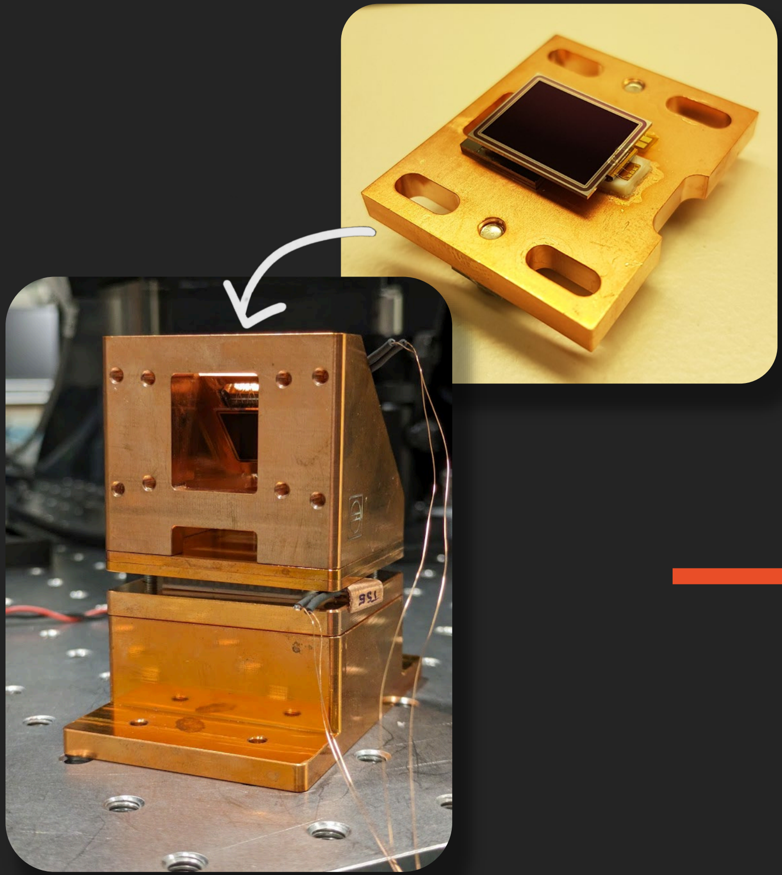


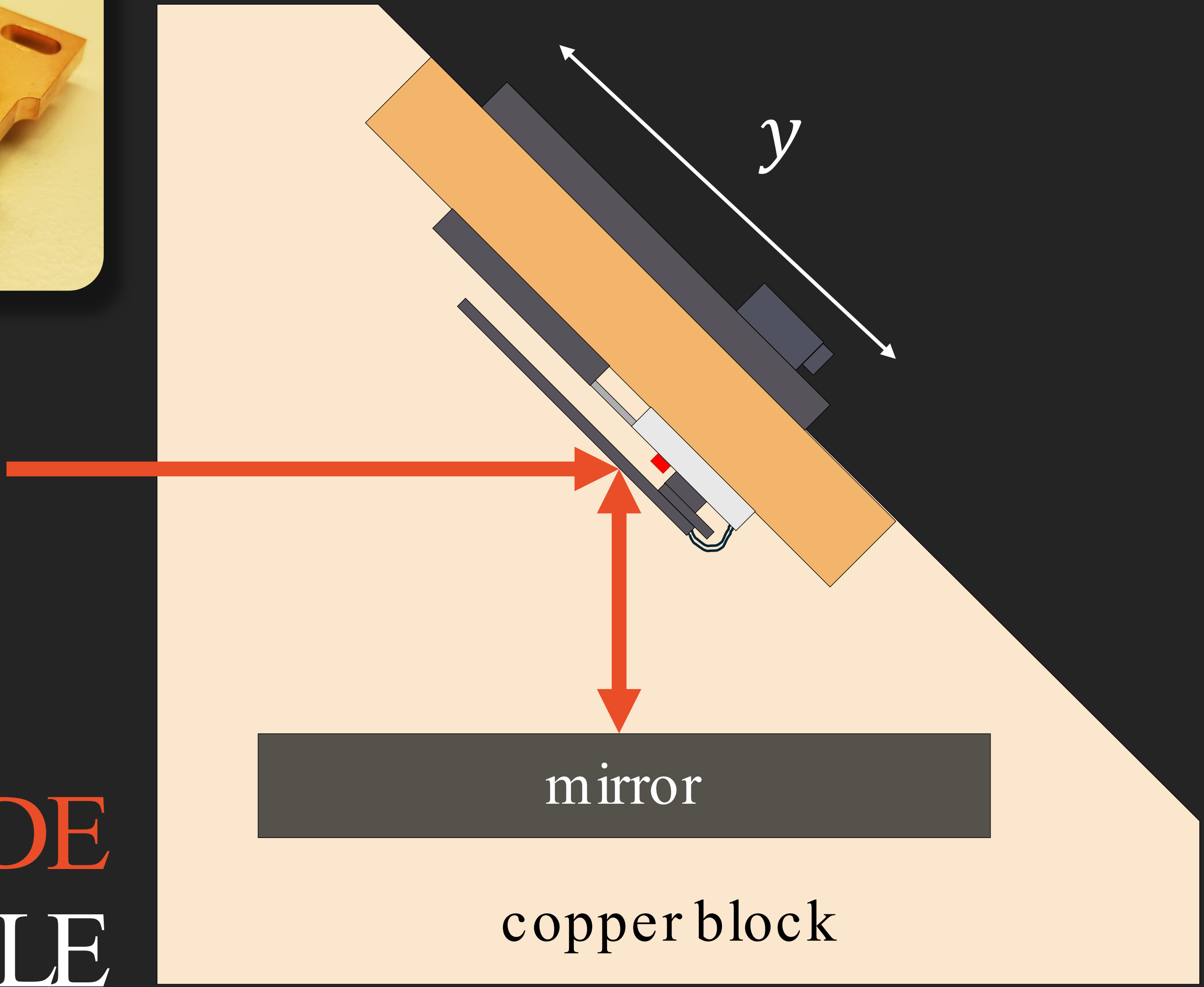
match electrical and optical power using temperature



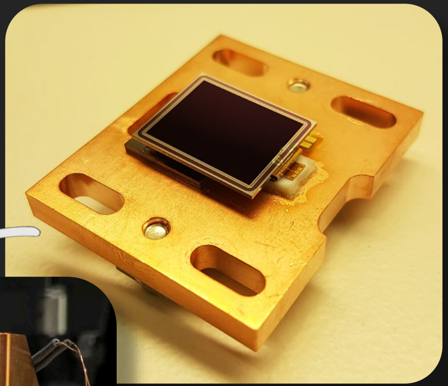


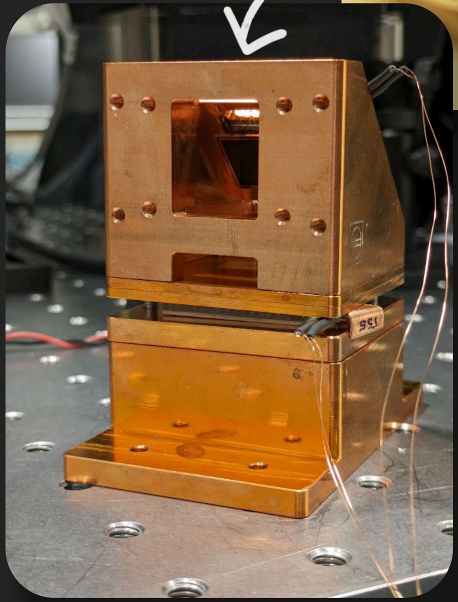
DUAL-MODE MODULE



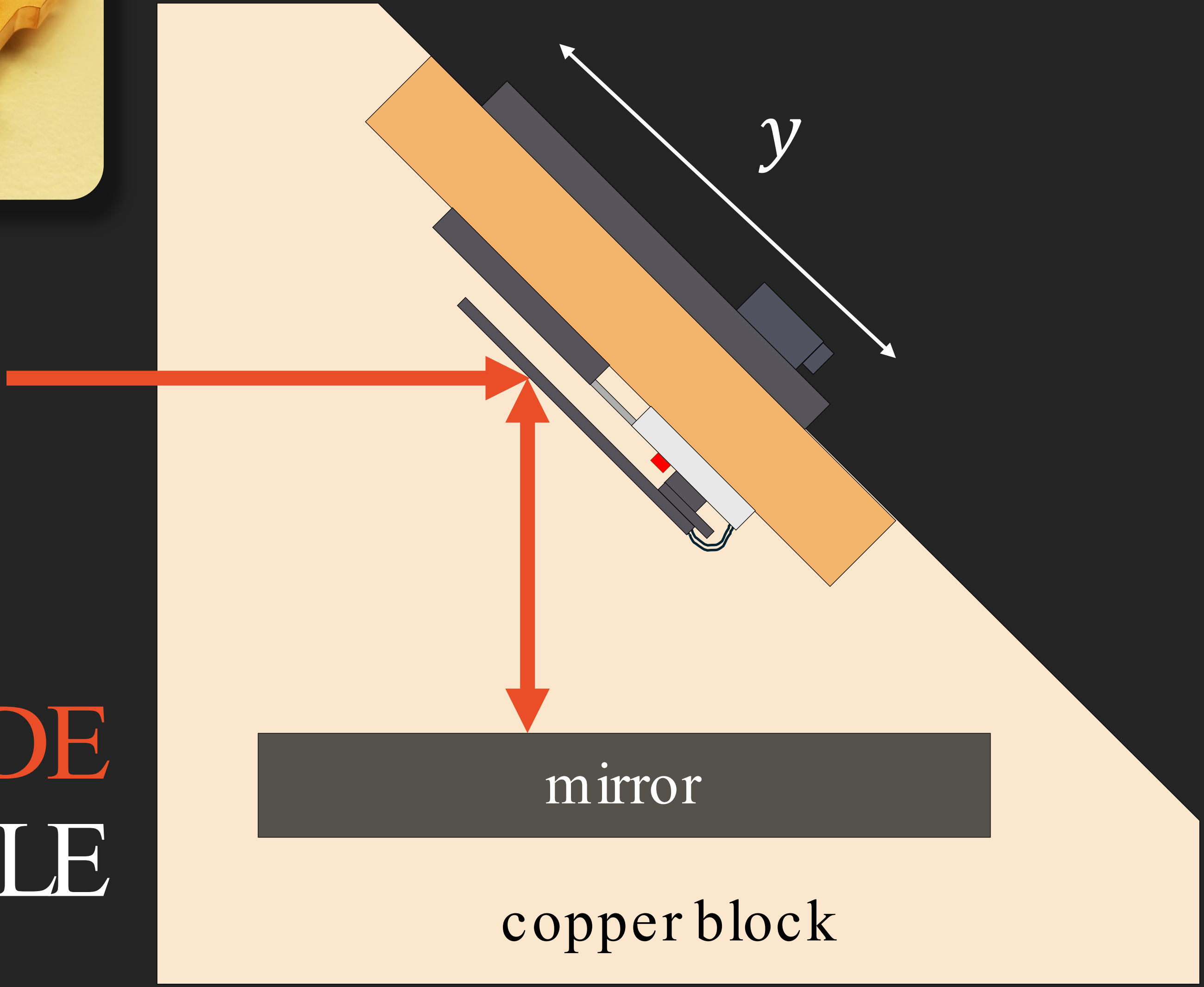


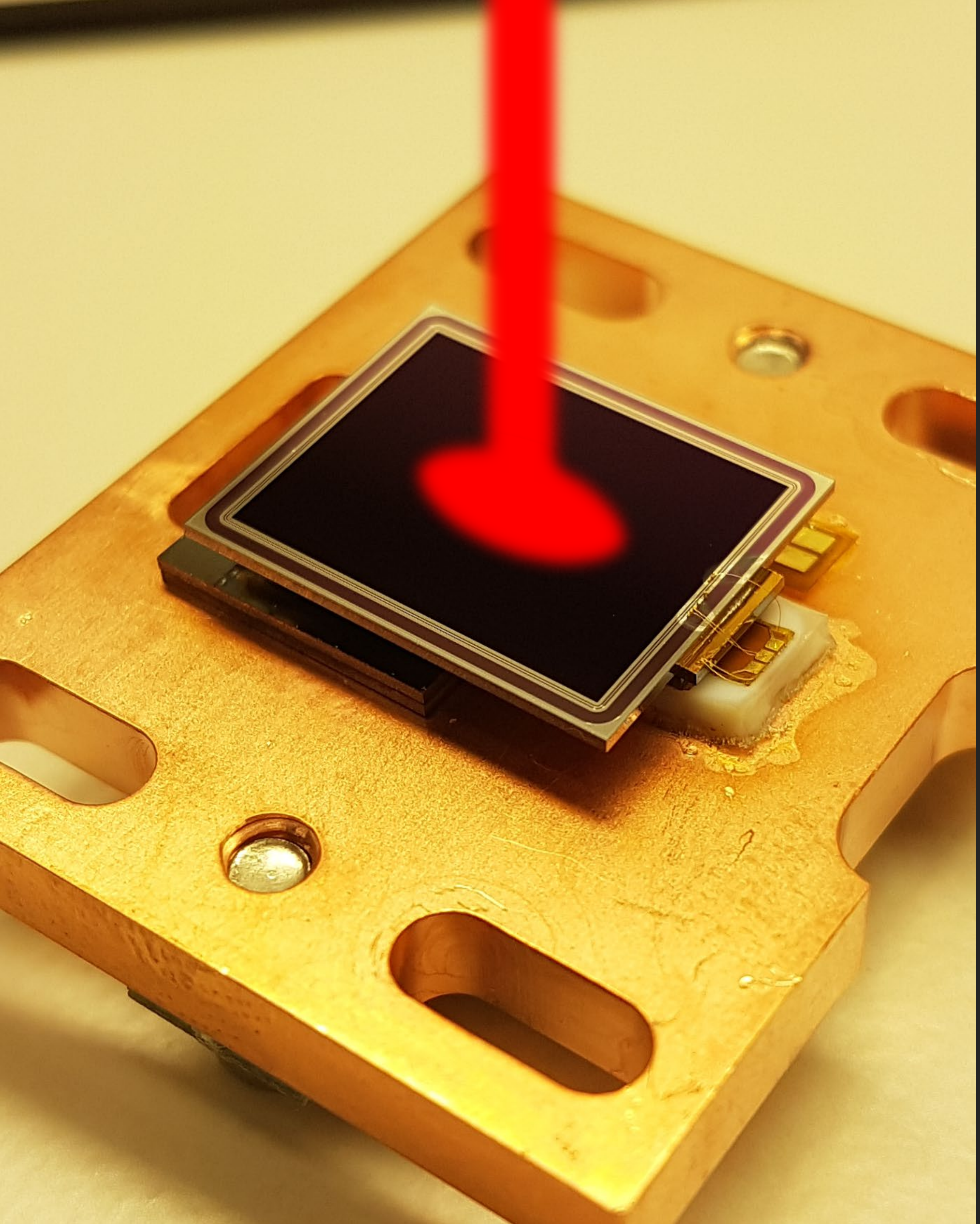
DUAL-MODE MODULE





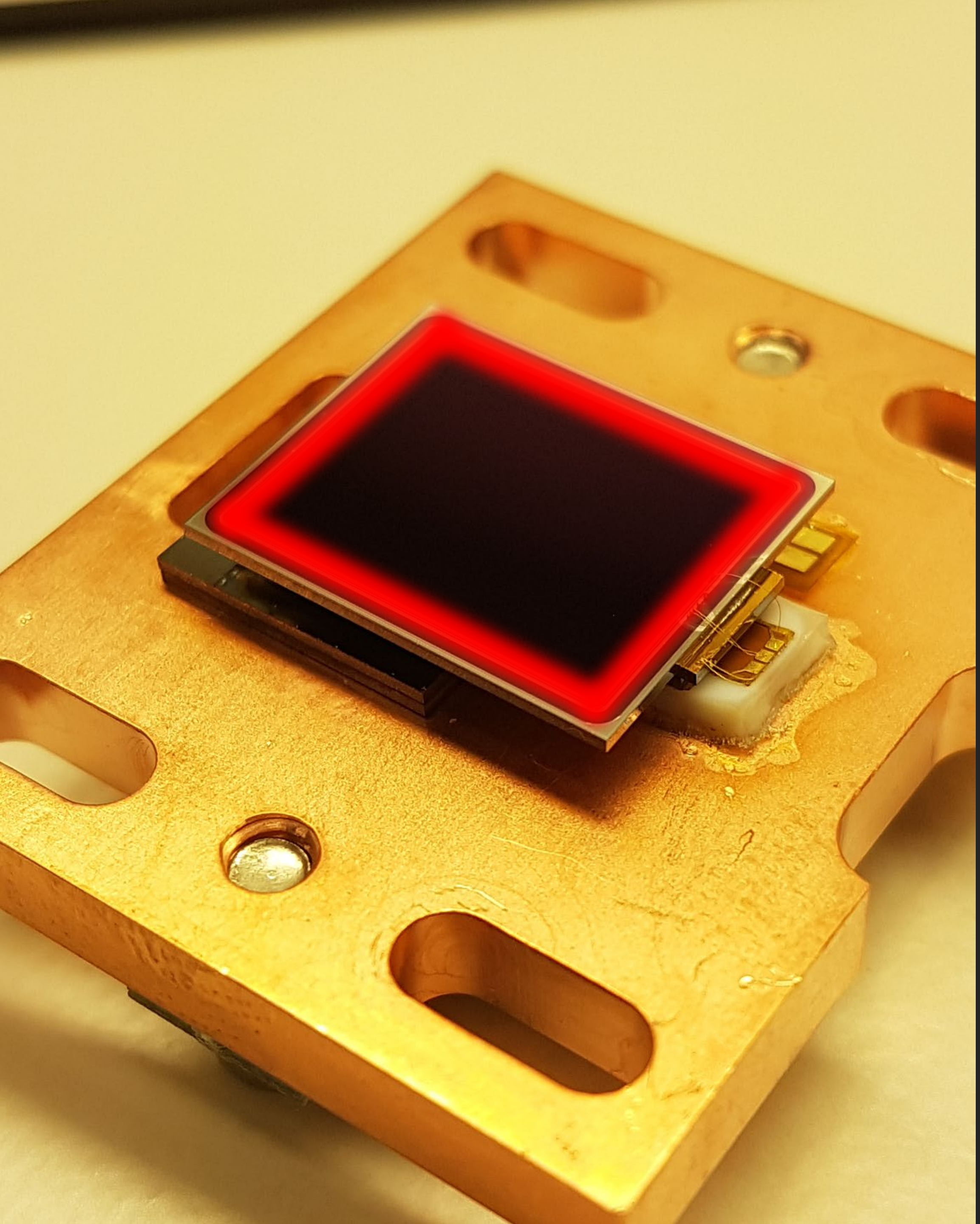
DUAL-MODE
MODULE





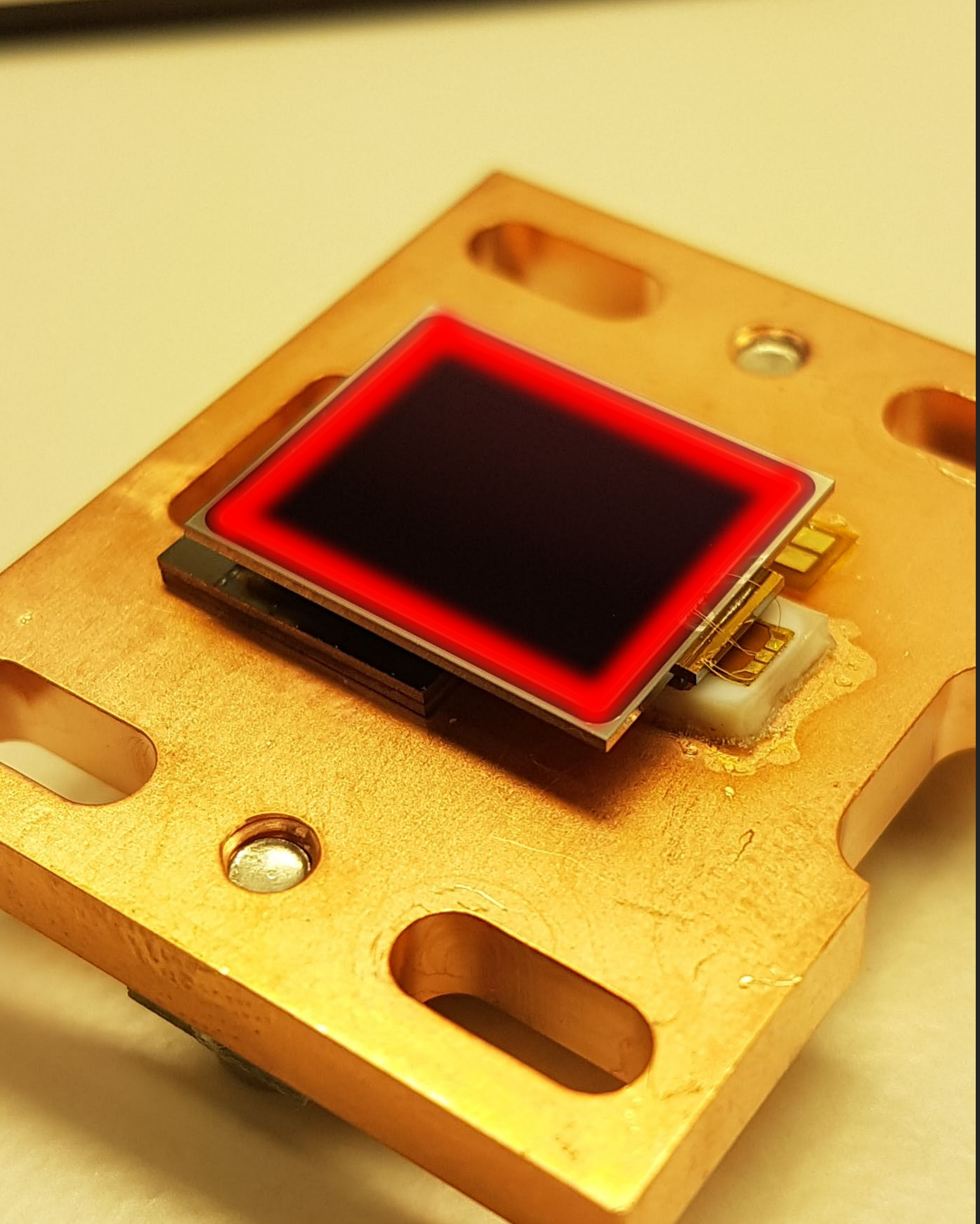
OPTICAL HEATING

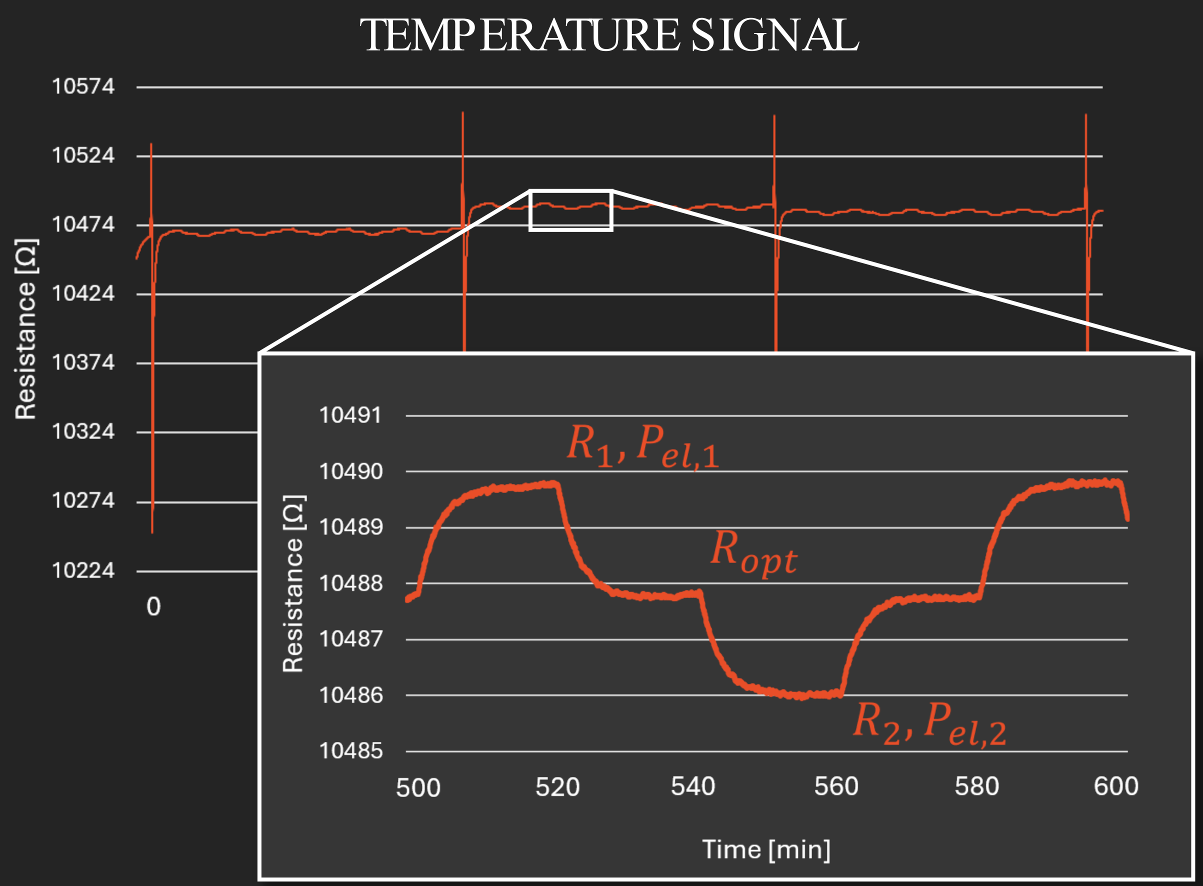
Using the diode as a passive absorbing element



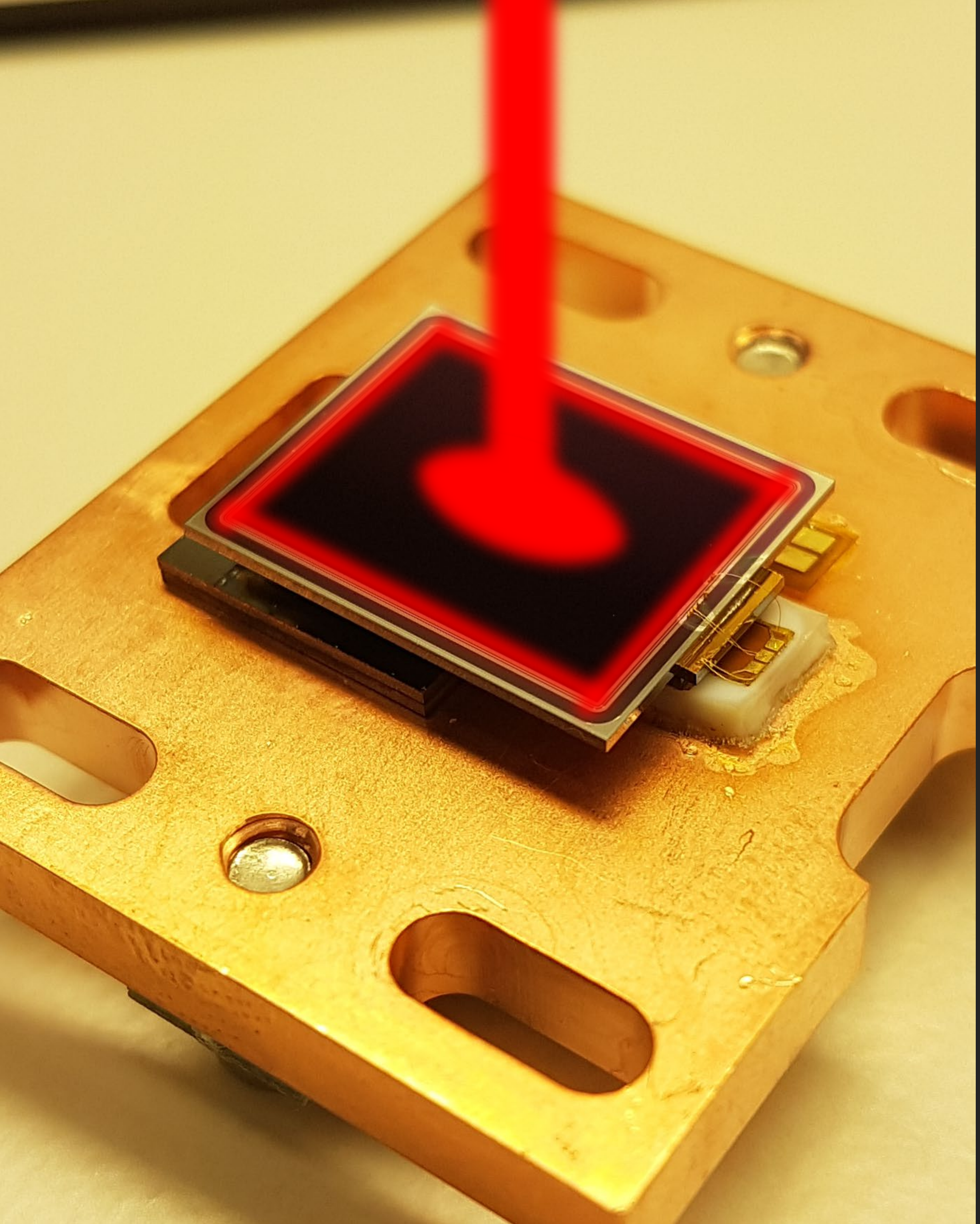
ELECTRICAL HEATING

Forward biasing the diode





$$P_{opt,es} = \frac{(R_{opt} - R_1)}{(R_2 - R_1)} \left(P_{el,2} - P_{el,1}\right) + P_{el,1}$$



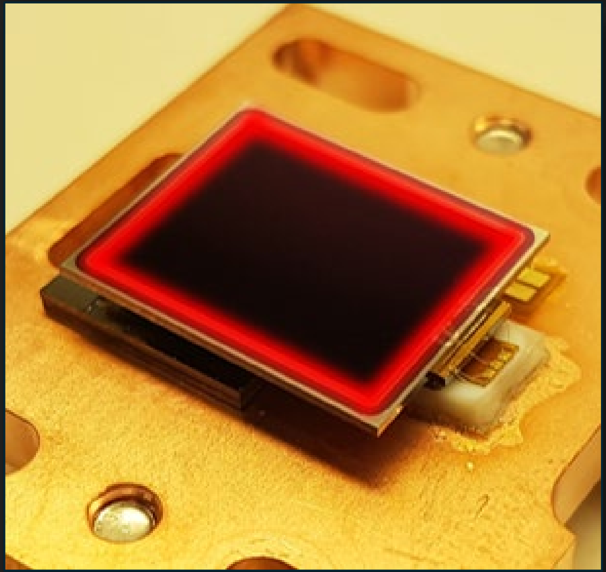
OPTICAL HEATING WITH BACKGROUND ELECTRICAL

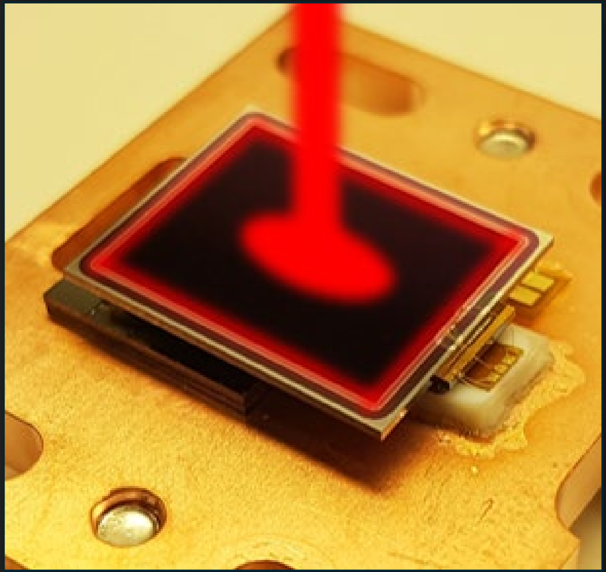
Preparation for closed-loop measurements

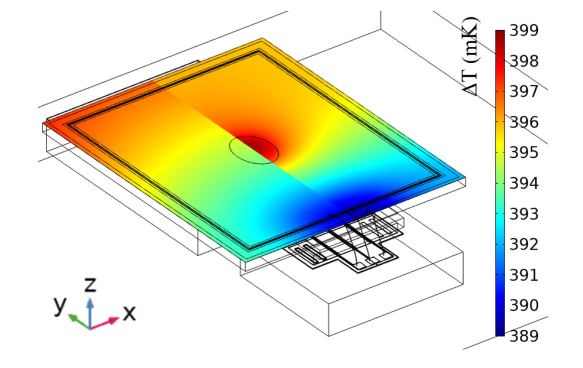
$$P_{opt,es} = \frac{(R_{opt} - R_1)}{(R_2 - R_1)}\left(P_{el,2} - P_{el,1}\right) + P_{el,1}$$

ELECTRICAL SUBSTITUTION REQUIRE EQUIVALENCE

BETWEEN ELECTRICAL AND OPTICAL HEATING







THERMAL NON-EQUIVALENCE

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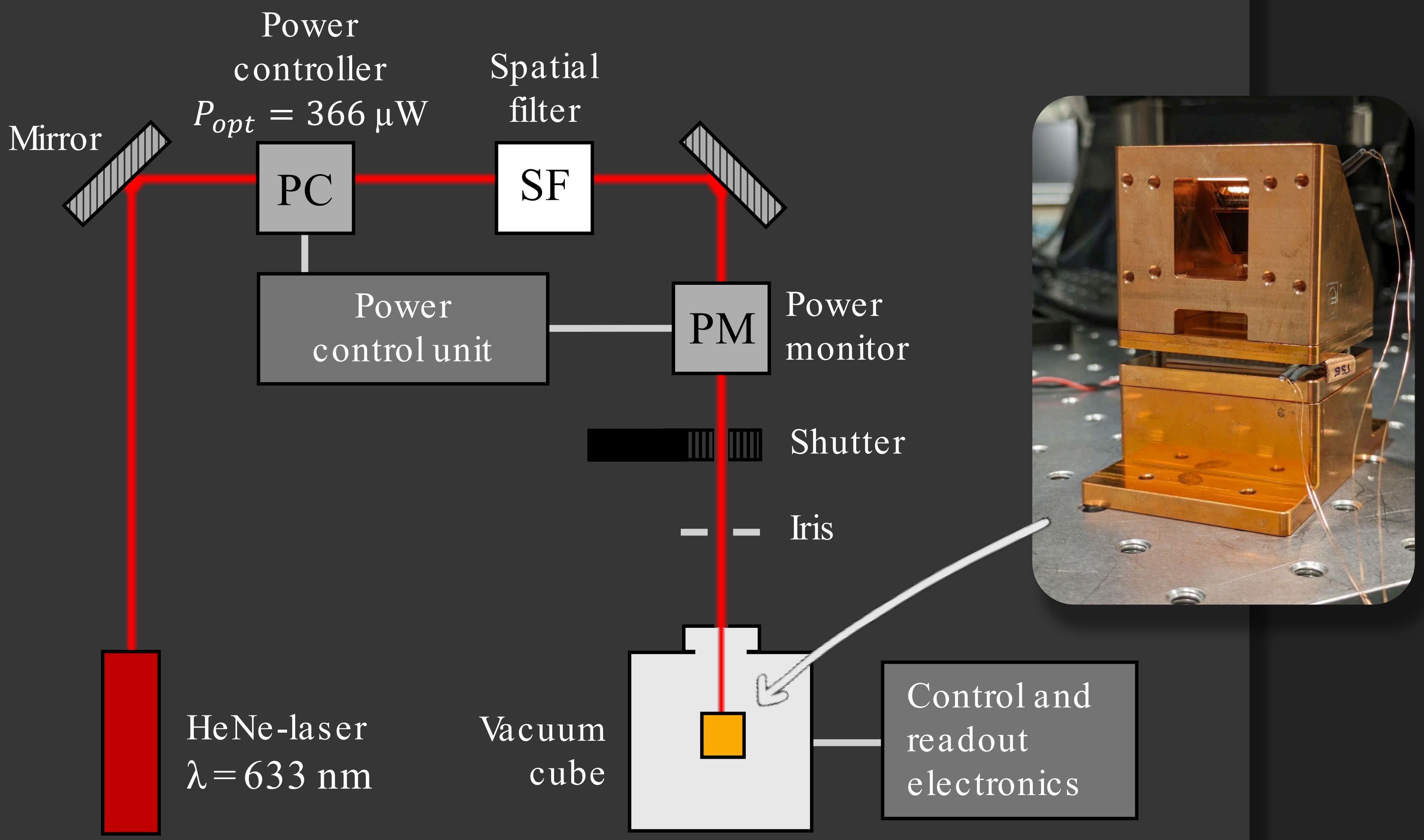
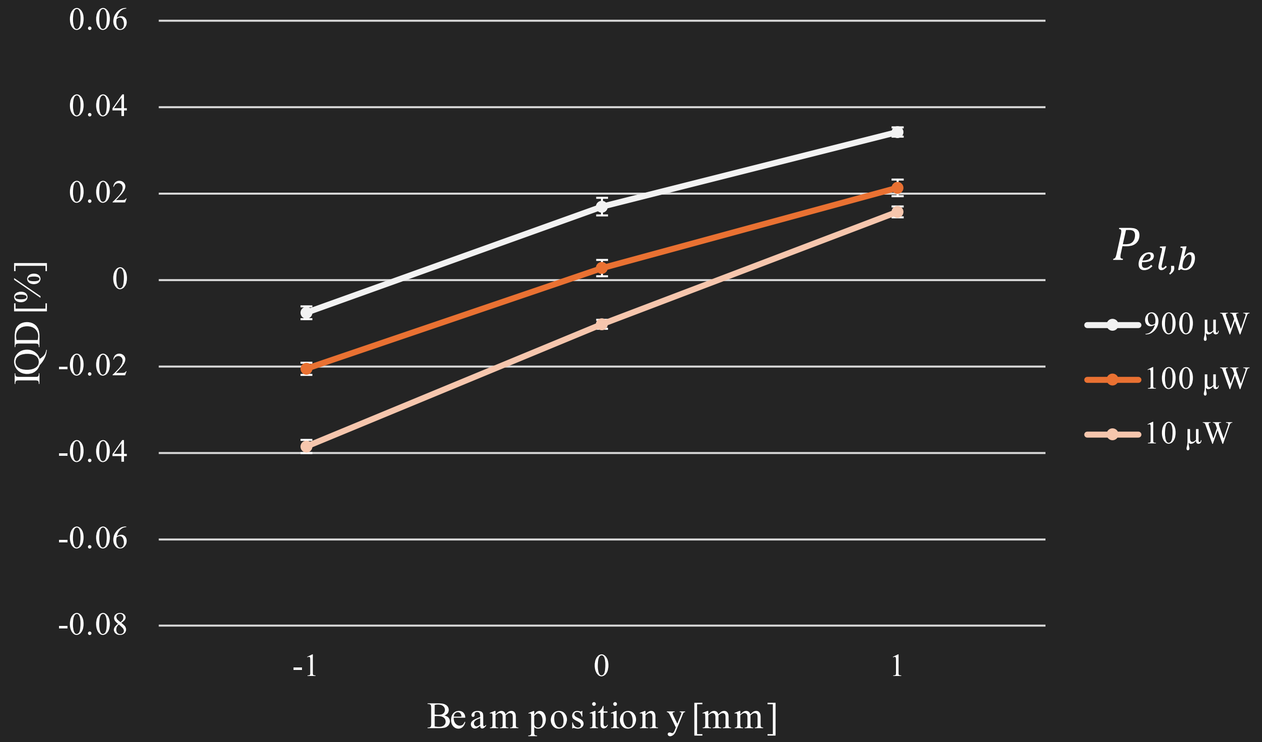
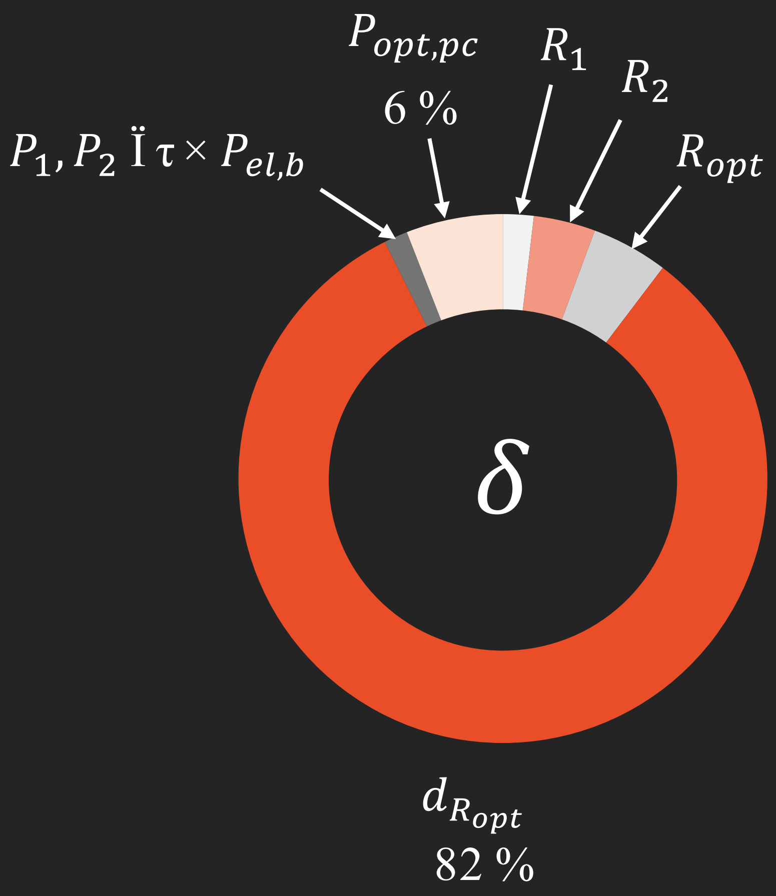

Power controller
$P_{opt} = 366\ \mu W$
Spatial filter
Mirror
PC
SF
Power control unit
PM
Power monitor
Shutter
Iris
HeNe-laser
$\lambda = 633$ nm
Vacuum cube
Control and readout electronics

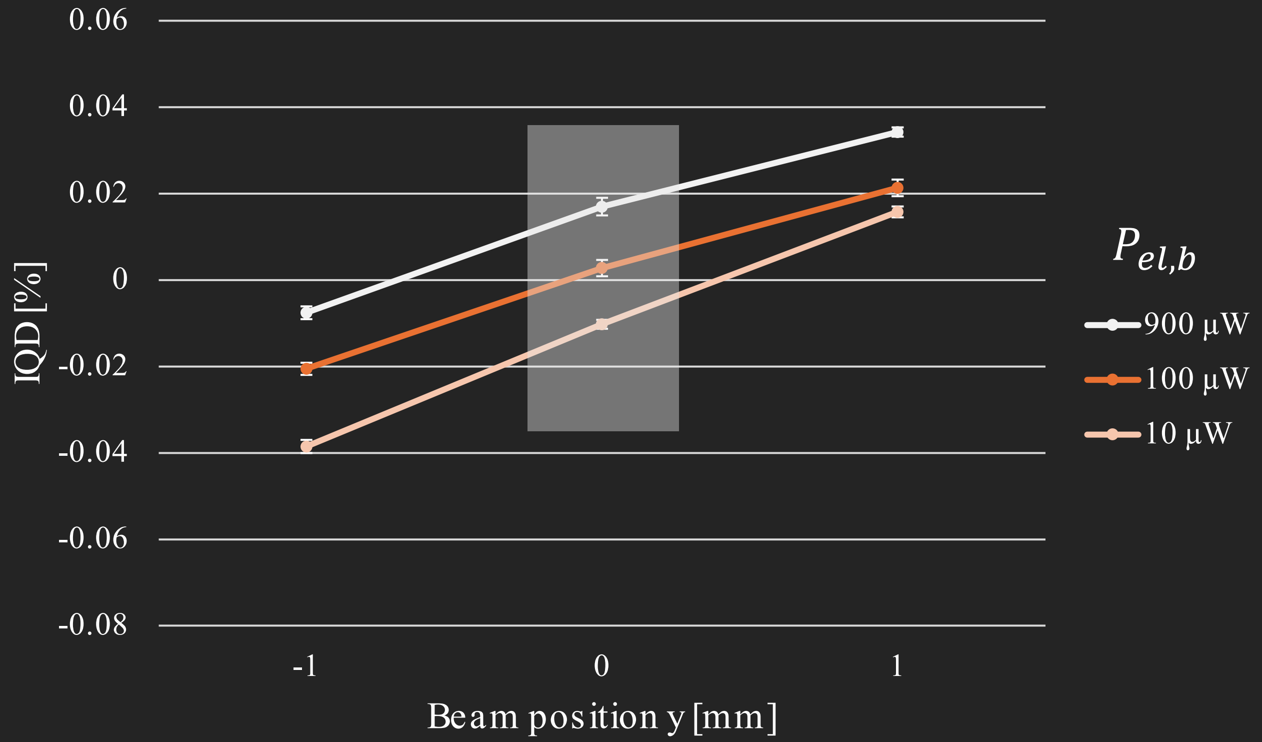


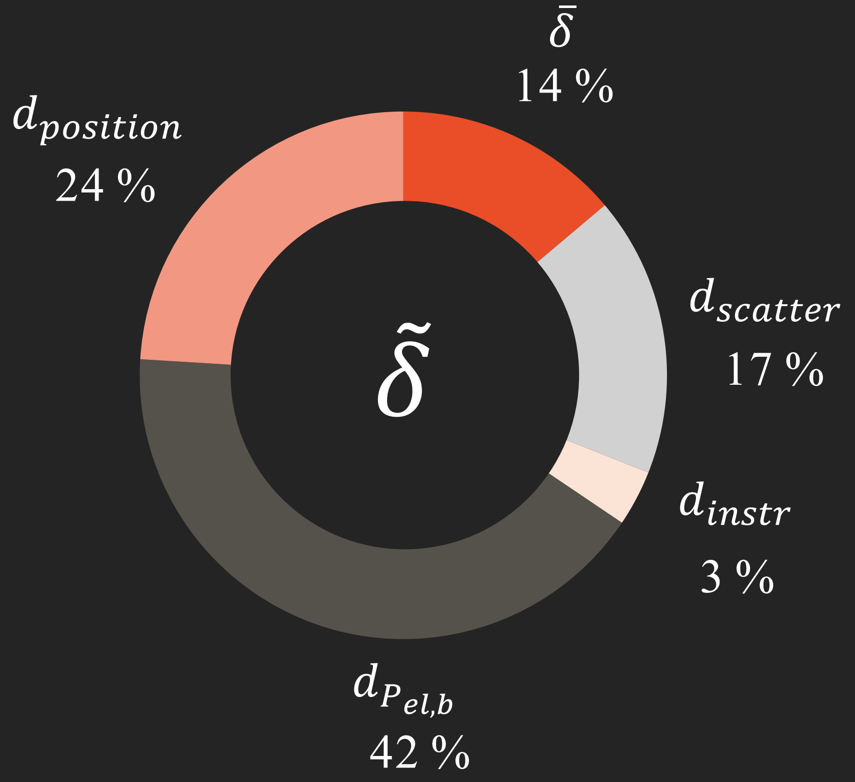


Paper submitted!

$$\tilde{\delta} = \bar{\delta} - d_{scatter} + \underbrace{d_{instr} + d_{P_{el,b}} + d_{position}}_{=0}$$

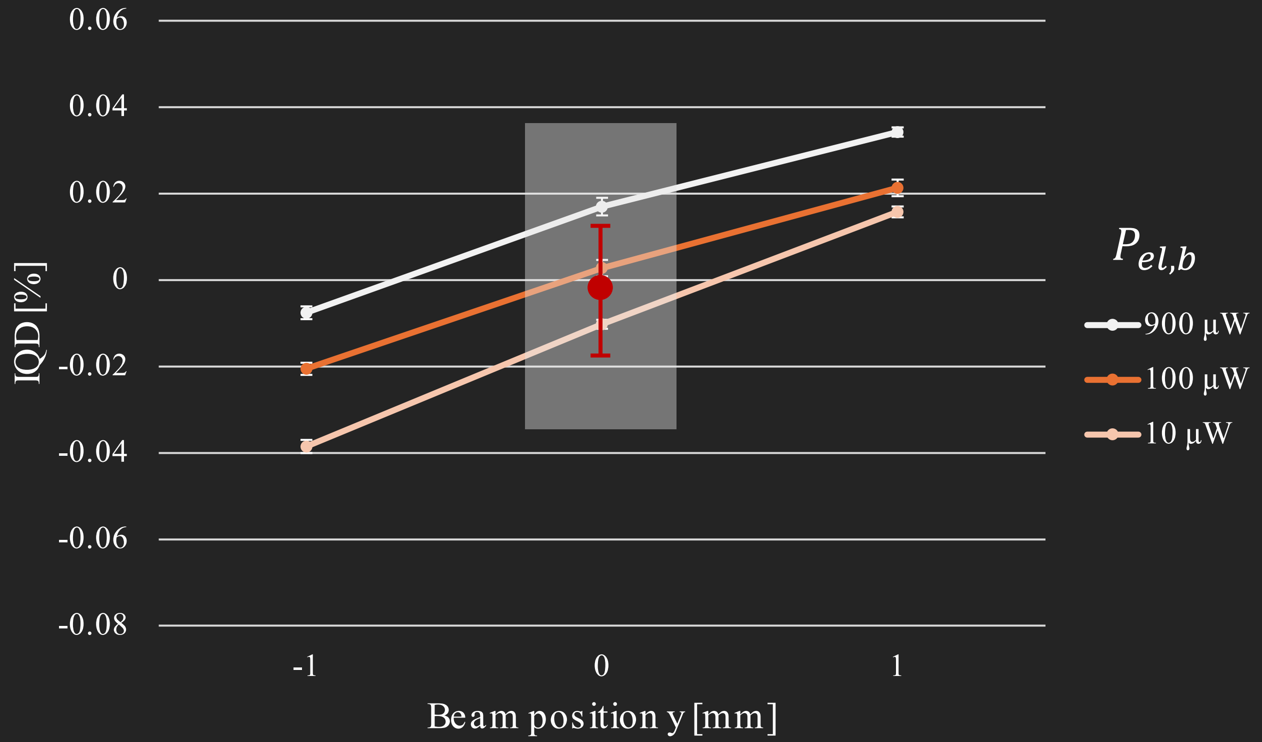
$= 50$ ppm





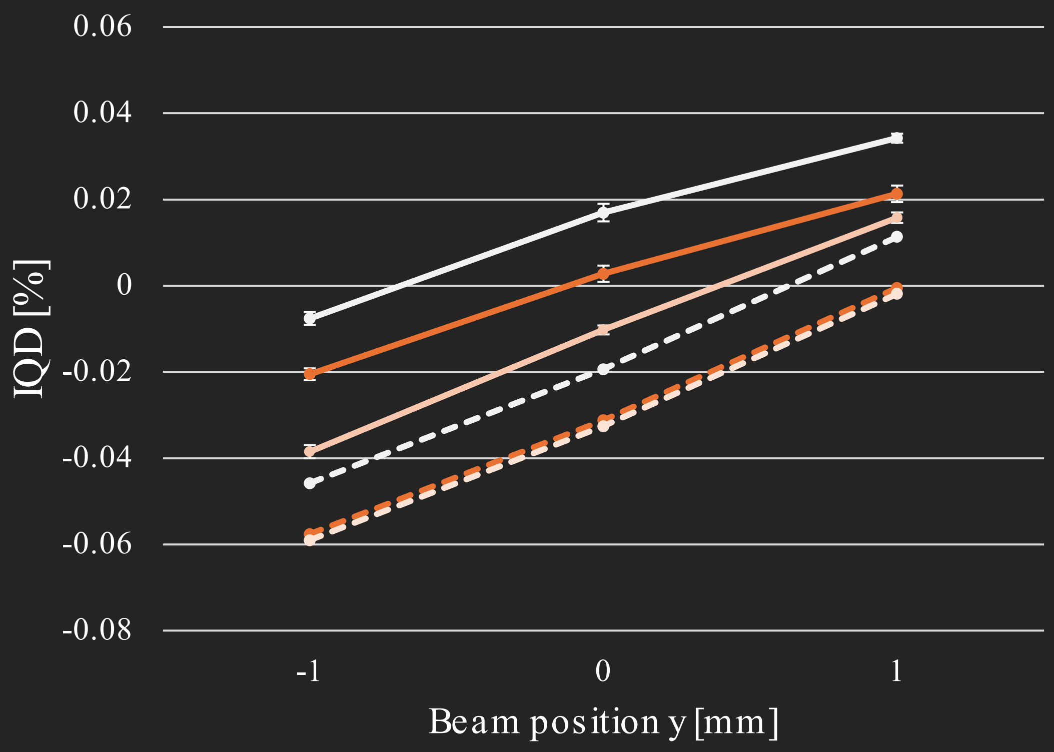
$$\tilde{\delta} = \bar{\delta} - d_{scatter} + \underbrace{d_{instr} + d_{P_{el,b}} + d_{position}}_{=0}$$

$= 50$ ppm



For $y = 0$ and $P_{el,b} = 100\ \mu W$

$$\tilde{\delta} = -22 \text{ ppm} \pm 154 \text{ ppm}$$



Dependence on *y*-position: thermal non-equivalence.

Fits well with COMSOL simulations.

Dependence on background electrical power not captured by the model.

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SUMMARY AND OUTLOOK

Results

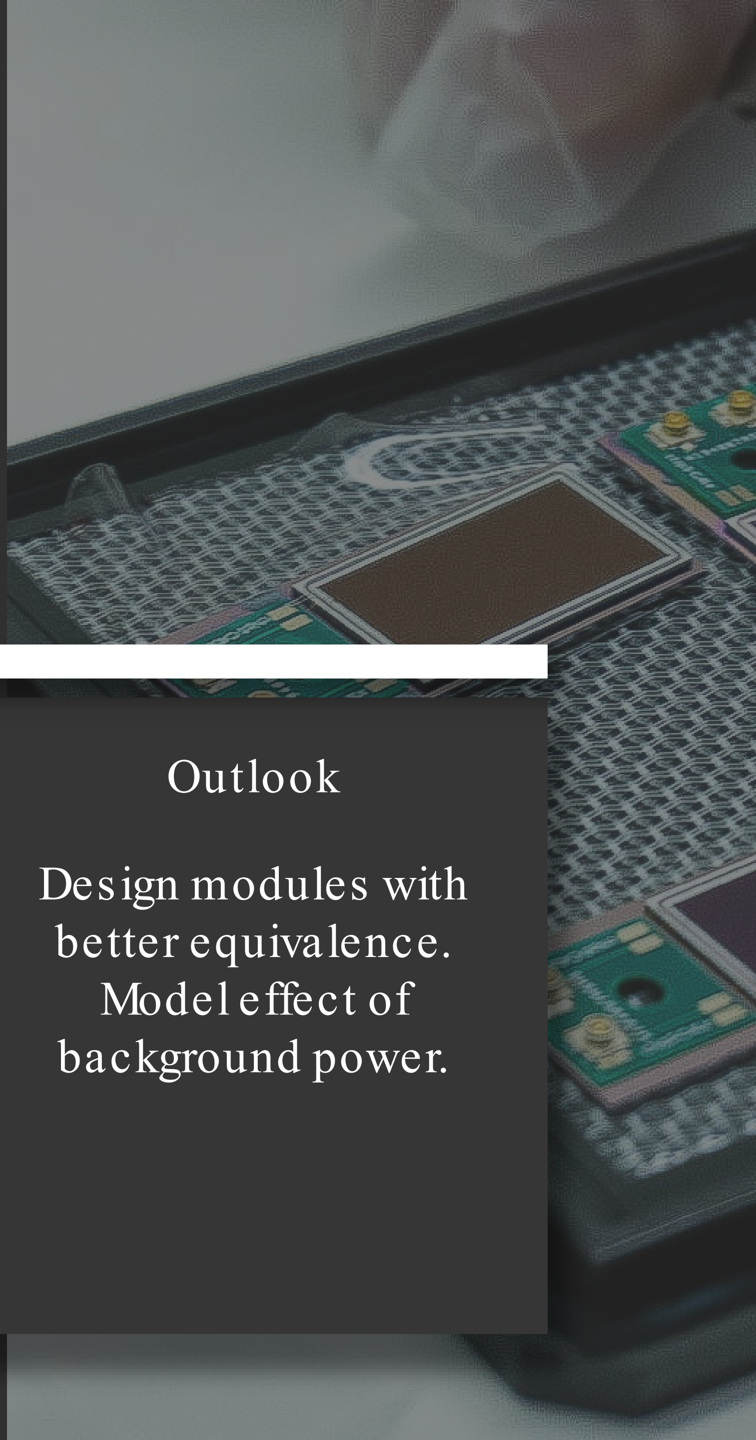
Room temperature calibration with uncertainty at 0.03 % (k=2).

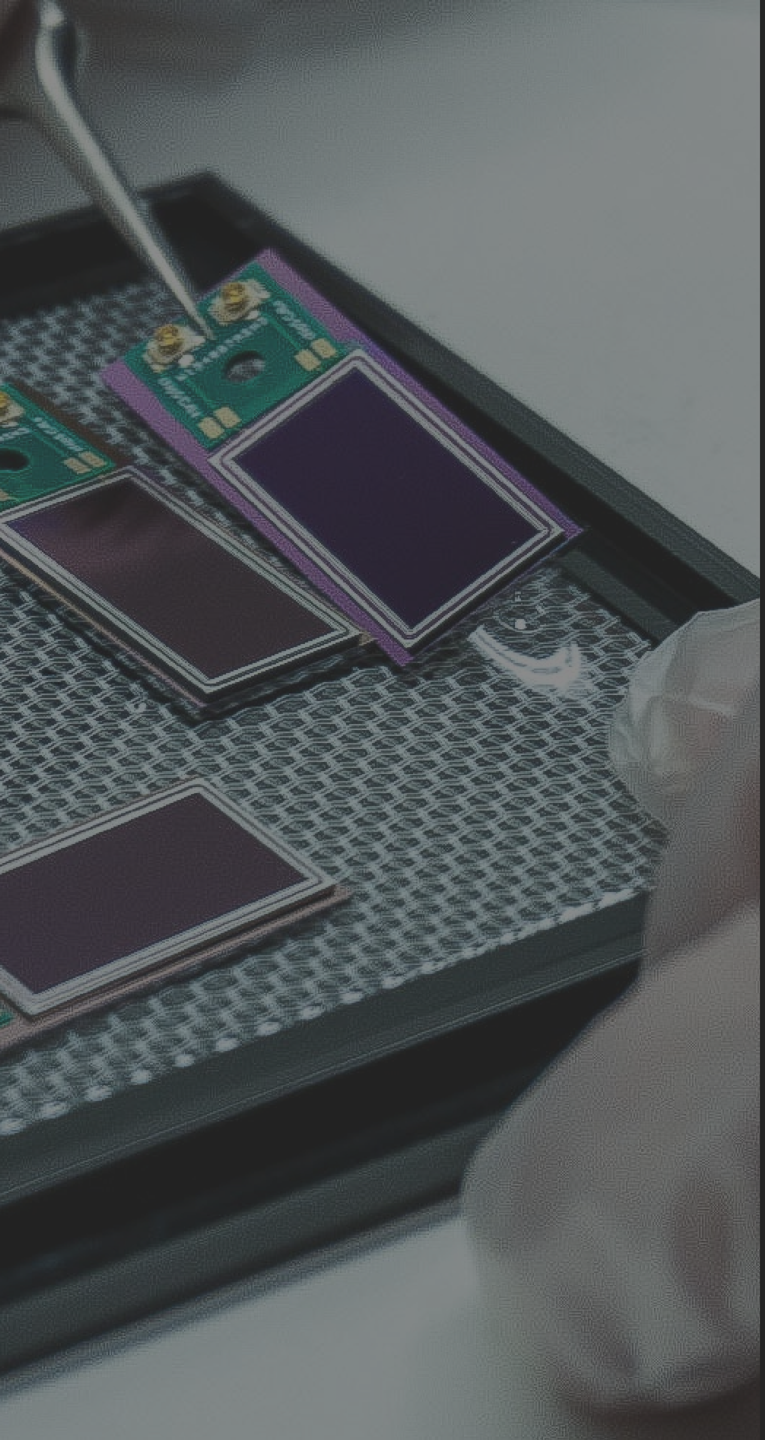
Limitations

Limited by thermal non-equivalence and background power.

Outlook

Design modules with better equivalence. Model effect of background power.





QUESTIONS?

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https://scaleup.aalto.fi/

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