Fully Lithographic Fiber-coupled Cryogenic Radiometer for Picowatt Powers

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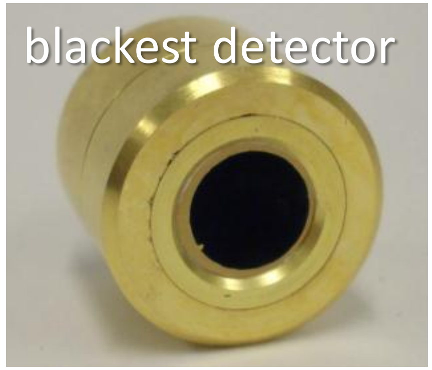
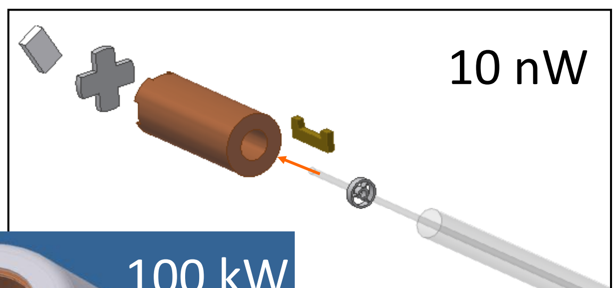
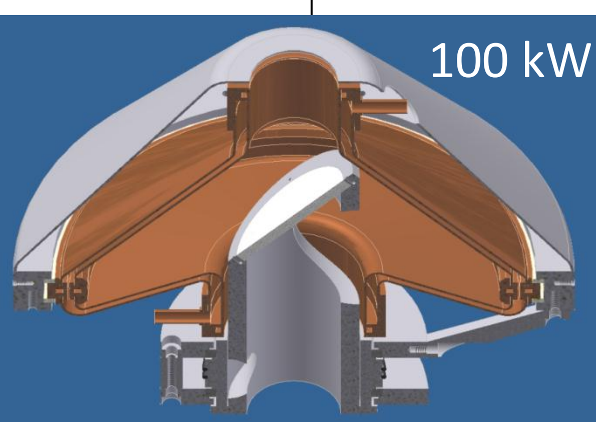
NIST Boulder groups & projects

Laser Radiometry

- Chris Cromer
- Marla Dowell
- Ari Feldman
- Josh Hadler
- John Lehman
- Xiaoyu Li
- Dave Livigni
- Nathan Tomlin
- Igor Vayshenker

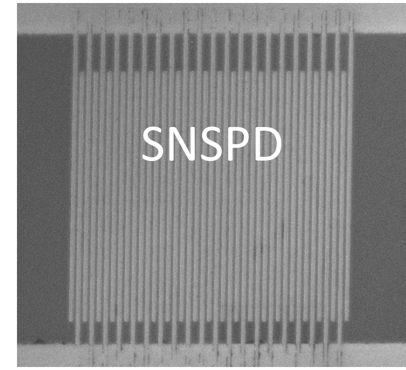


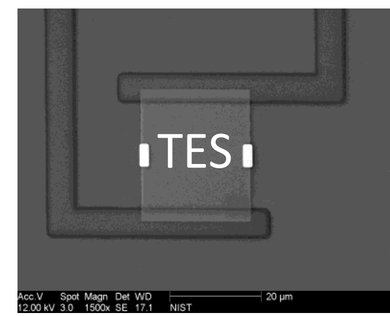


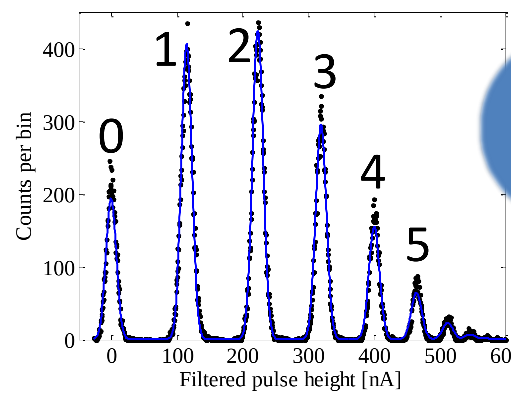


Quantum Information

- Burm Baek
- Scott Bradley
- Brice Calkins
- Shellee Dyer
- Shelley Etzel
- Thomas Geritts
- Antia Lamas-Linares
- Adriana Lita
- Rich Mirin
- Sae Woo Nam
- Marty Stevens
- Varun Verma

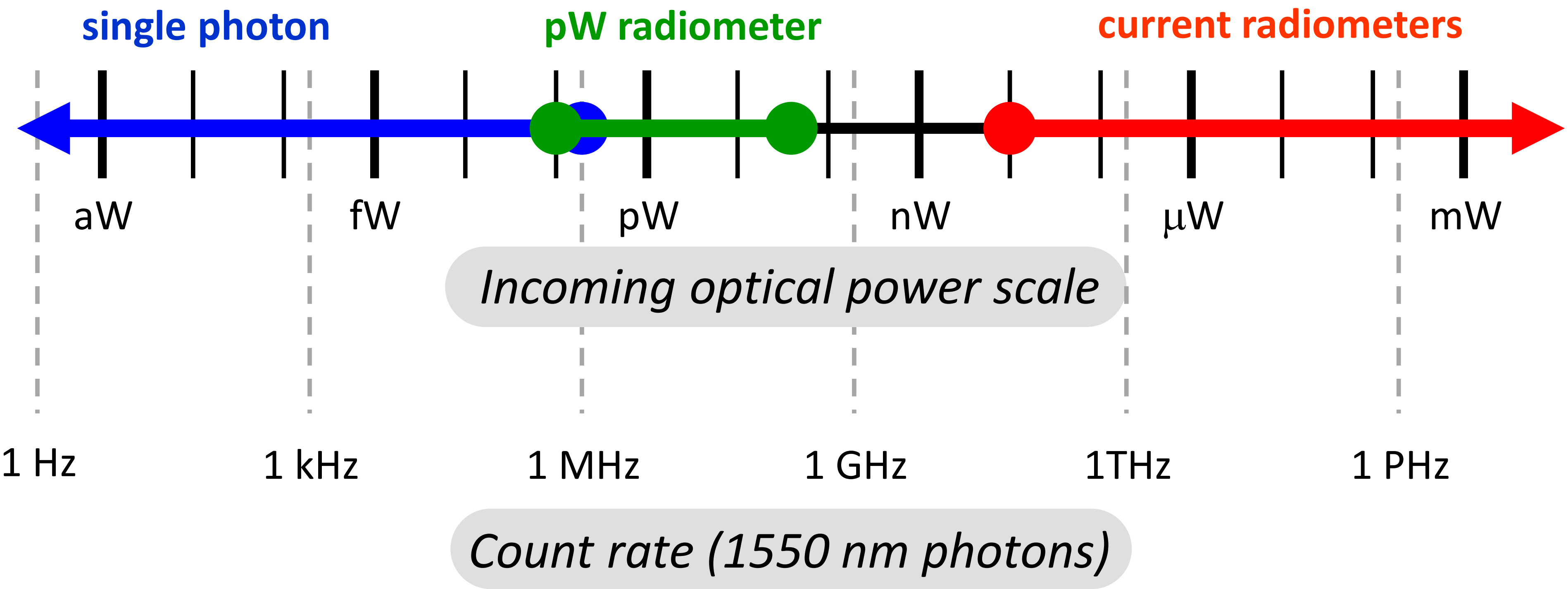






see T. Gerrits' talk this afternoon

The power gap

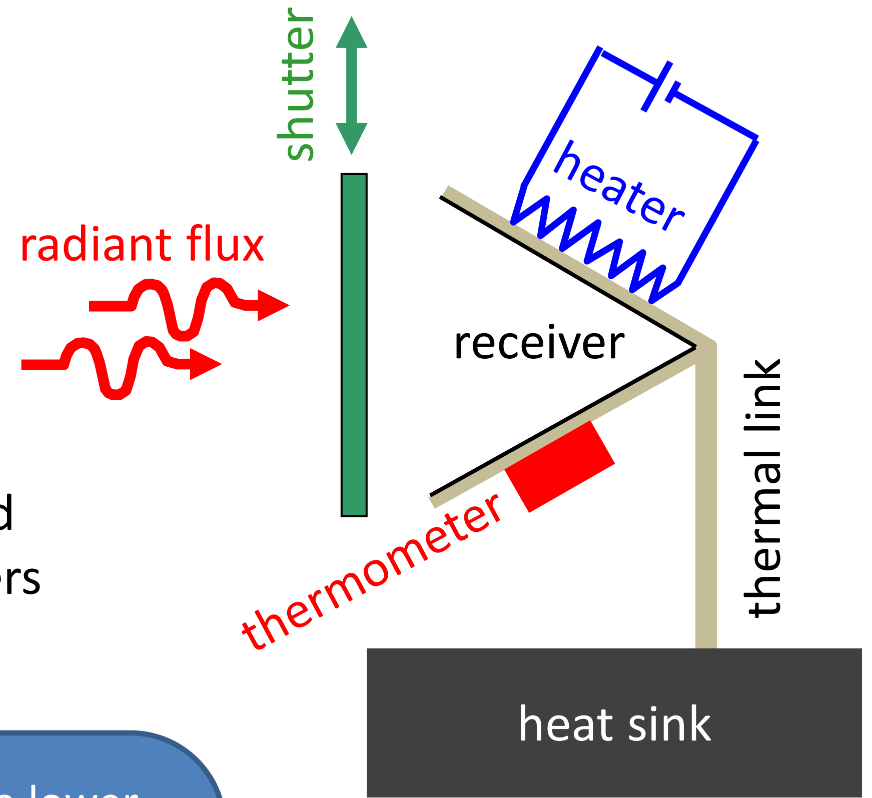


no NMI-traceable single-photon sources or detectors

see Alan Migdall's talk after coffee break

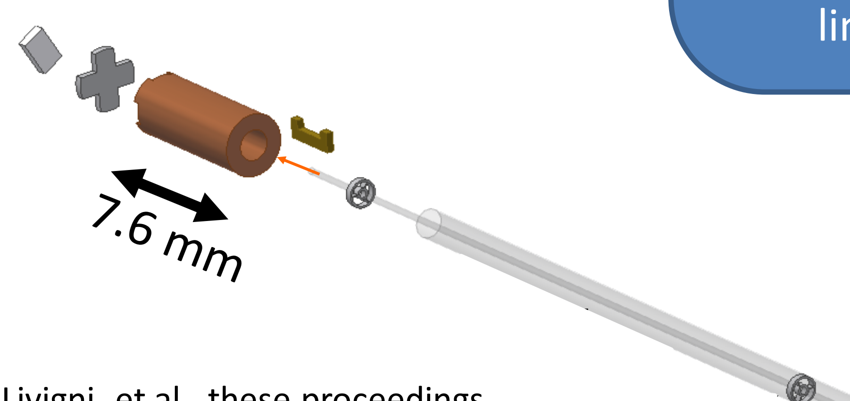
Hand-assembled absolute radiometers

- Receiver
  - Absorber
  - Electrical heater
  - Thermometer
- Weak thermal link to heat bath

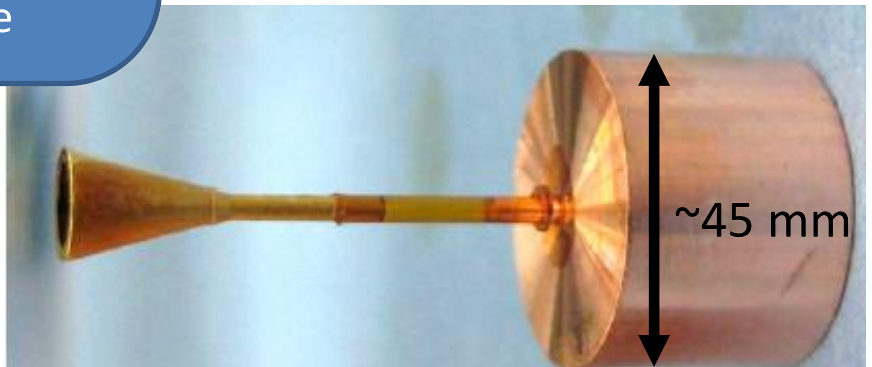


- Macroscopic components hand assembled
- Limited by size constraints to higher powers

pushing the lower limit on size

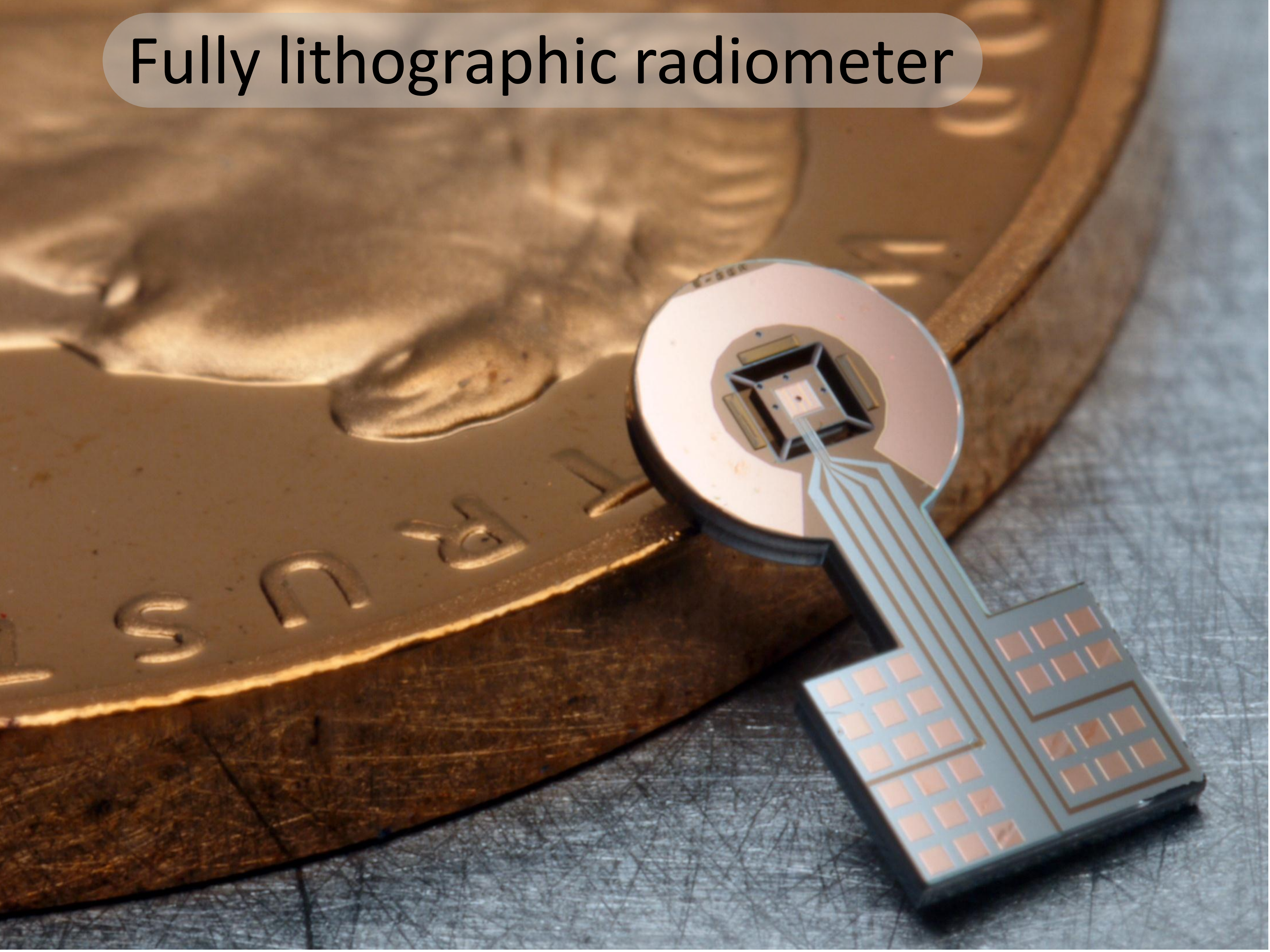


Livigni, et al., these proceedings.

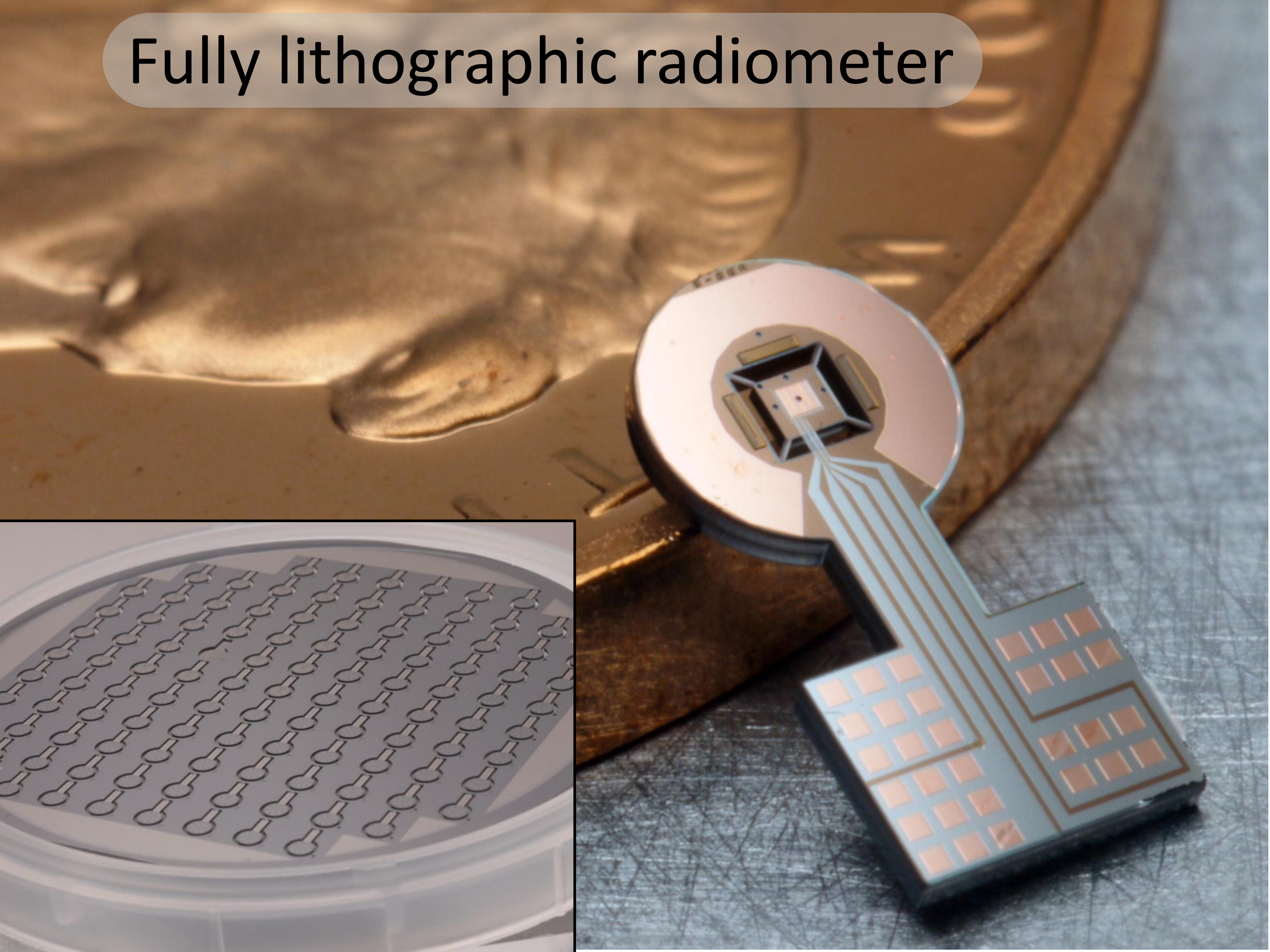


Carter, et al., *Metrologia*, **46**, S146, 2009.

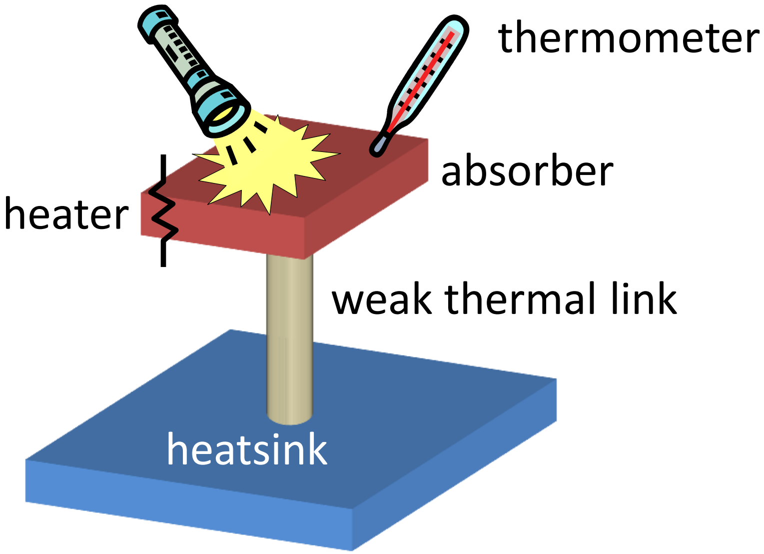
Fully lithographic radiometer

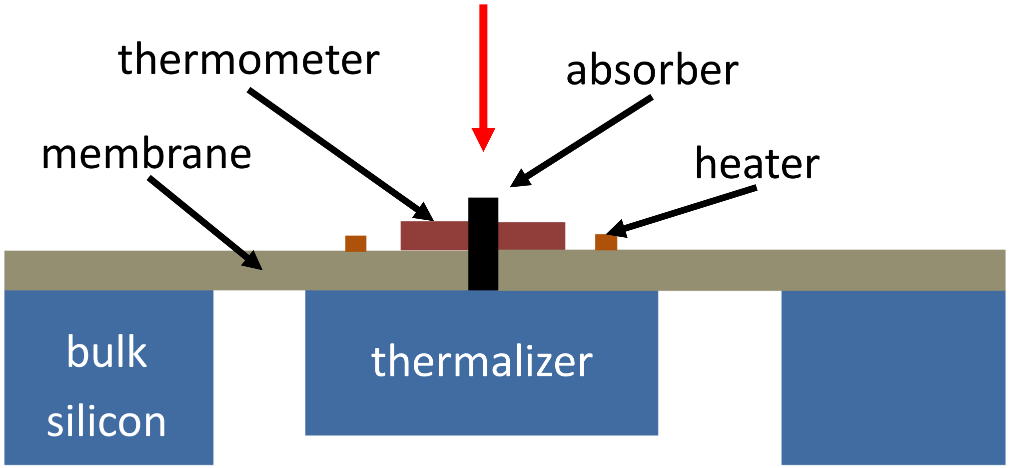


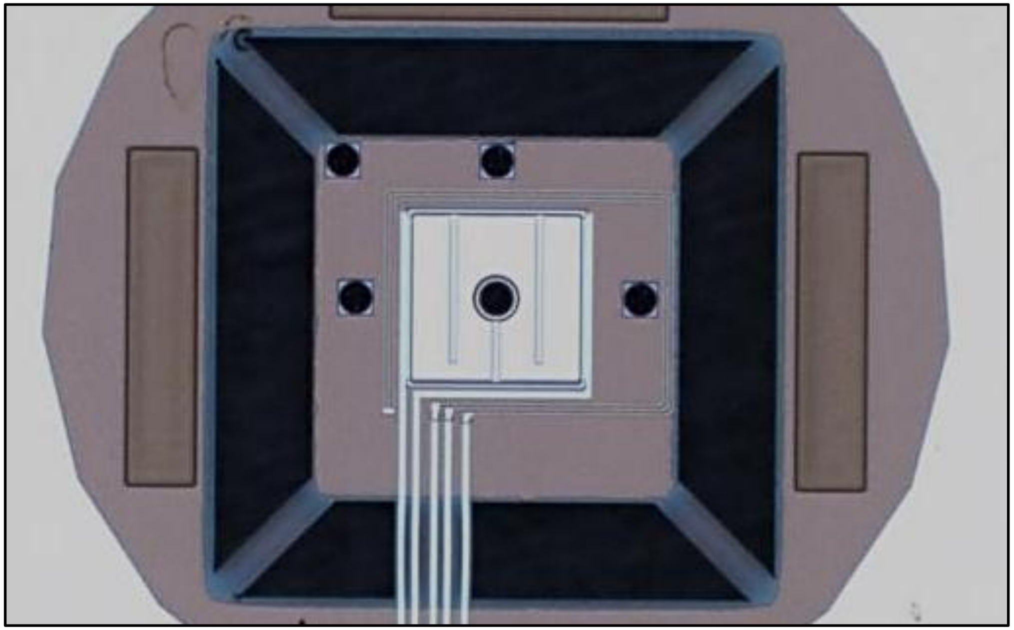
Fully lithographic radiometer



Lithographic radiometer





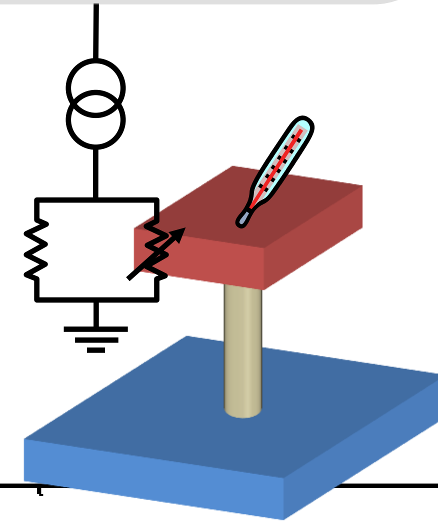


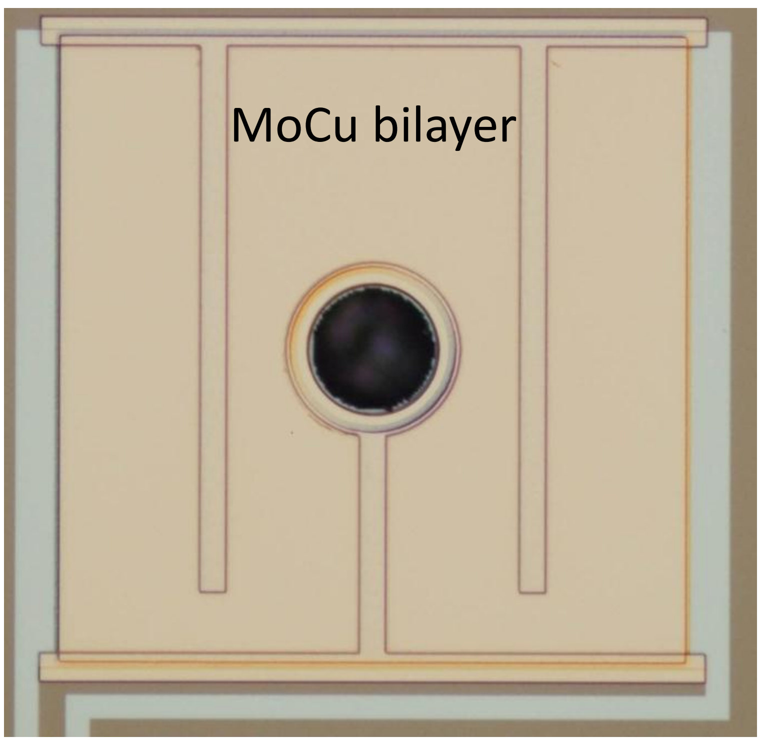
<u>Components:</u>

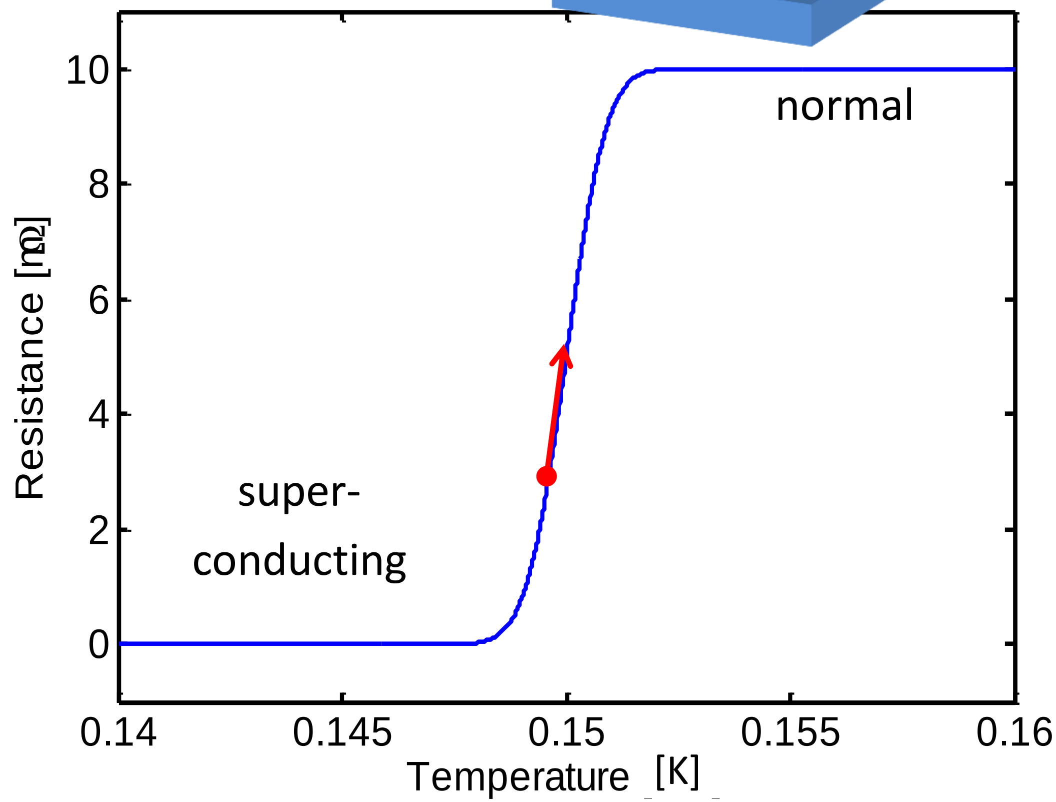
- Thermometer
- Heater
- Weak thermal link
- Absorber

Thermometer: Transition-Edge Sensor

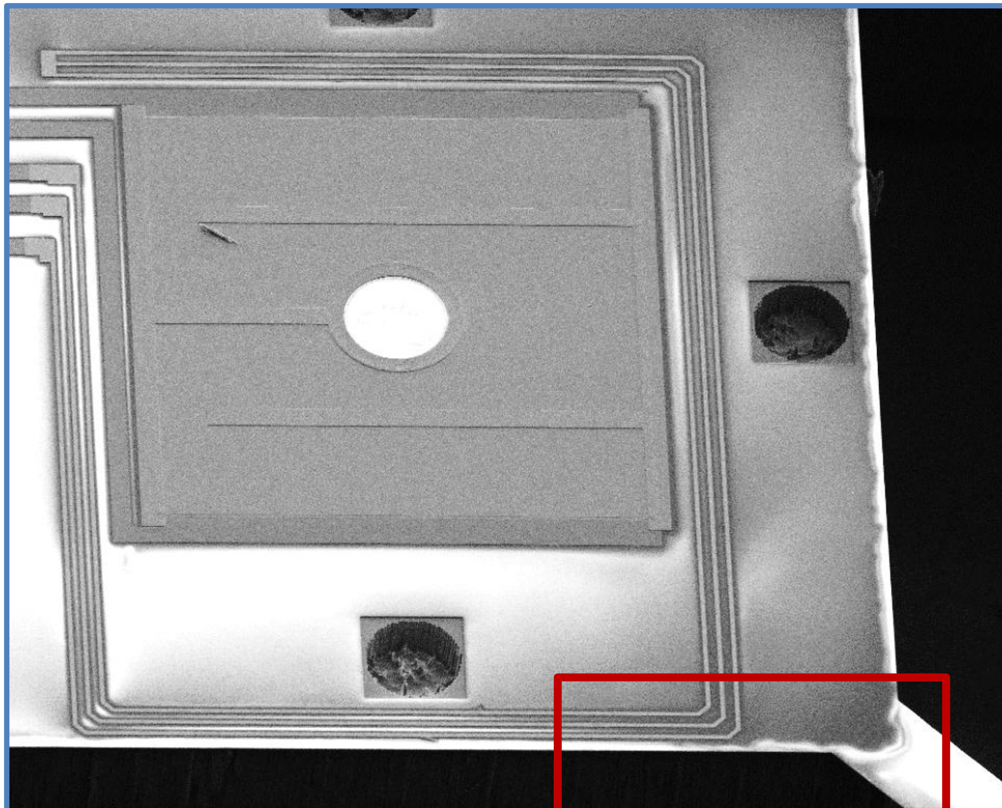
- superconducting thin film, MoCu bilayer
- Tunable transition temperature, typically ~150 mK
- extremely sensitive thermometer
- Voltage biased – SQUID current readout





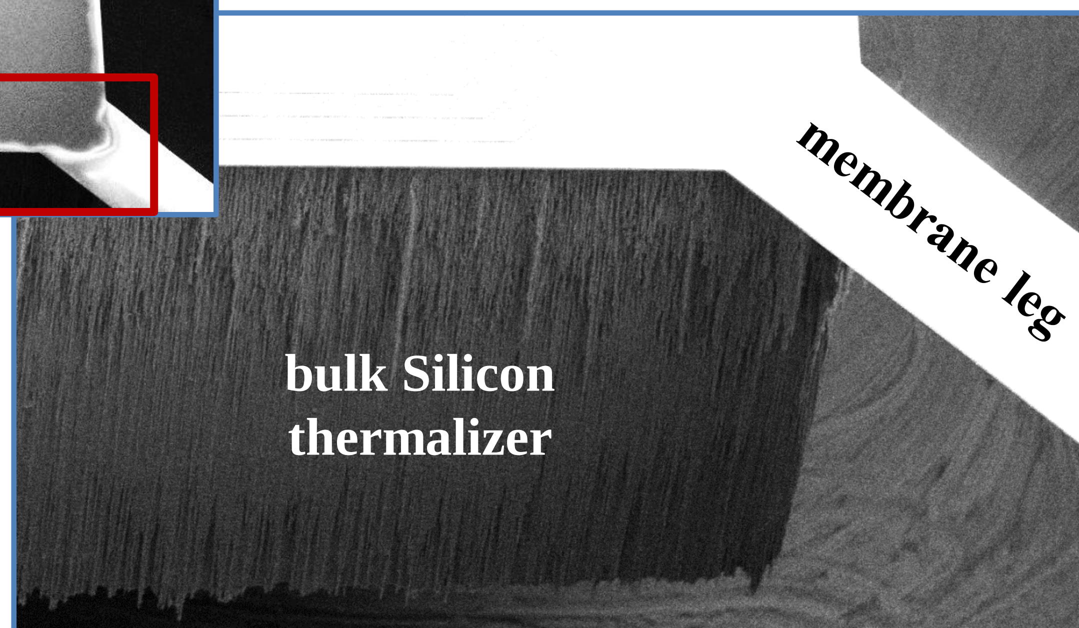


Heater & weak thermal link



<u>Weak thermal link</u>

- Low stress silicon nitride membrane
  - 1 μm thick
- Bulk silicon left behind device to help thermalize heater and TES

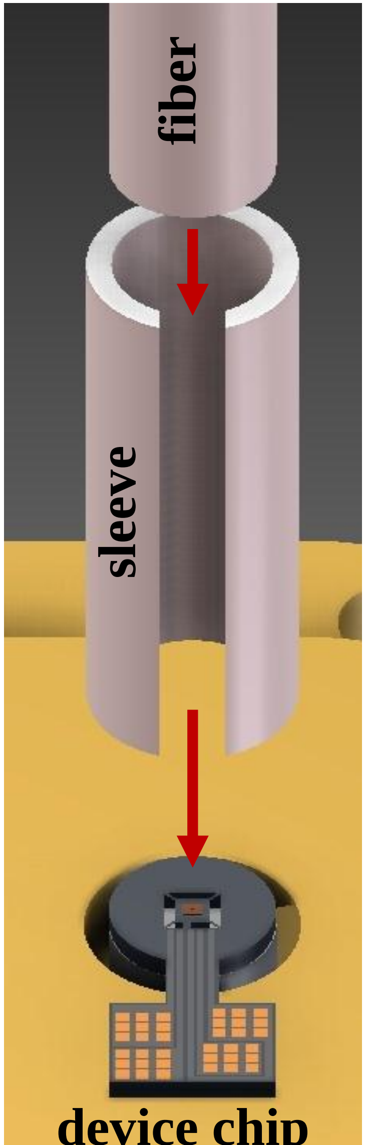


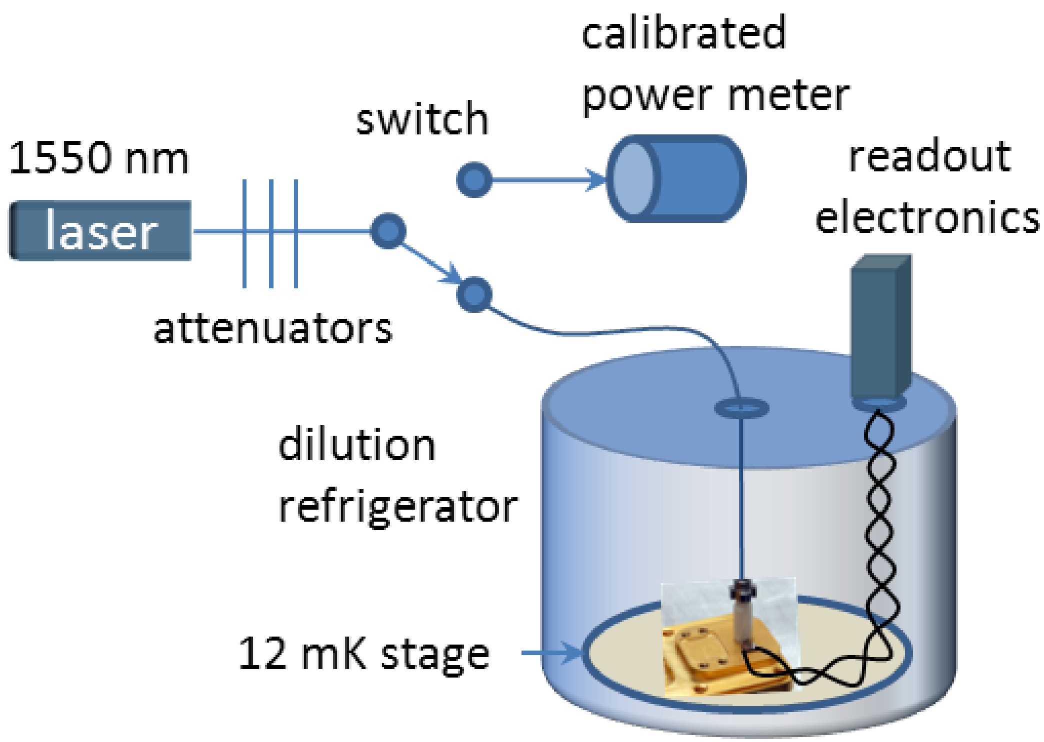
<u>Electrical heater</u>

- PdAu thin film wiring
  - 2 μm wide
  - 60 nm thick
  - 4.5 kΩ cold

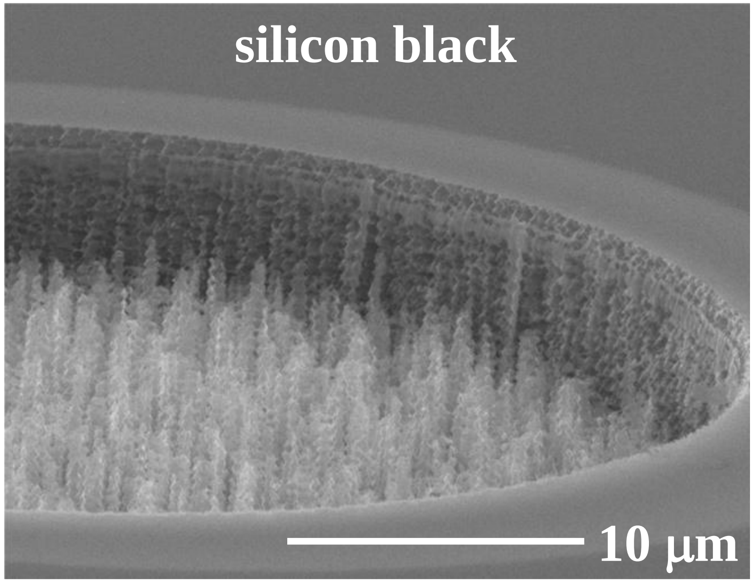
Optical power

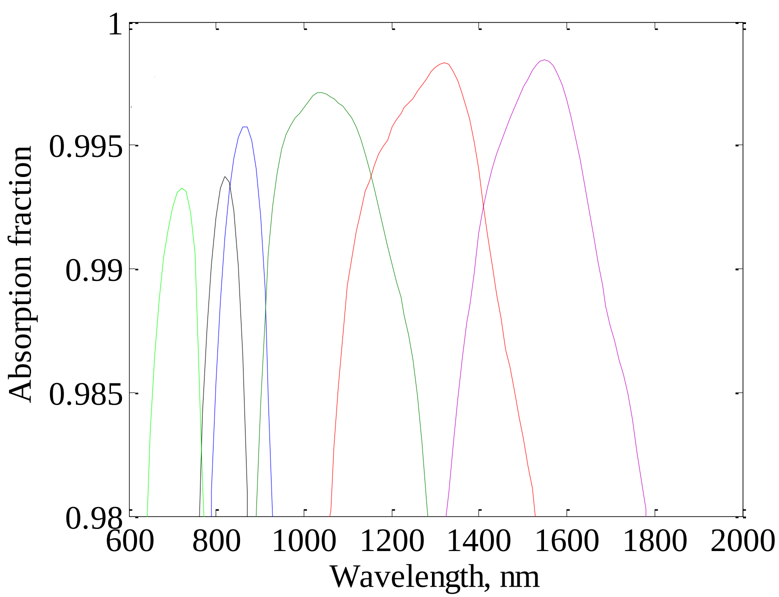
- SMF28 optical fiber
  - 8.2 μm core diameter
- chip self-aligns to fiber
- use calibrated power meter and programmable attenuators



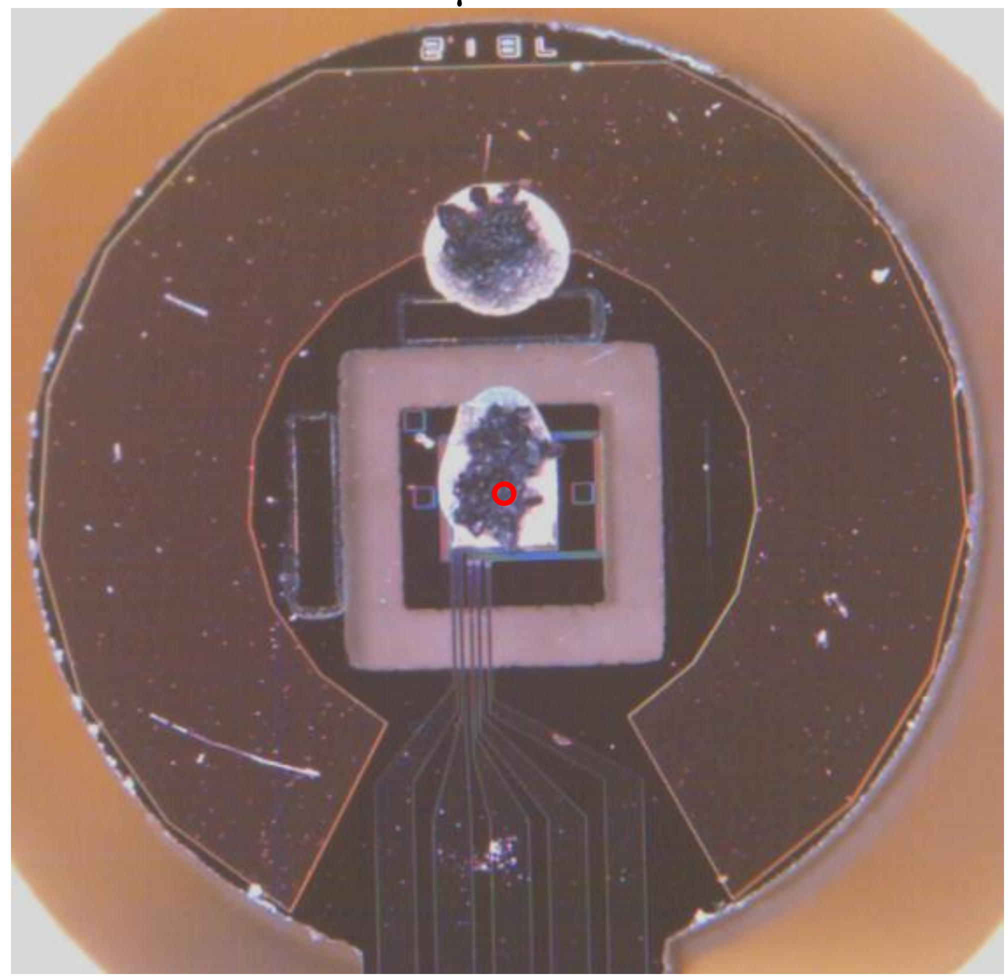


Absorber

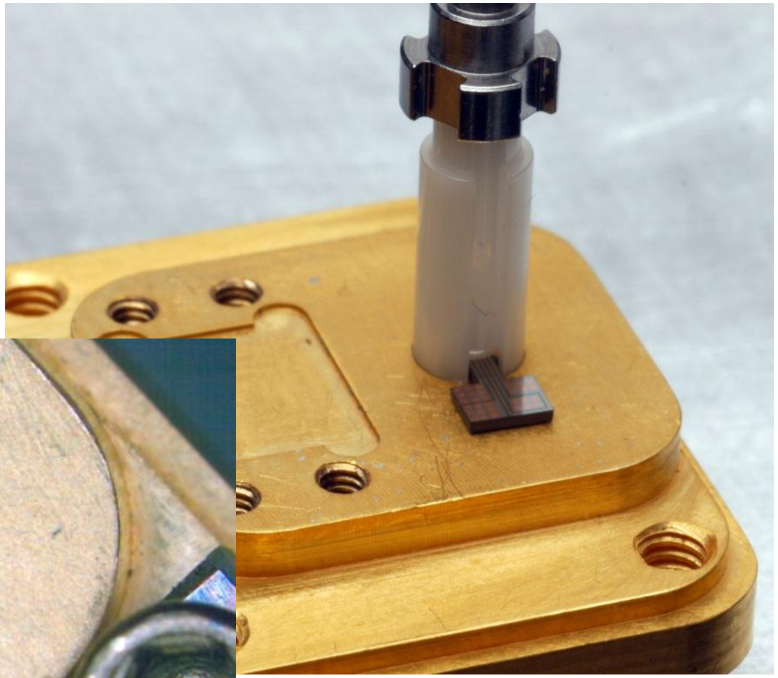


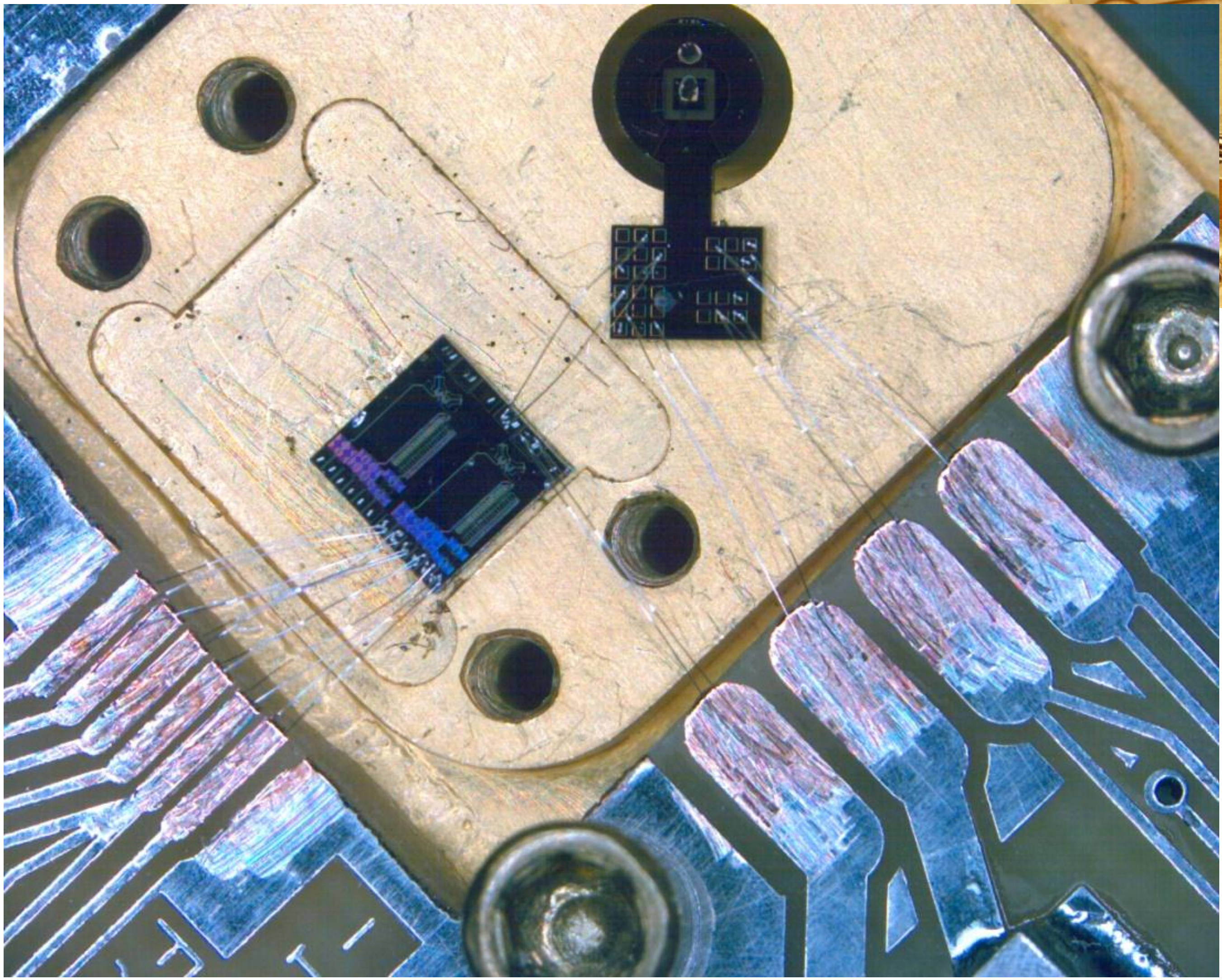


- epoxy used to attach multiwall carbon nanotubes over the TES
  - Nanocyl, > 99% absorption from visible to 10 μm



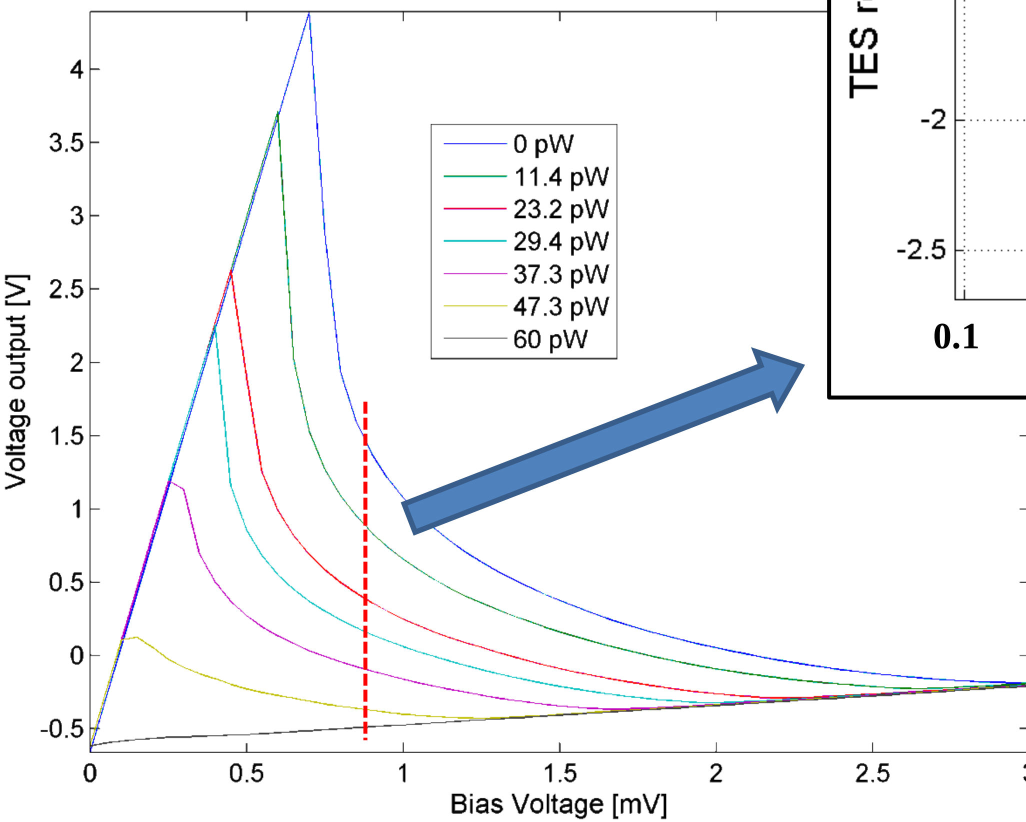
Complete radiometer

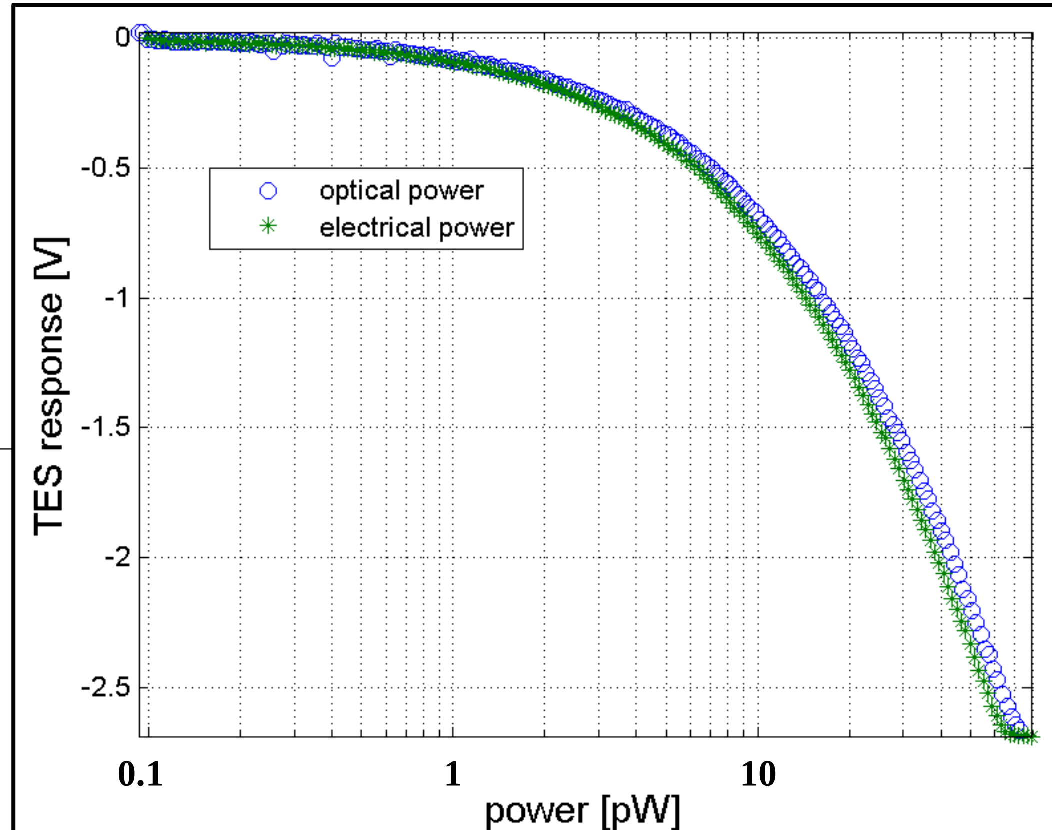




Initial pW radiometer data

- TES readout changes non-linearly with bias, temperature, and power

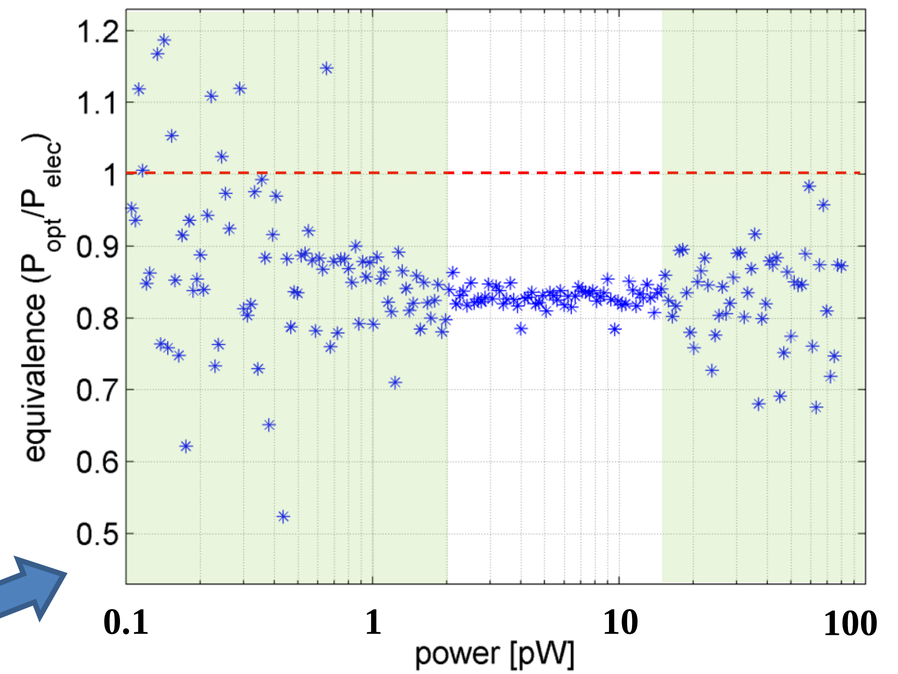


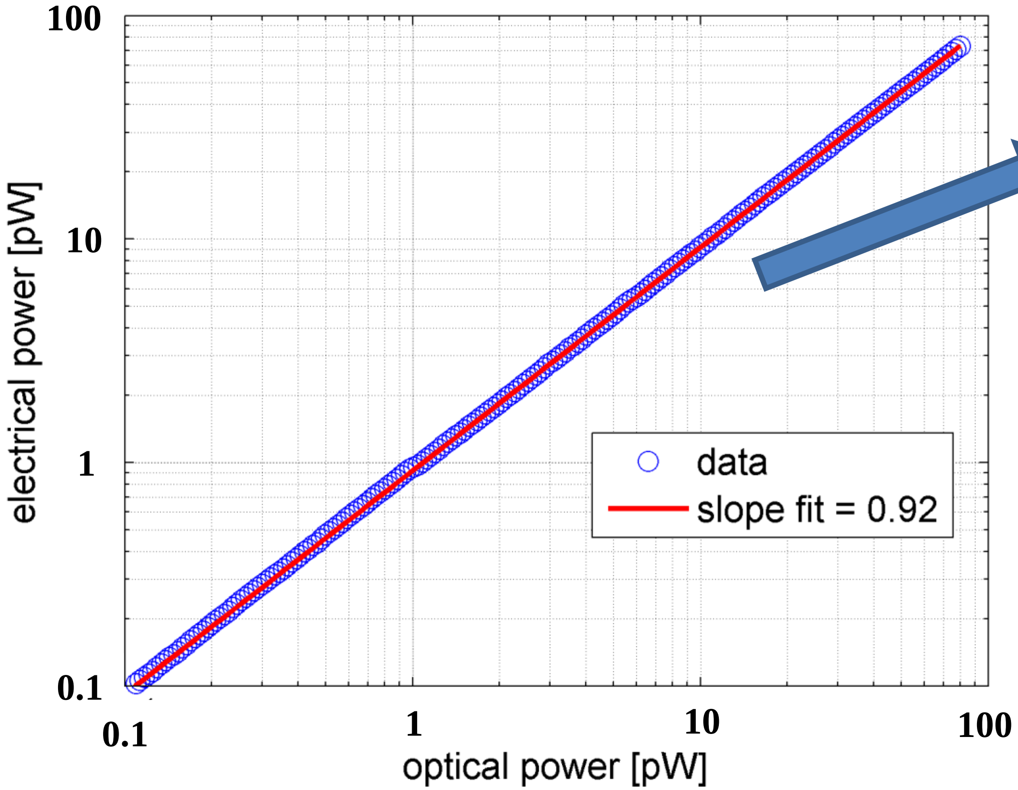


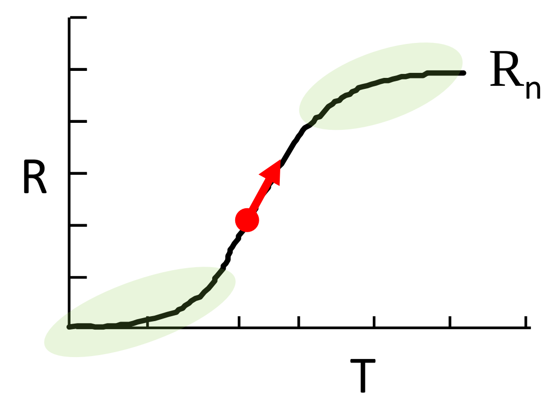
- Input powers: 0.1 pW to 70 pW

Initial results

- Equivalence (optical / electrical) below 1
- Not all optical light is absorbed
  - Possibly due to wetting of carbon nanotubes by epoxy

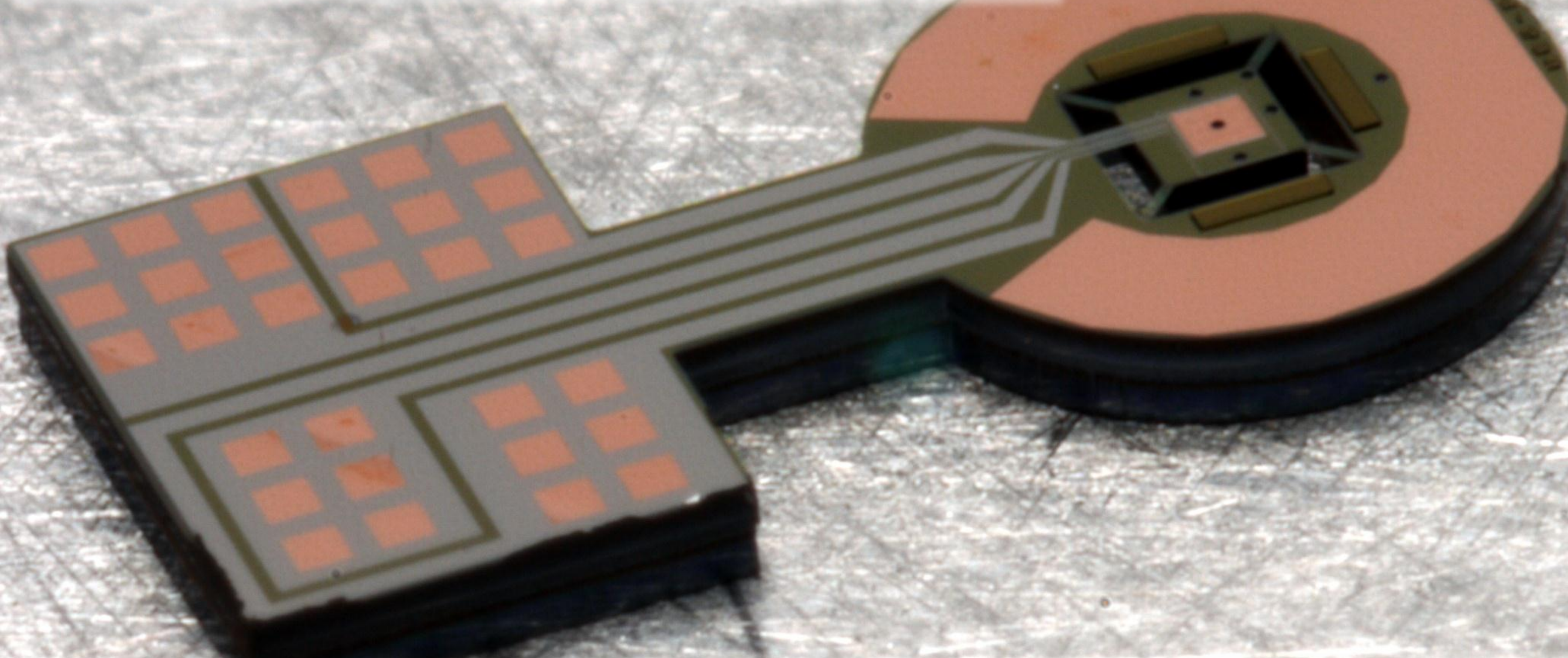






Conclusions

- We have built the first prototype of a lithographic pW cryogenic radiometer
- Measured power levels from 0.1 to 70 pW



- Optical / electrical inequivalence of ~0.83
  - Need to improve absorber
- Work to reduce noise and extend range

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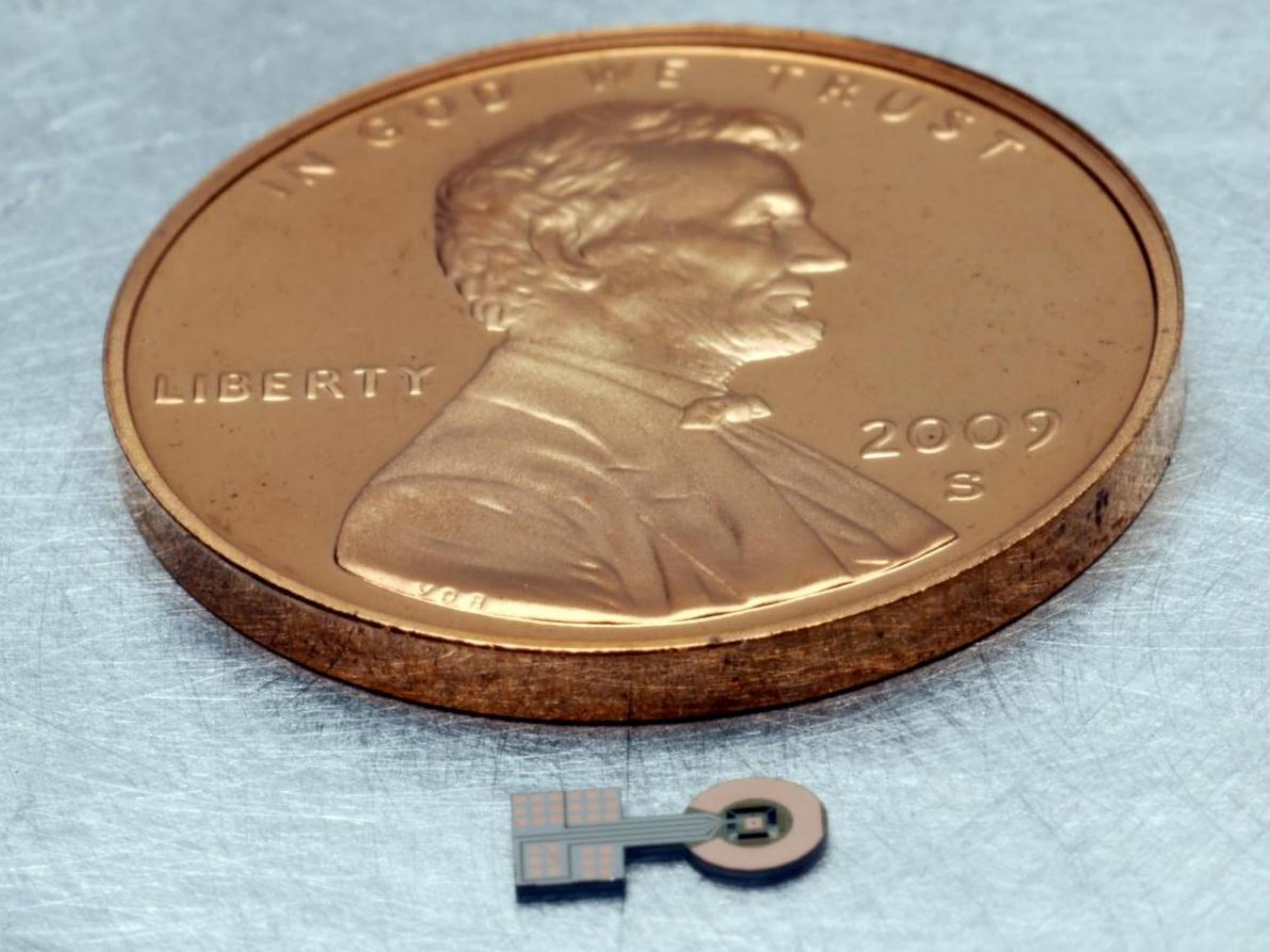
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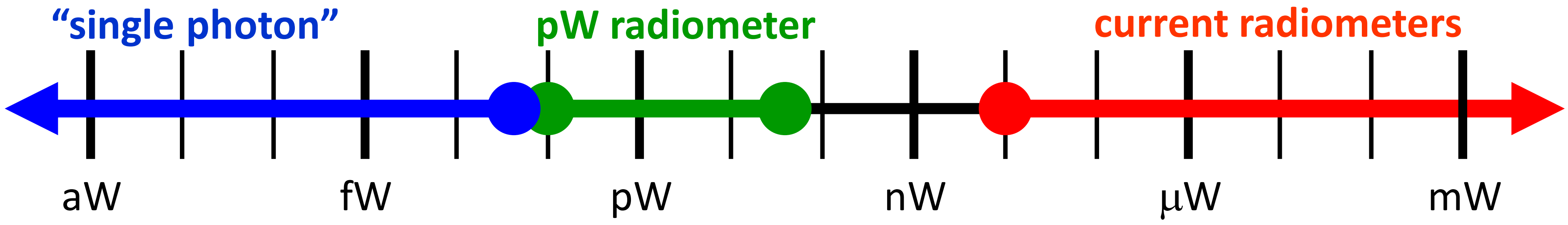
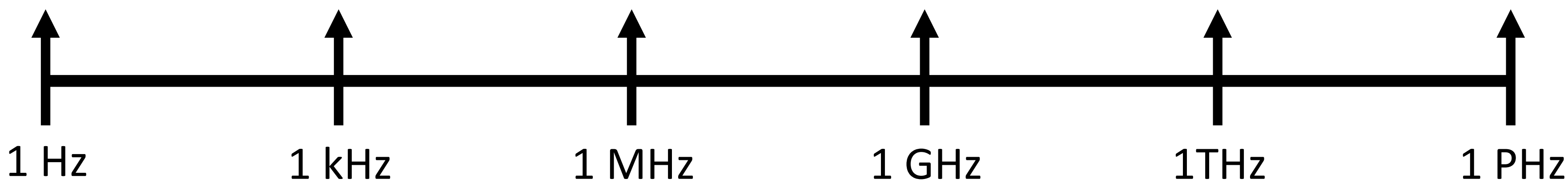
Single-photon power levels



Incoming optical power scale



Count rate (1550 nm photons)

See Alan Migdall’s talk after coffee break

- No calibrated single-photon source
- Commercially-available components from telecommunications industry.
- Calibrated power meter (dynamic range ≈ -50dBm – 0dBm) +/- 0.5%
- Programmable attenuators (x3), deliver femtowatt power levels