Internal losses measurement of a dual-mode photodiode at cryogenic temperature

C.Pepe[1,2],
M.Rajteri[1], G. Brida[1]

(1)

(2)

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Title breakdown

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Photons are converted into e-h pairs

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Photodiode operated at 77K

Photodiode

Predictable Quantum Efficiency Detector (PQED)

The PQED is intended to become a **primary detector standard** for wavelengths **from 400 nm to 800 nm**

*J. Geist, G. Brida and M. L. Rastello, Prospects for improving the accuracy of silicon photodiode self-calibration with custom cryogenic photodiodes, Metrologia**40**, 132-135, 2003

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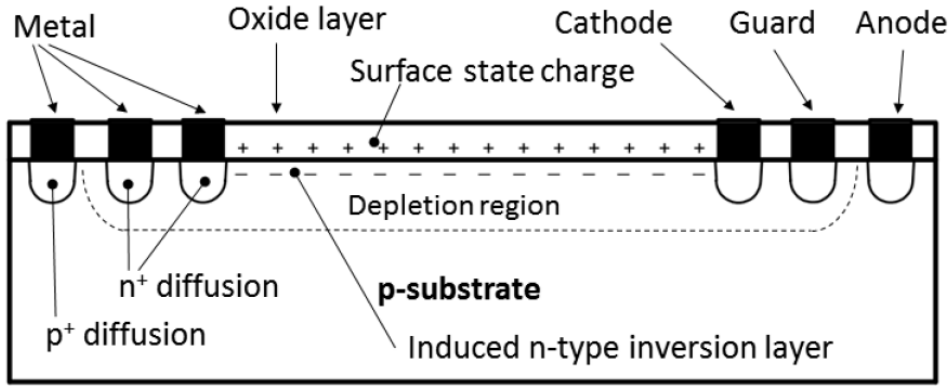
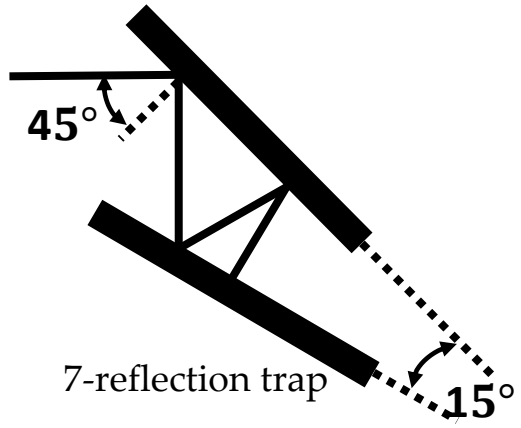


Induced junction photodiodes in a wedge trap configuration.



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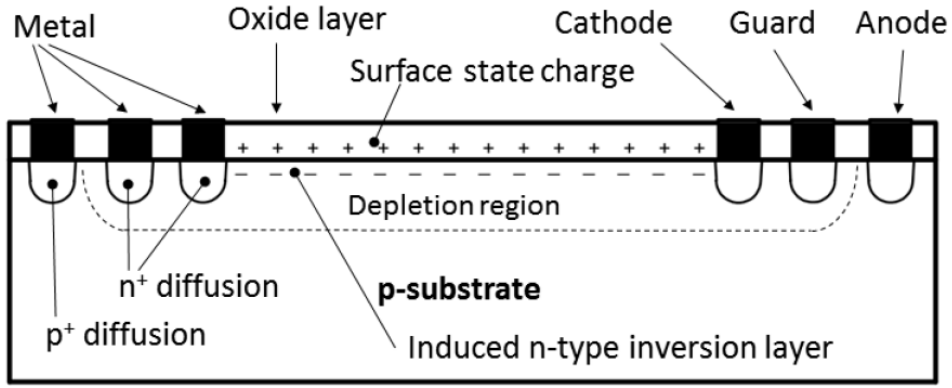

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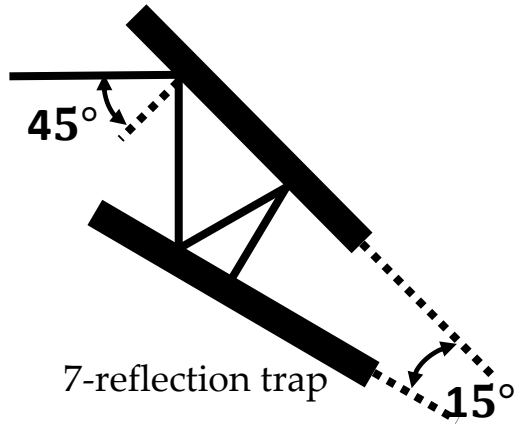

Predictable **internal losses** of the photodiodes: 1ppm at CT and 500 at RT

Calculable reflection losses

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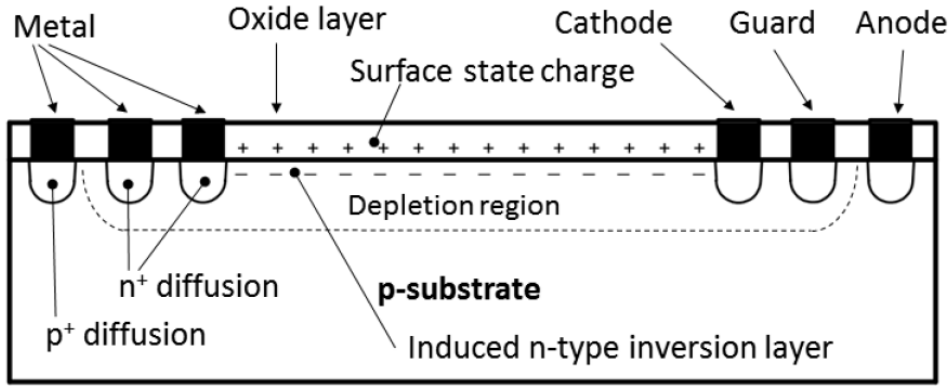

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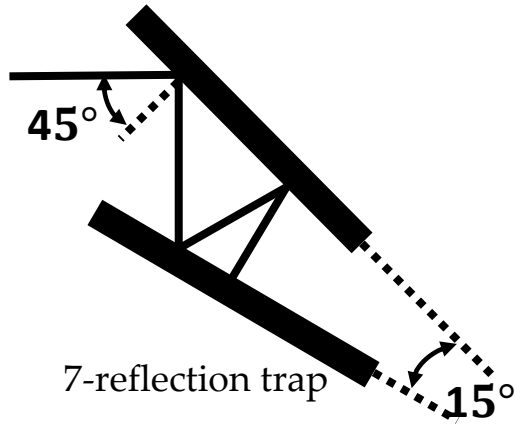

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How do we verify the prediction of the internal losses?

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Dual-mode

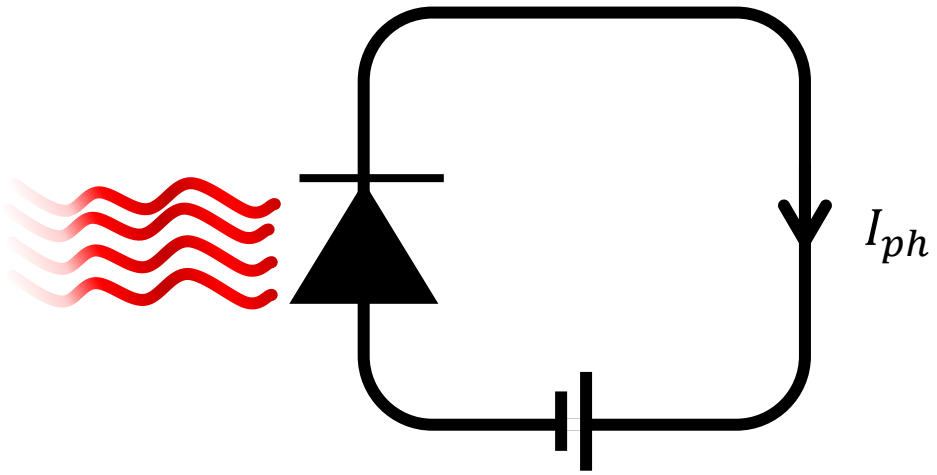
Photocurrent mode

Electrical substitution mode

Dual-mode

Photocurrent mode

Physical effect:
photons create electron-hole pair in pn junction



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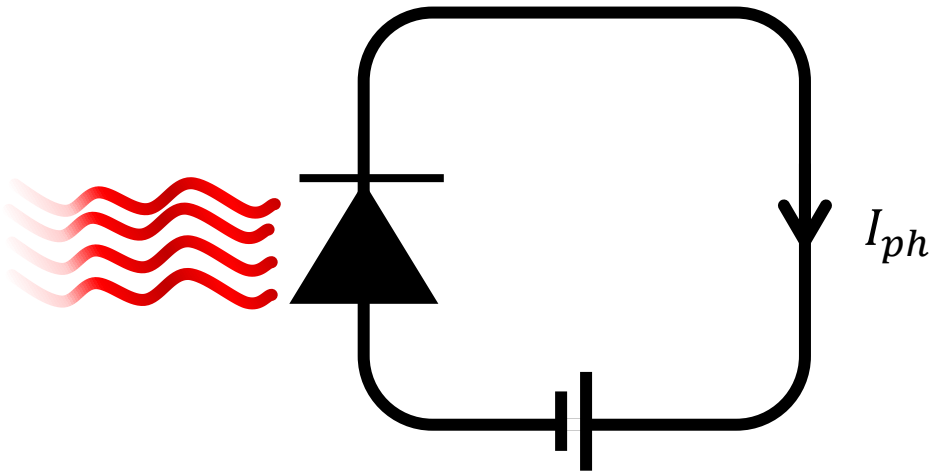

$$P_{ph} = \frac{I_{ph}}{R(\lambda)} = \frac{I_{ph}}{\frac{e\lambda}{hc}(1-\delta(\lambda))}$$

responsivity

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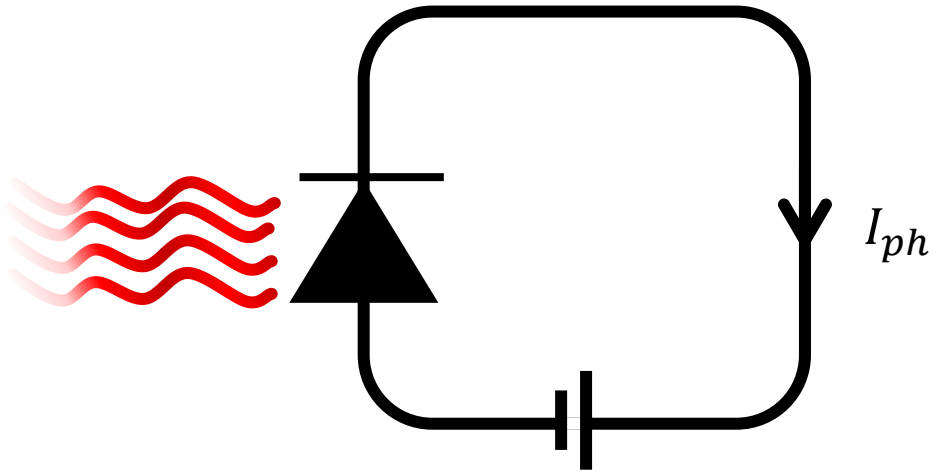

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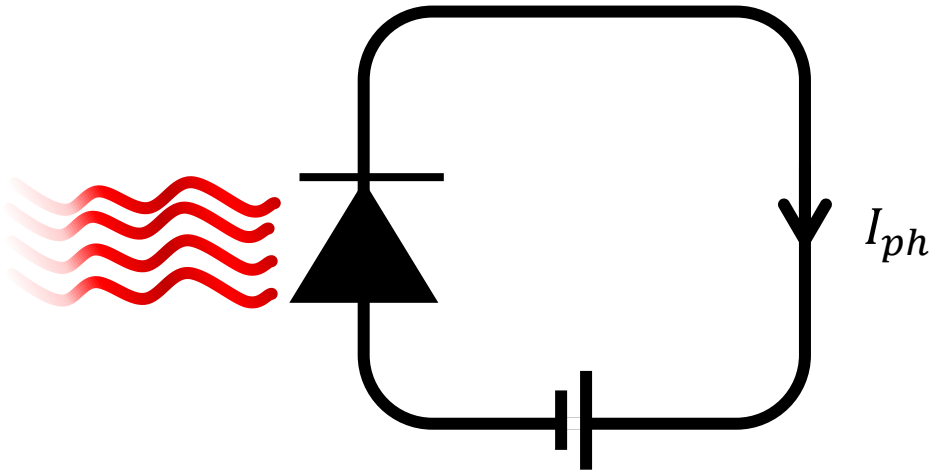

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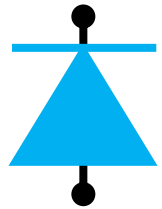

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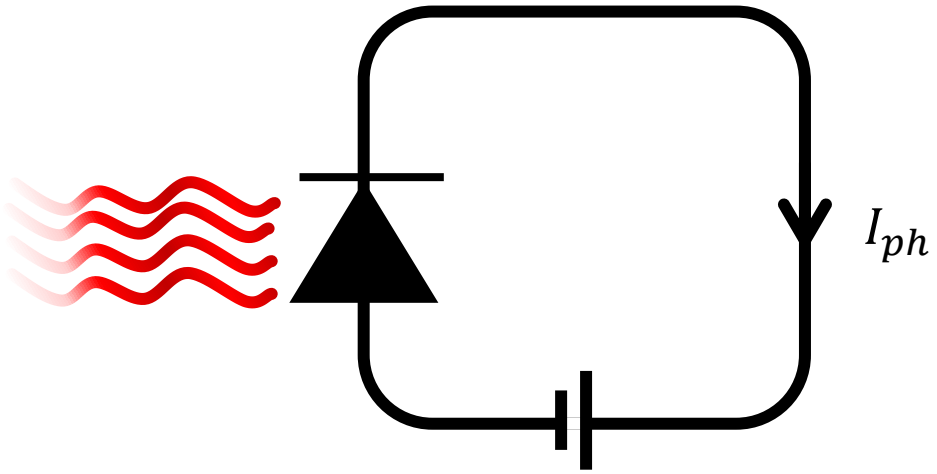

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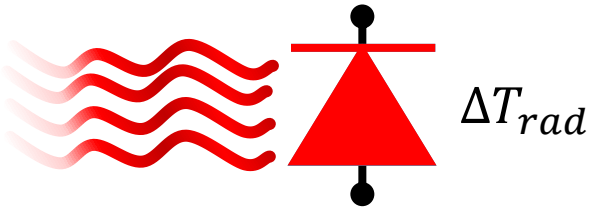

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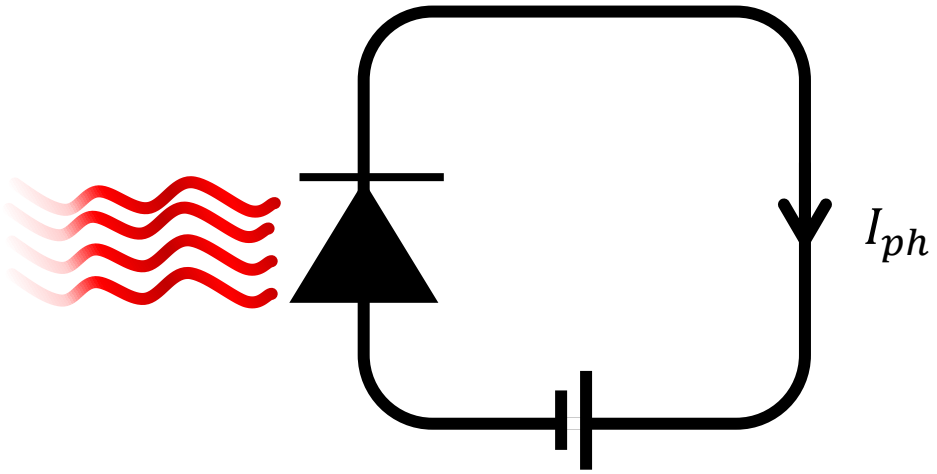

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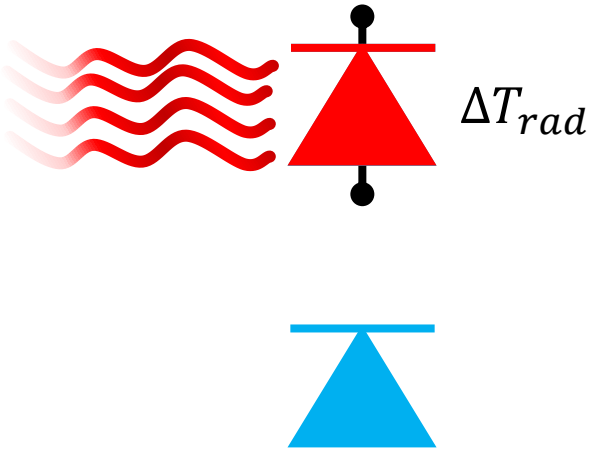

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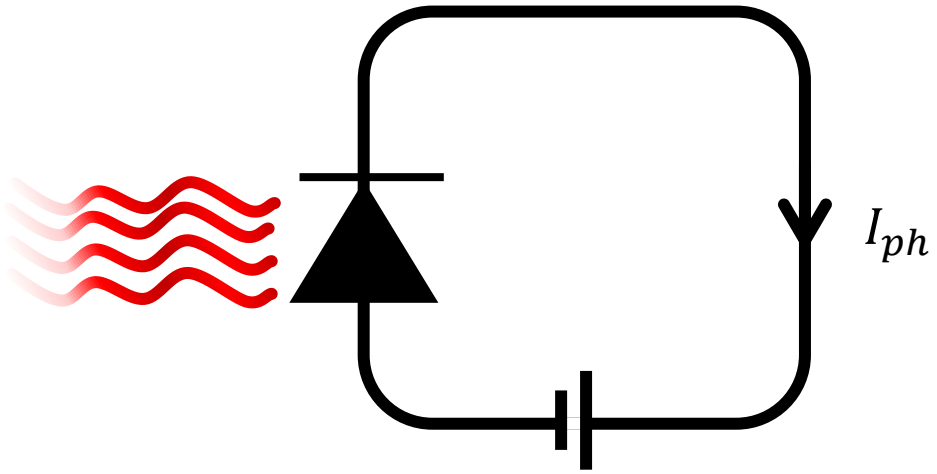

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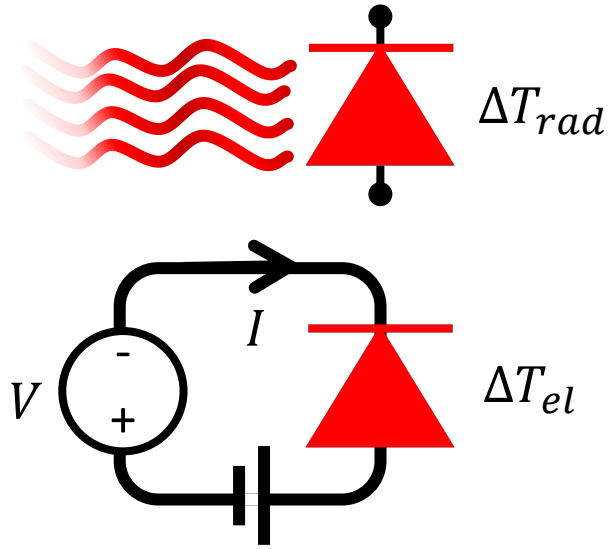

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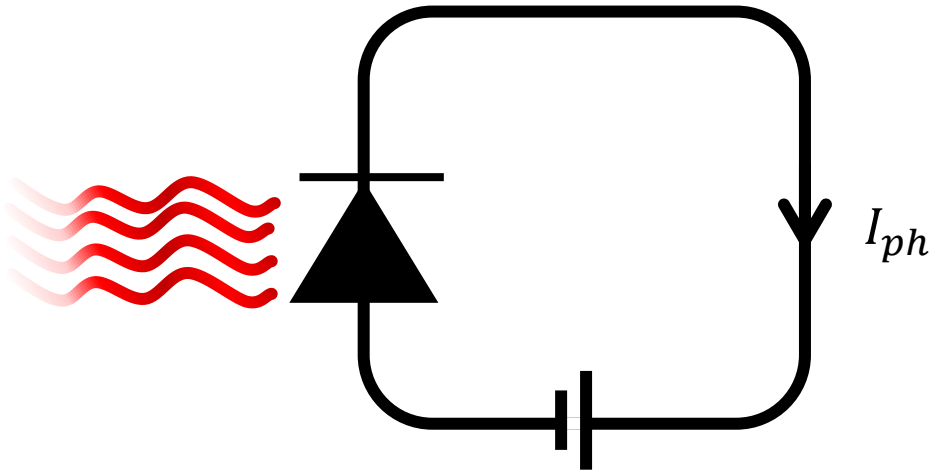

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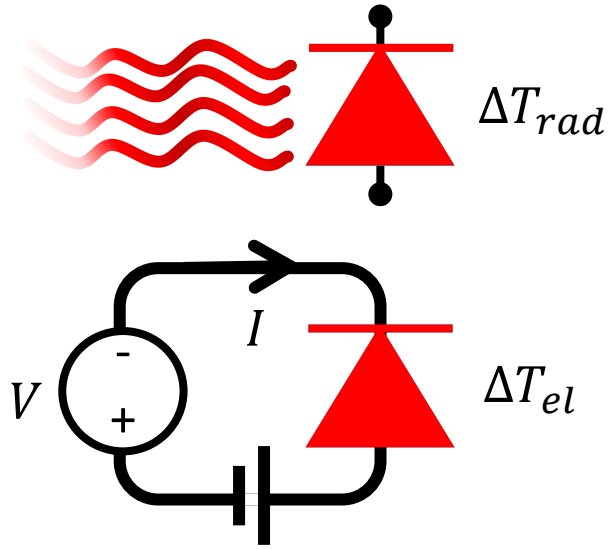

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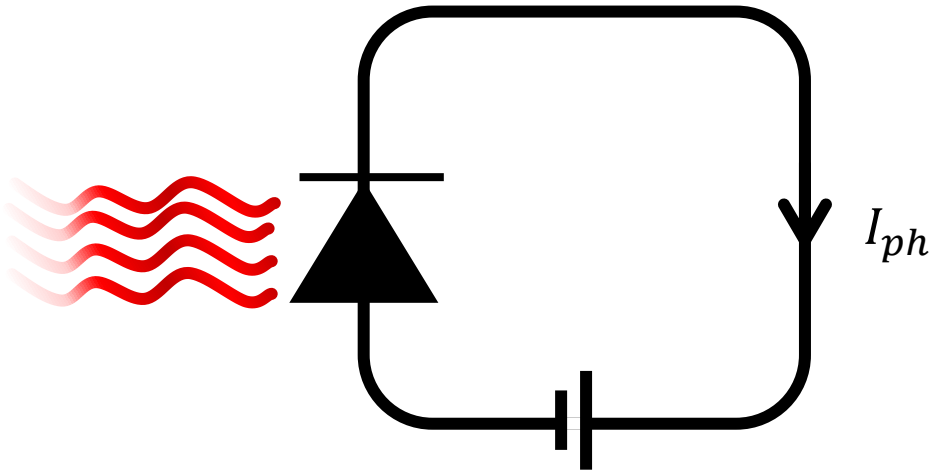

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$\delta(\lambda)$?

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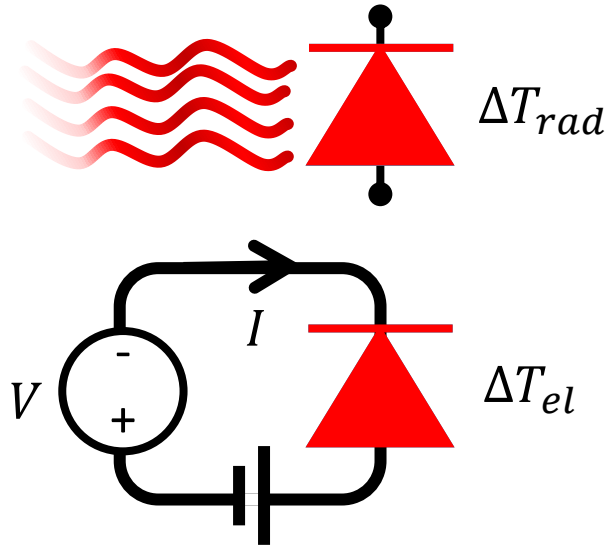

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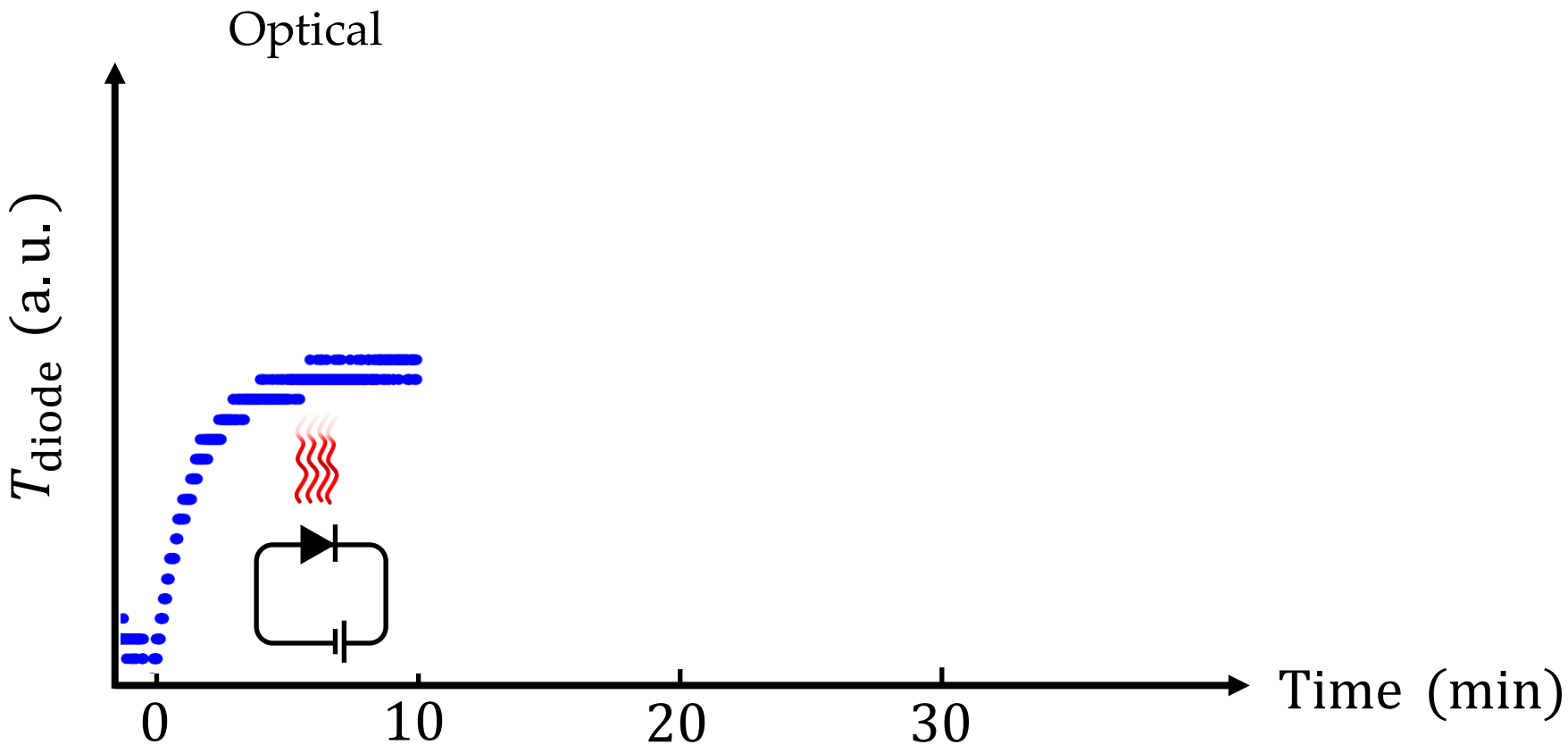
$$\delta(\lambda) = 1 - \frac{I_{ph} e \lambda}{P_{sub} hc}$$

Electrical substitution



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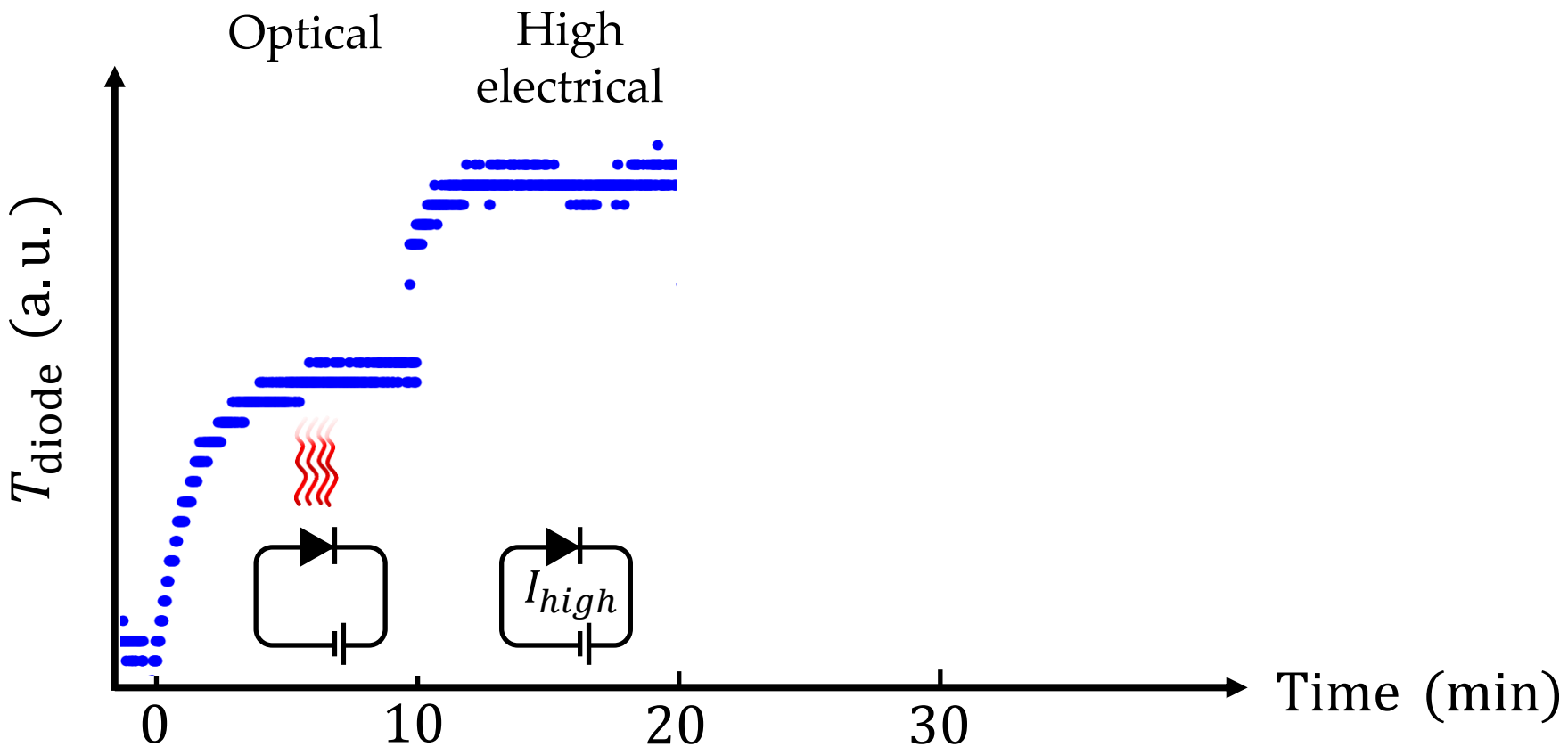

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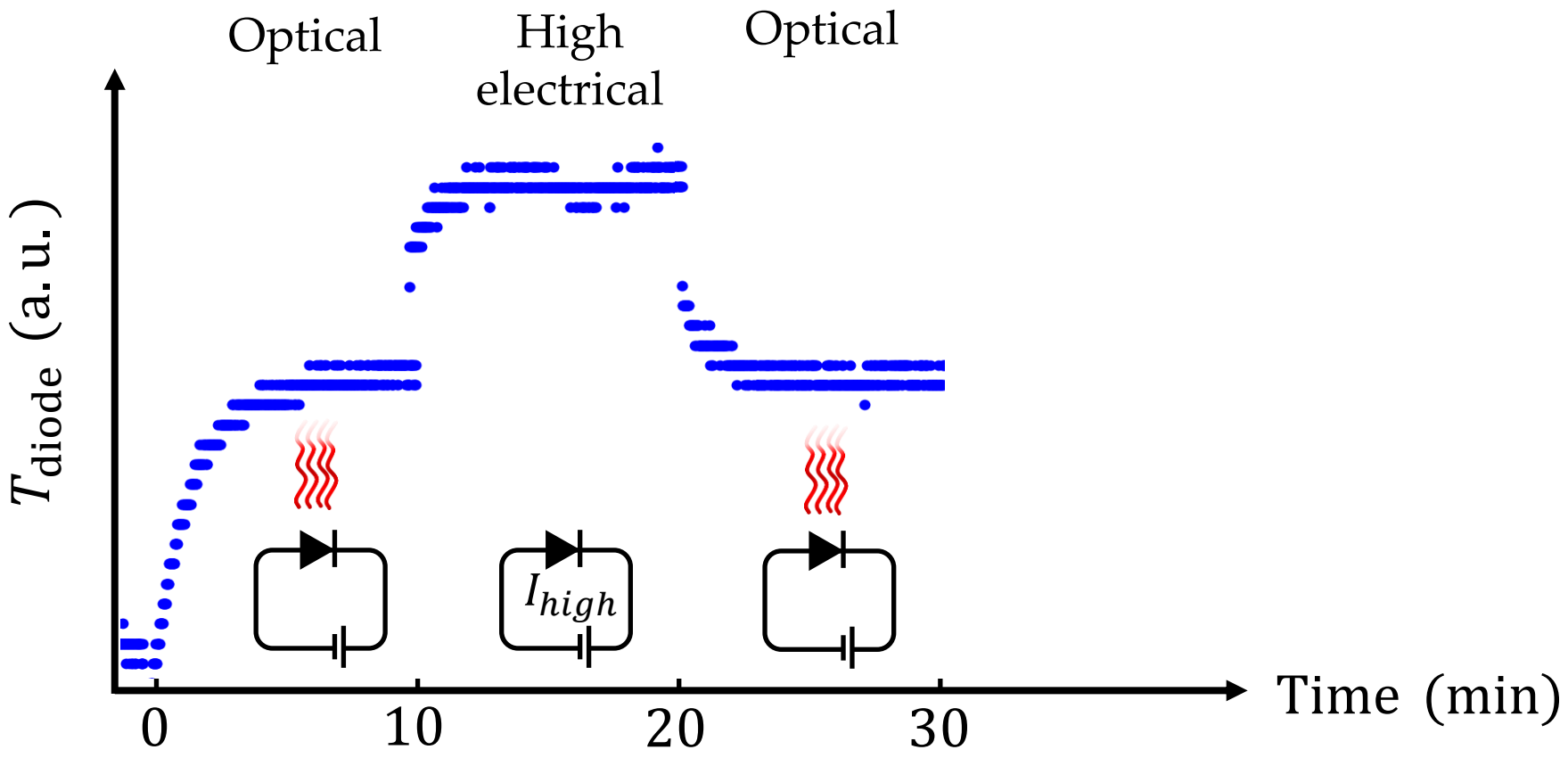

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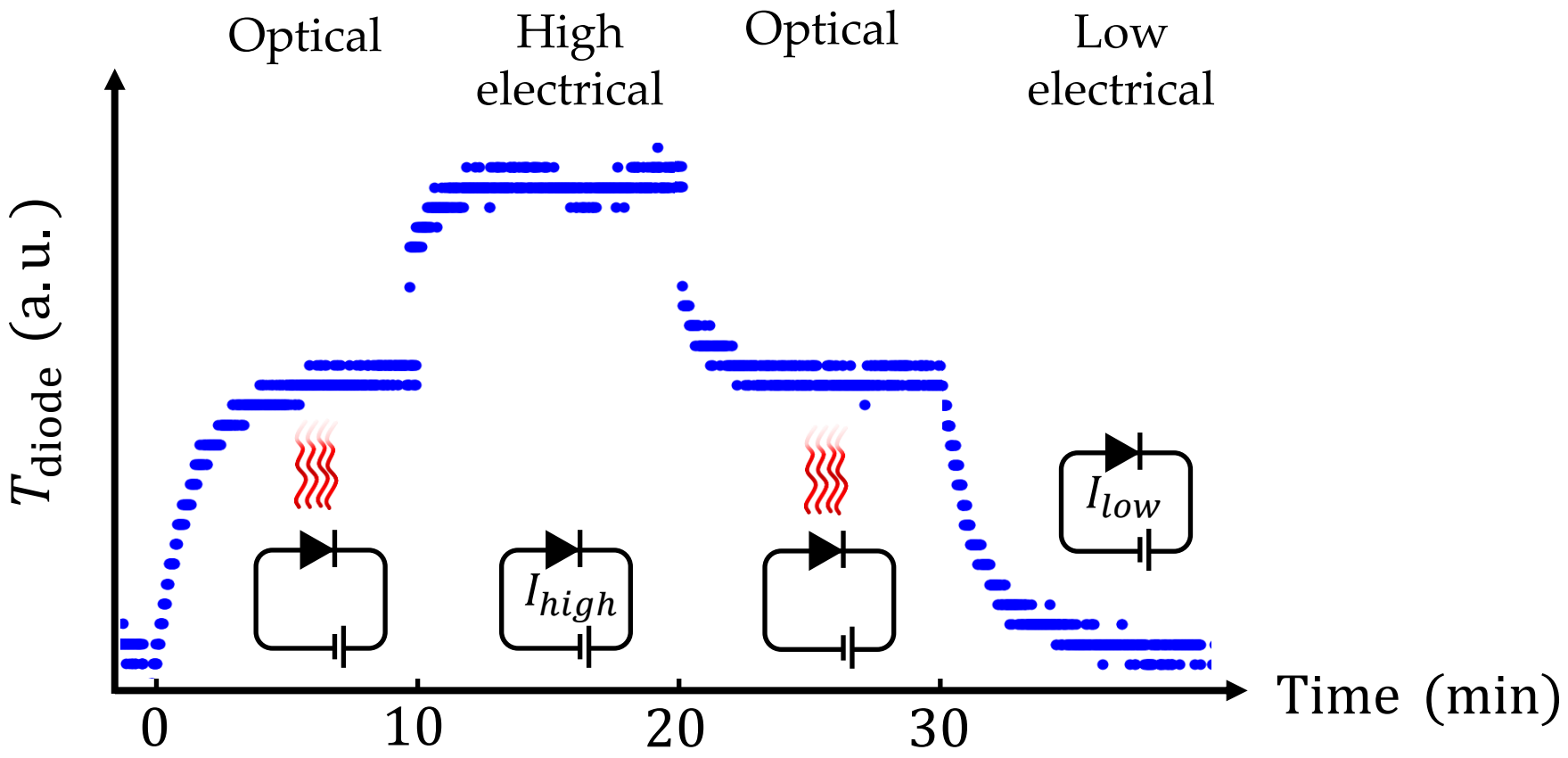

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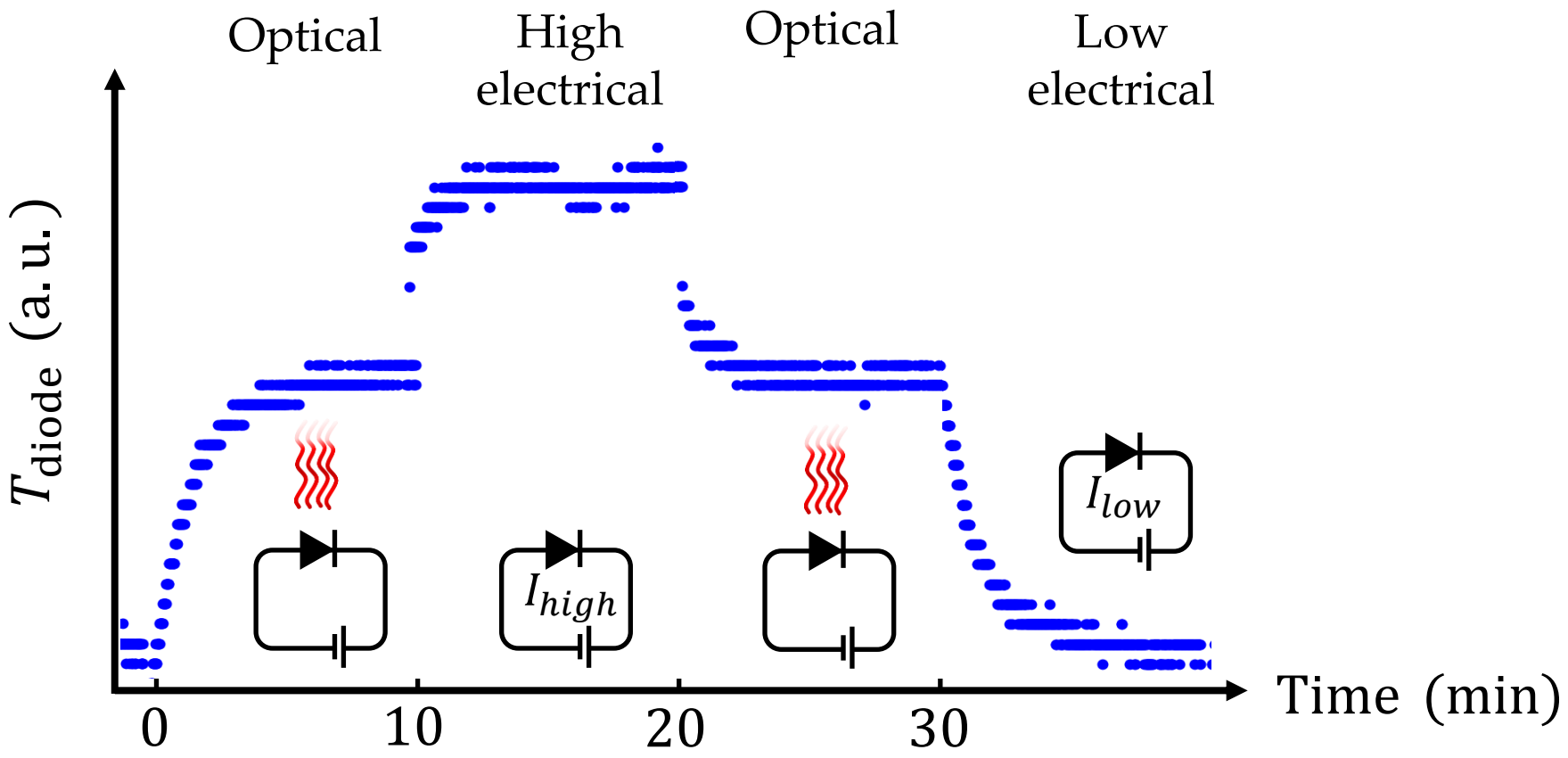
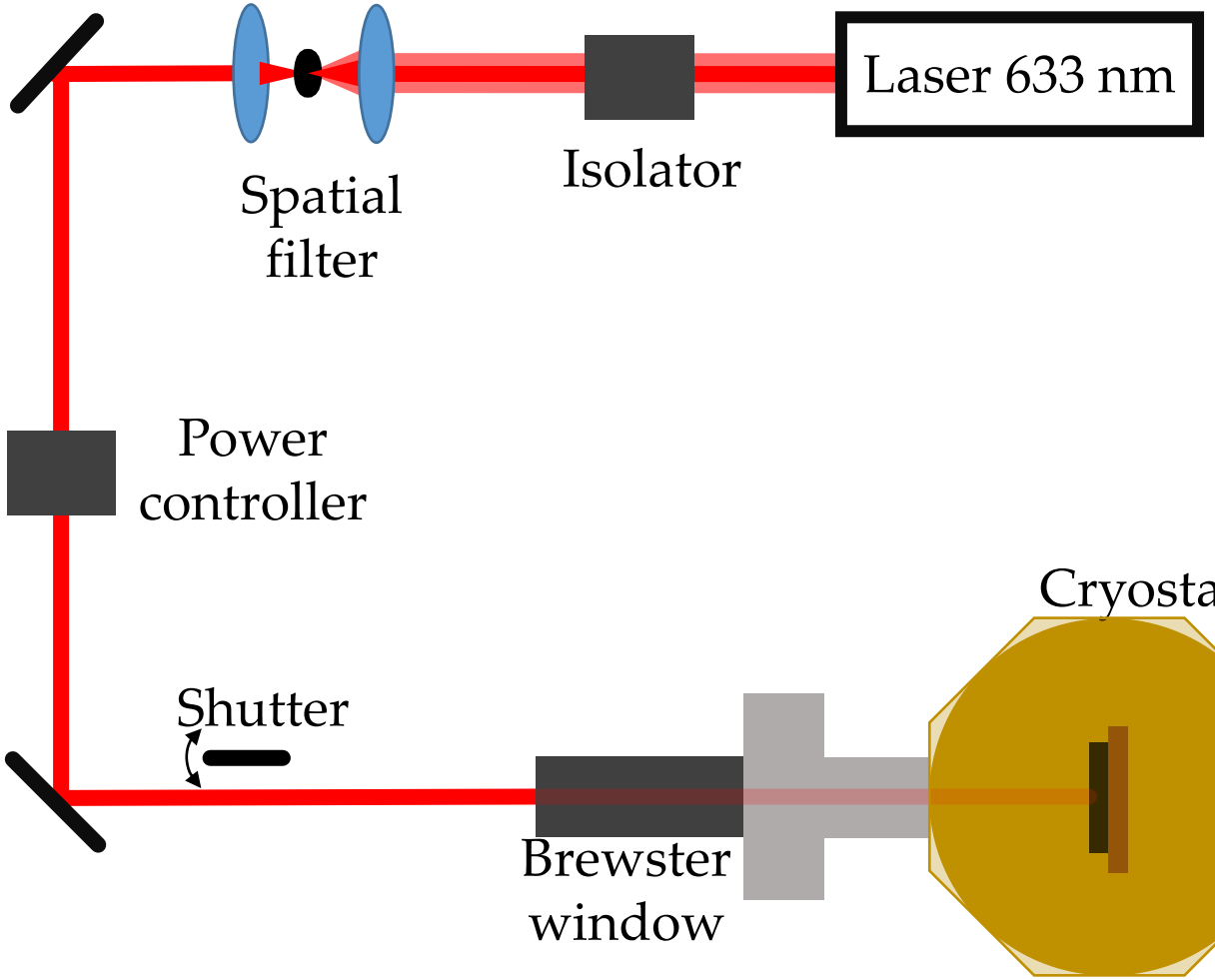
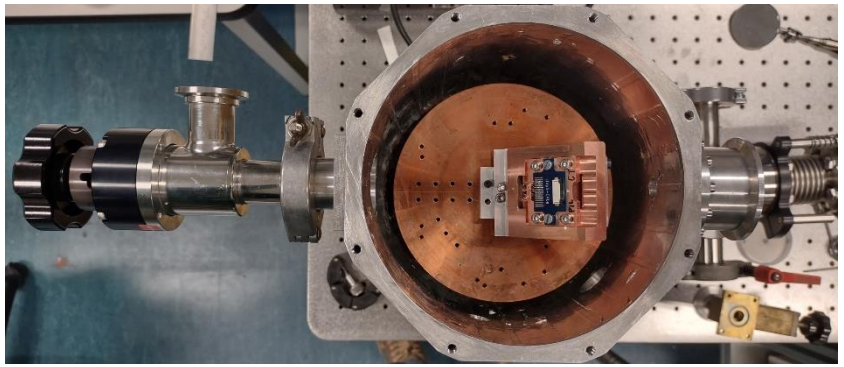
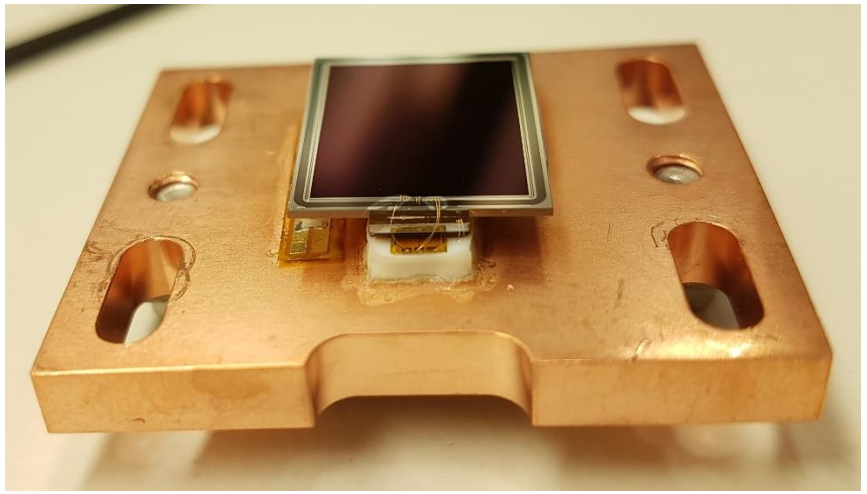


$$P_{sub} = P_{low} + (P_{high} - P_{low}) \frac{(T_{opt} - T_{low})}{(T_{high} - T_{low})}$$

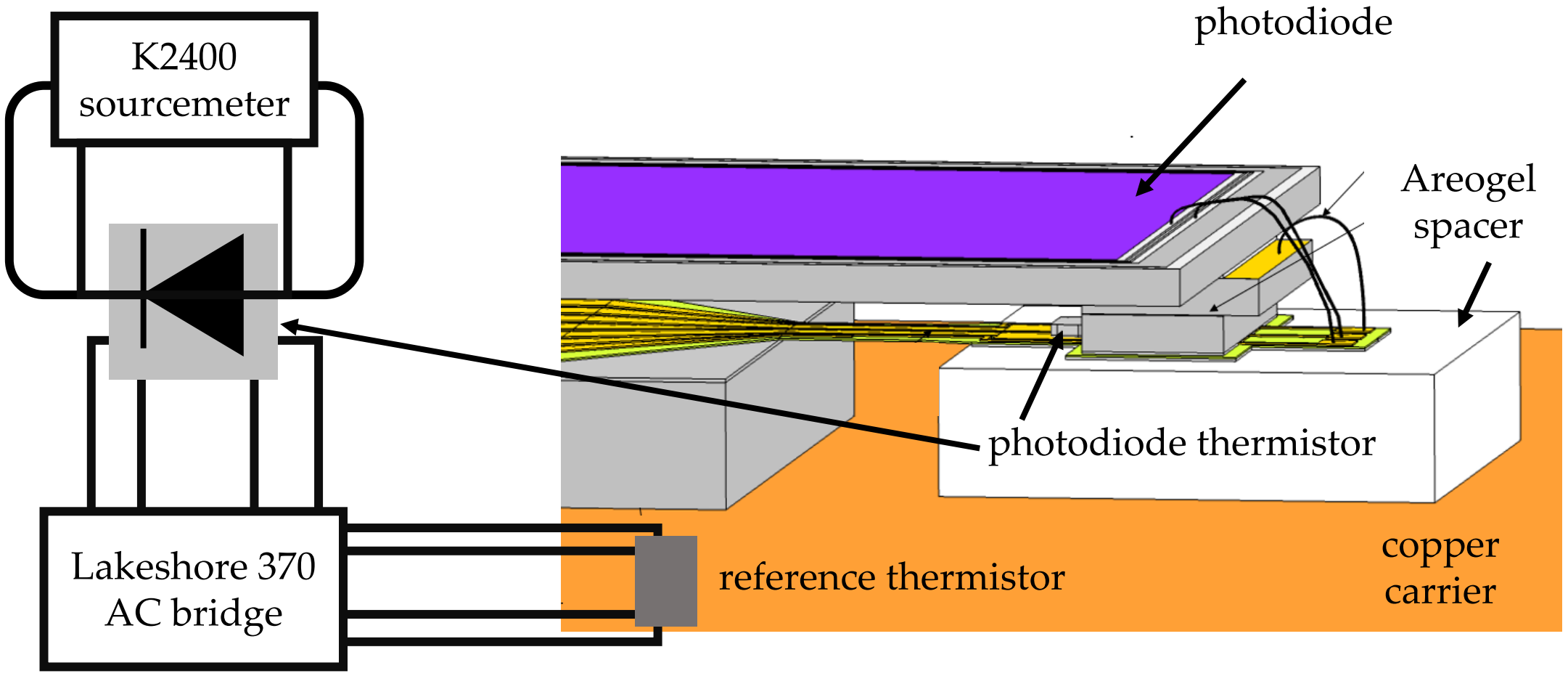
Optical setup



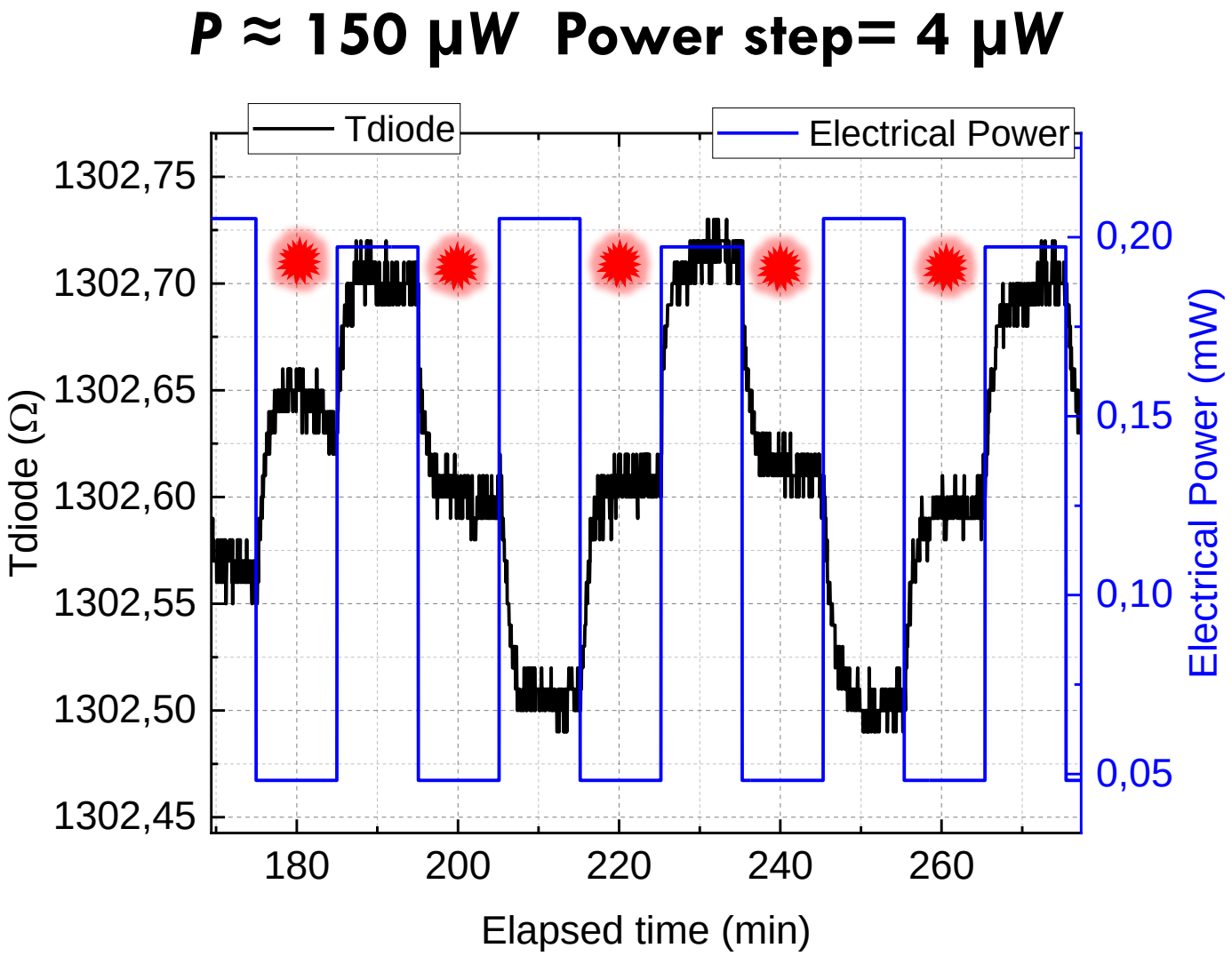




Electrical and thermal setup



Internal losses measurement at CT



λ= 632 nm

T= 79 K

V_{bias} =-5 V

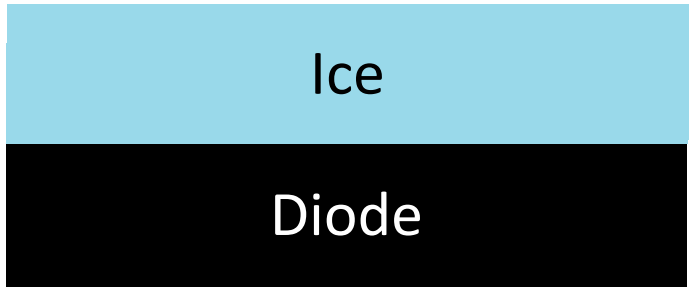
Power step= 4 μW

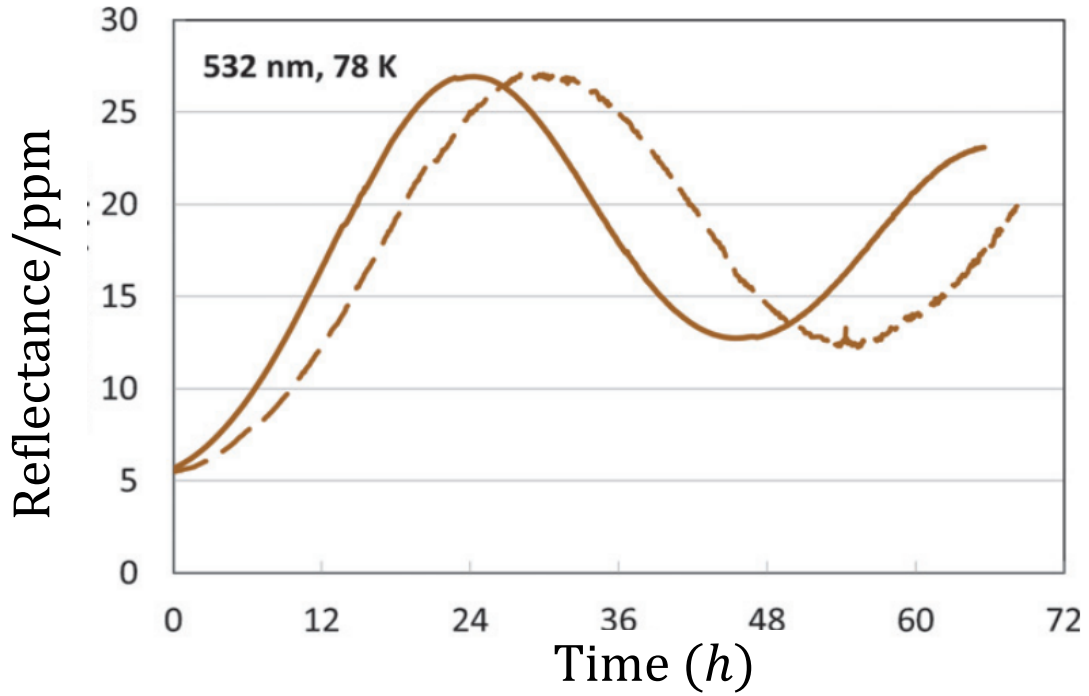
P_{sub} = 152.7407 μW

δ ≈ **1000 ppm**

Ice forming on surface of the diode

Performing long run measurement, we notice that the optical level was changing in time





Sildoja, Meelis, et al. "Predictable quantum efficient detector: I. Photodiodes and predicted responsivity." *Metrologia* 50.4 (2013): 385.

Manoocheri, F., et al. "Liquid nitrogen cryostat for predictable quantum efficient detectors." *Journal of Physics: Conference Series*. Vol. 972. No. 1. IOP Publishing, 2018.

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- Cryostat modification to improve experimental condition
  - Vacuum < 1E-6 mbar
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  - New laser with power range up to 2 mW
  - xy stage mounted
  - Preliminary internal losses measurement of 2000 ppm and 5000 ppm at 1.5 mW and 2.0 mW respectively

Take-away

PQED simpler than cryogenic radiometer:

Fast

Small

Chip

Thank you for the attention

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(1)

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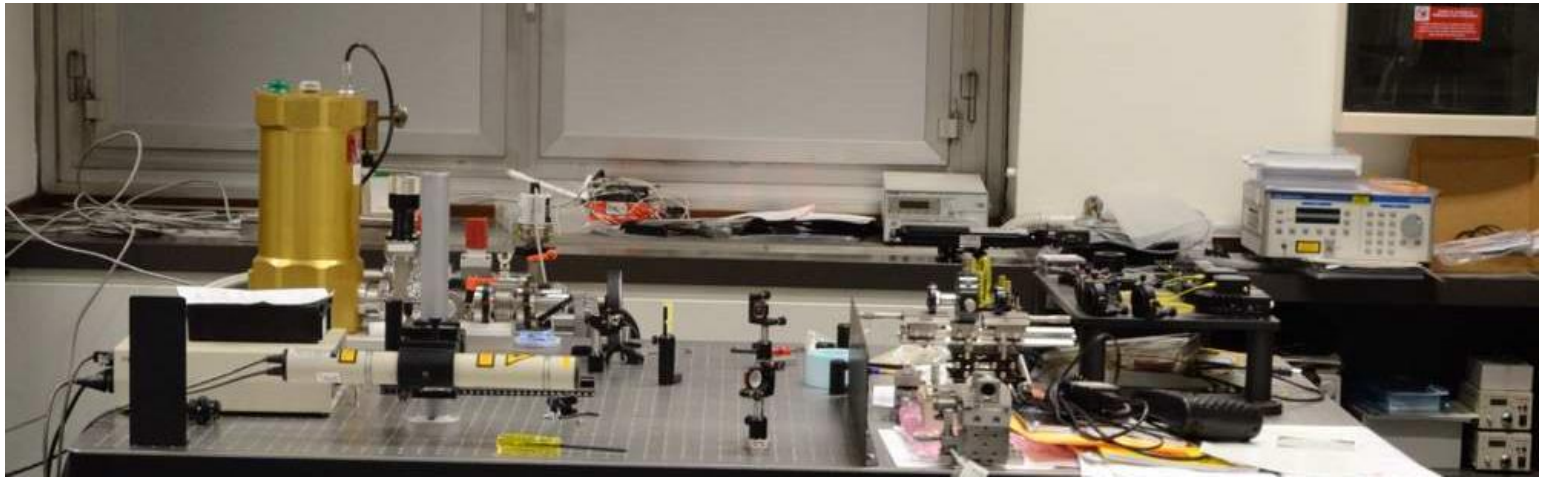
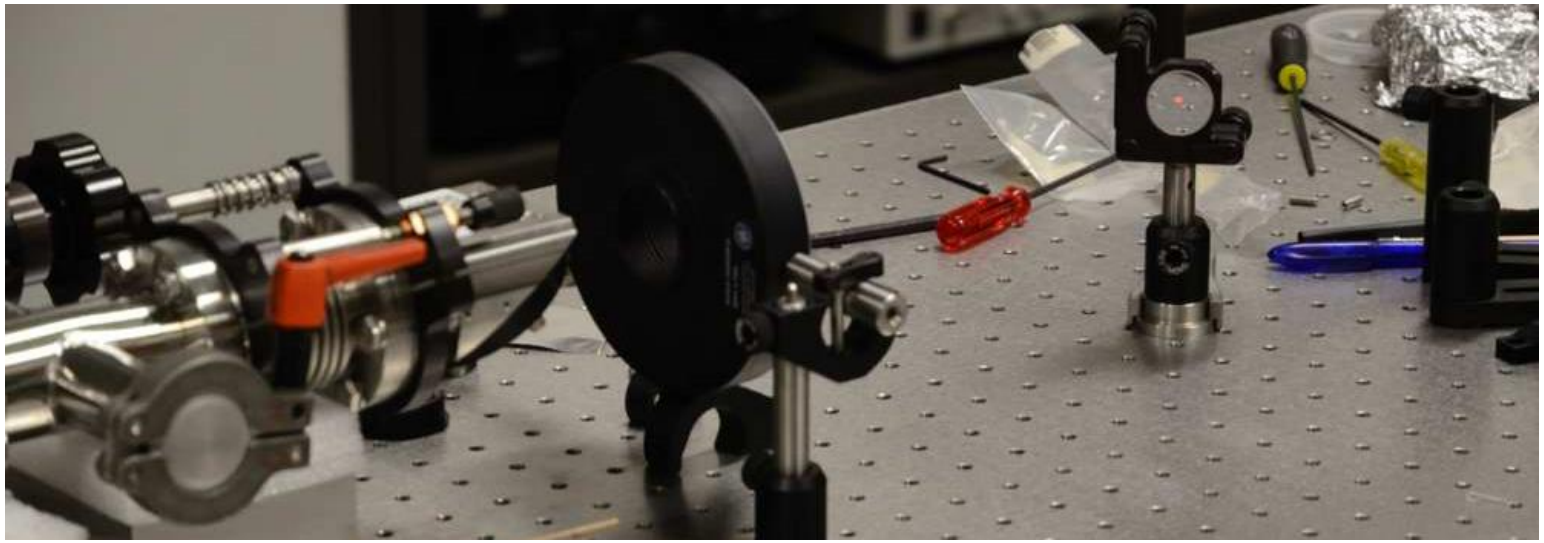
Setup





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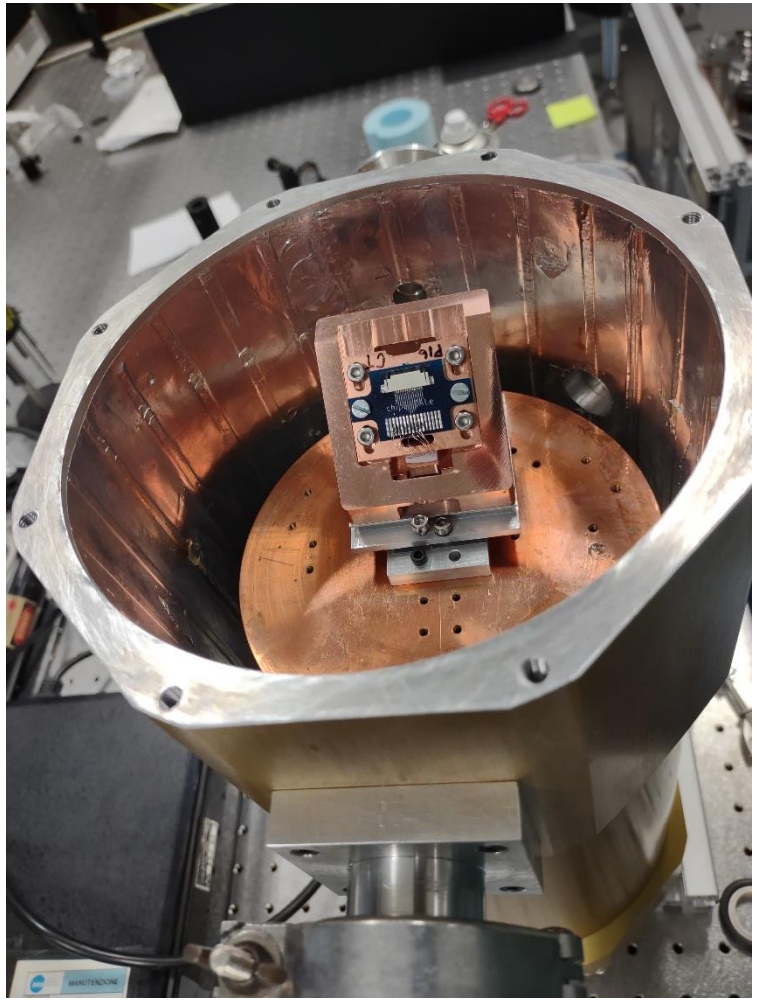

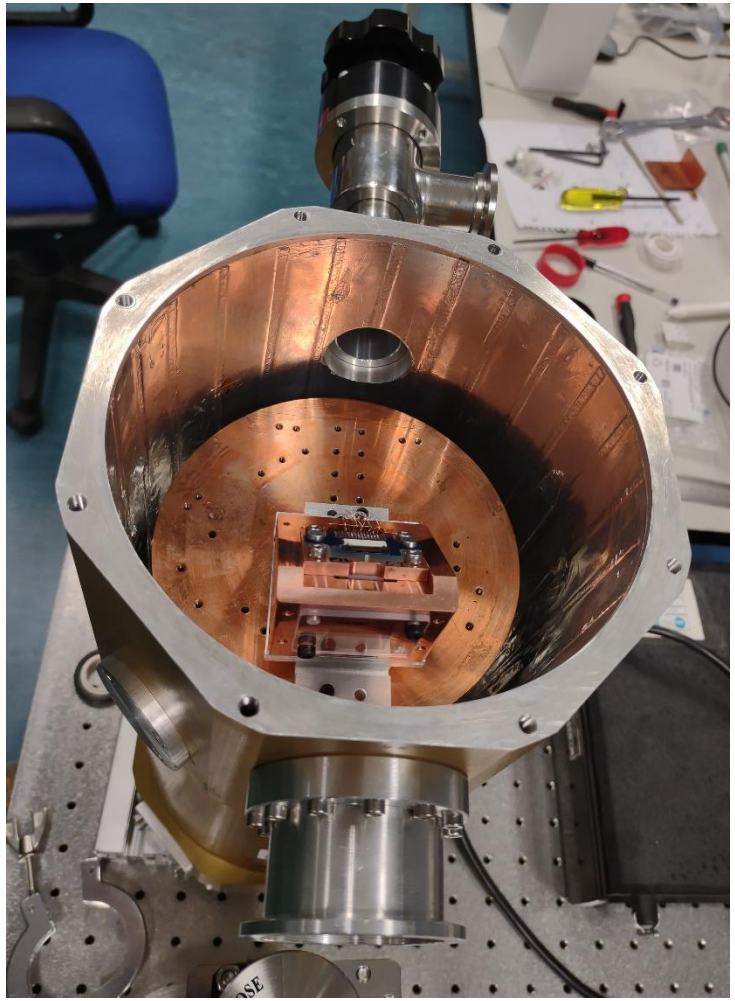

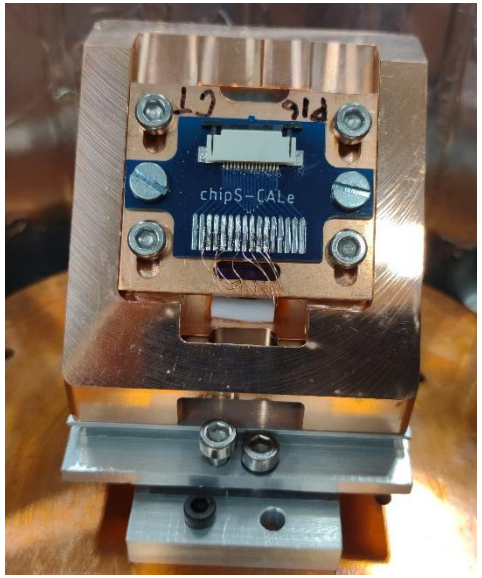

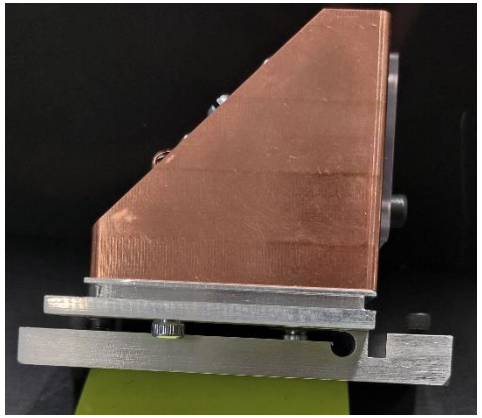

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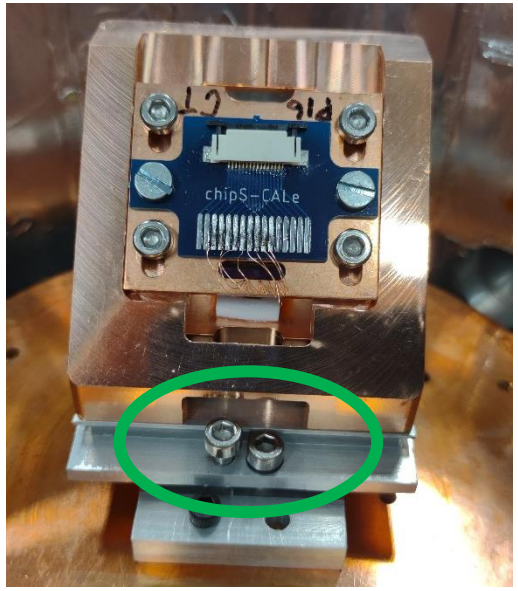
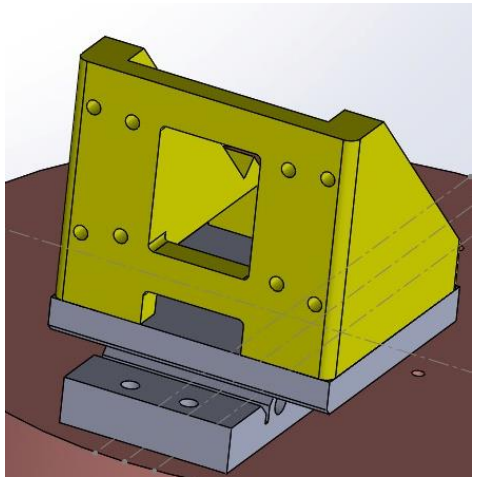
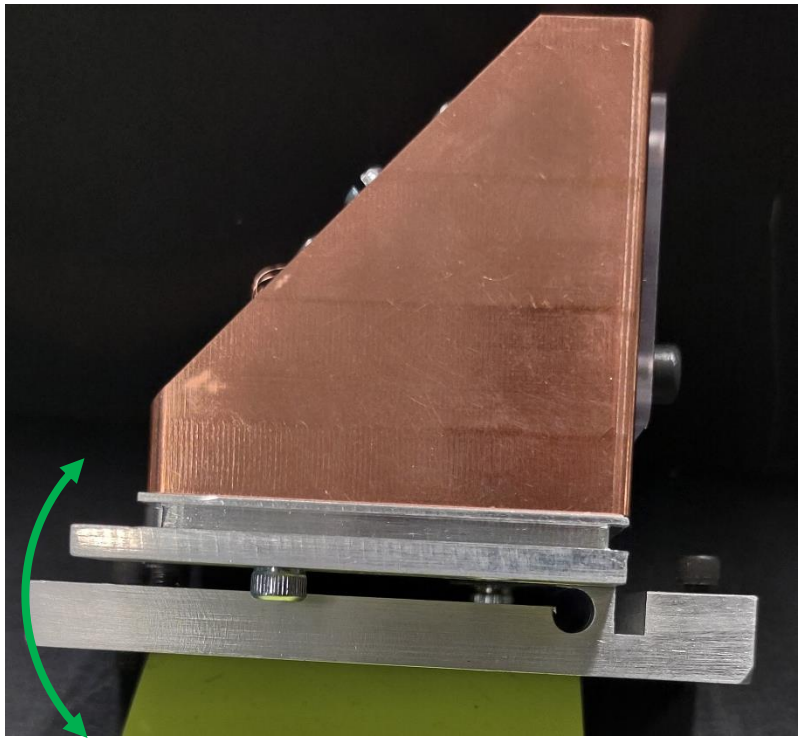
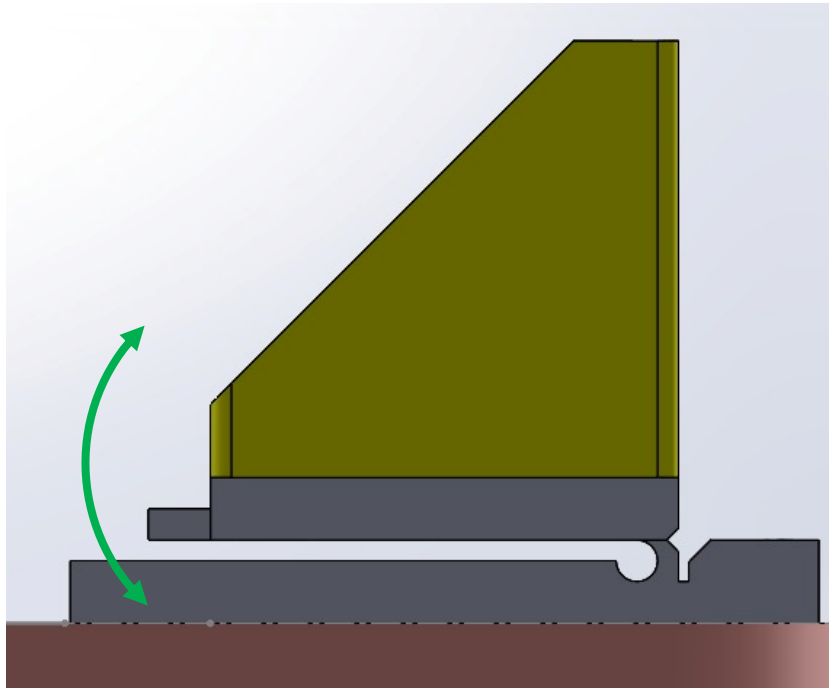
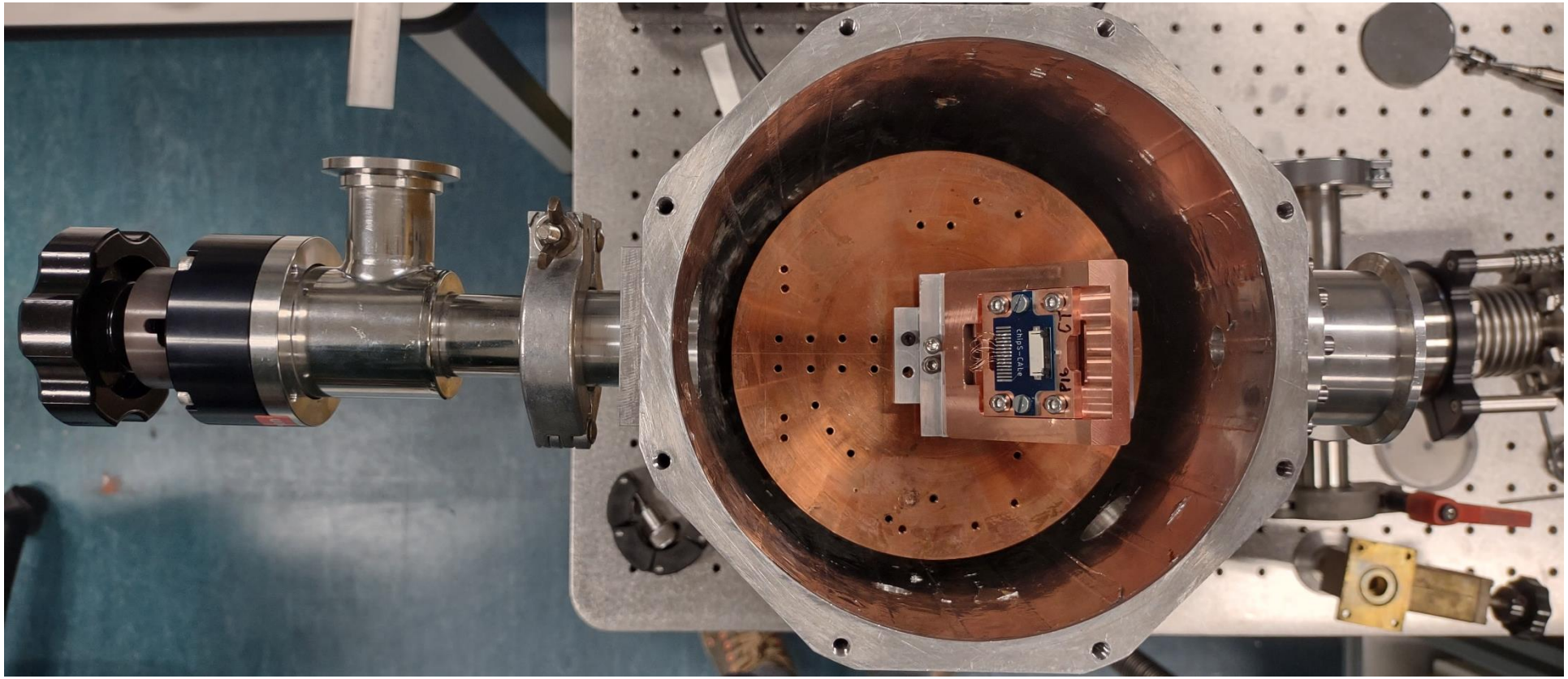








Setup



2. IQD measurement of PQED in 3-reflection trap at CT

- The cryostat is baked while pumping before cooling down with LN_2

- In the 1st cooldown after the modifications, the vacuum at RT was good (p=5E-6 mbar). When filling with LN2 one of the new **O-ring (in FKM) freezed** and we lost the vacuum completely (**p>E-1 mbar**).

- In the 2nd cooldown at RT p=5E-6 mbar→ at CT **p=1E-3 mbar**.

- **In the 3rd cooldown at RT p=1E-6 mbar → at CT p= 8.9E-7 mbar**

- During Easter holiday a blackout caused a stop of the pumps while cryostat was cold. Oil went in the system. **Brewster window get dirty**. (**the trap was not inside the cryostat**)