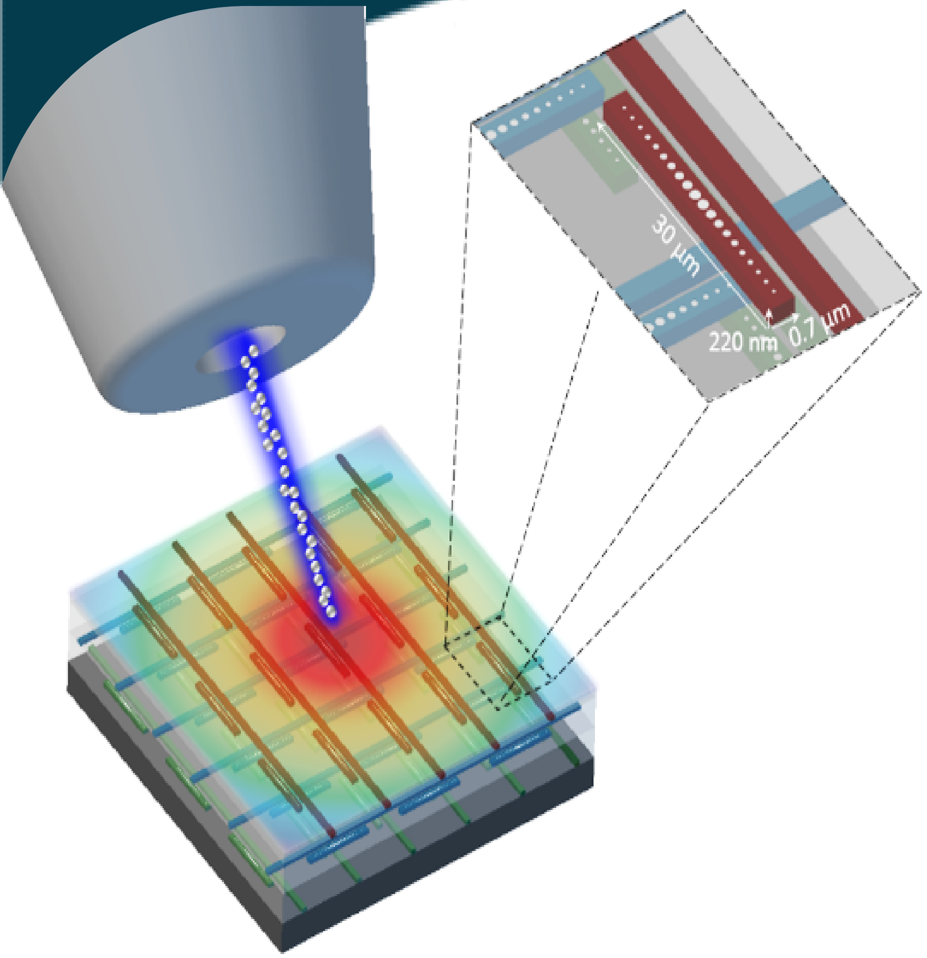


Future of Chip-Scaled Radiation Dosimetry

Council of Ionizing Radiation Measurements and Standards

April 17, 2018

Ileana M. Pazos, Ph.D.

Dosimetry Group, Radiation Physics Division

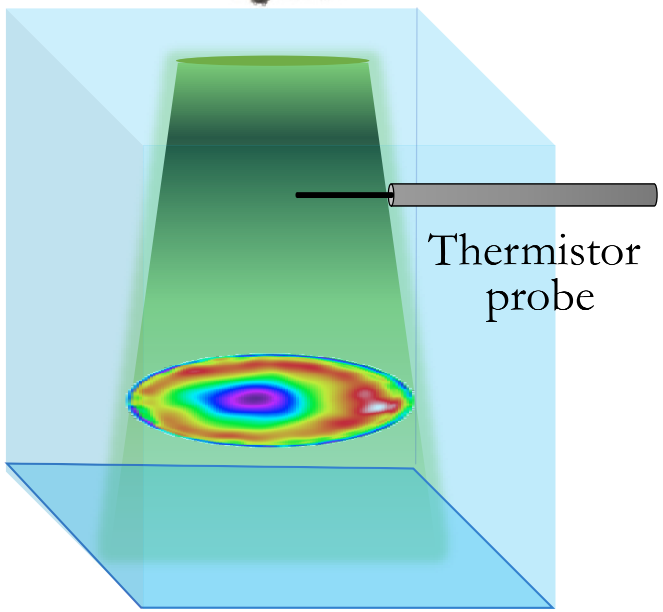
Physical Measurement Laboratory

National Institute of Standards and Technology

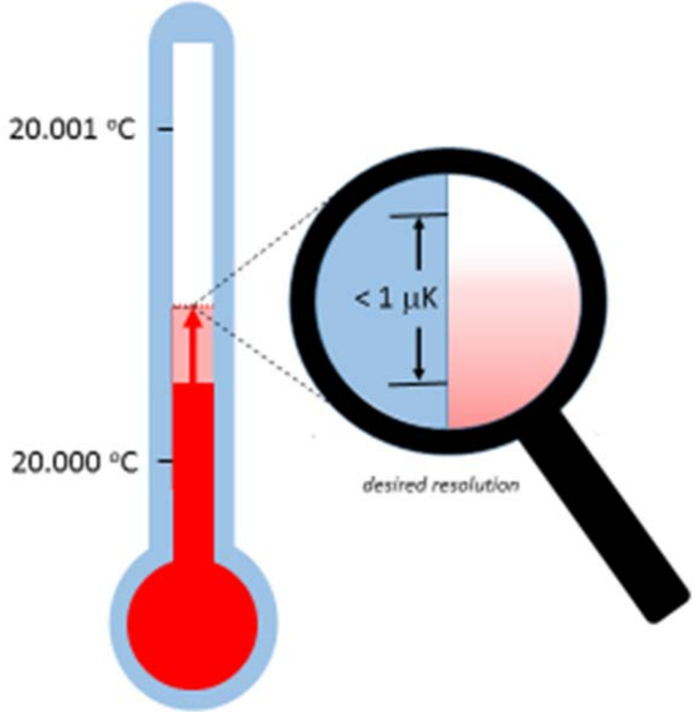
Macro-scale realization of the gray

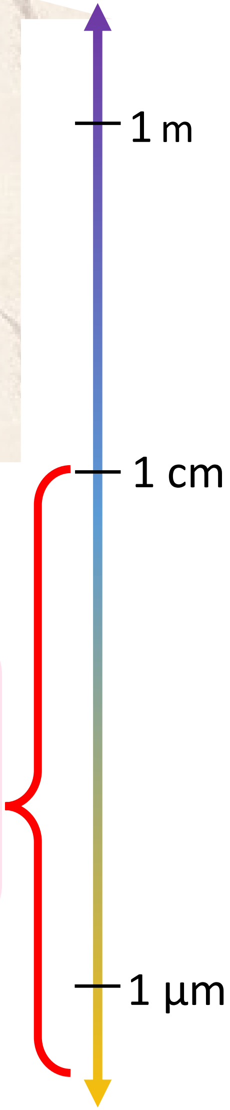
Only valid for fields uniform for >> the probe size

[Steady-state temperature rise
~0.239 mK per Gy (1 Gy = 1 J/kg)]



Ultrasonic image of temperature distribution in an irradiated water phantom (NIST 2012)



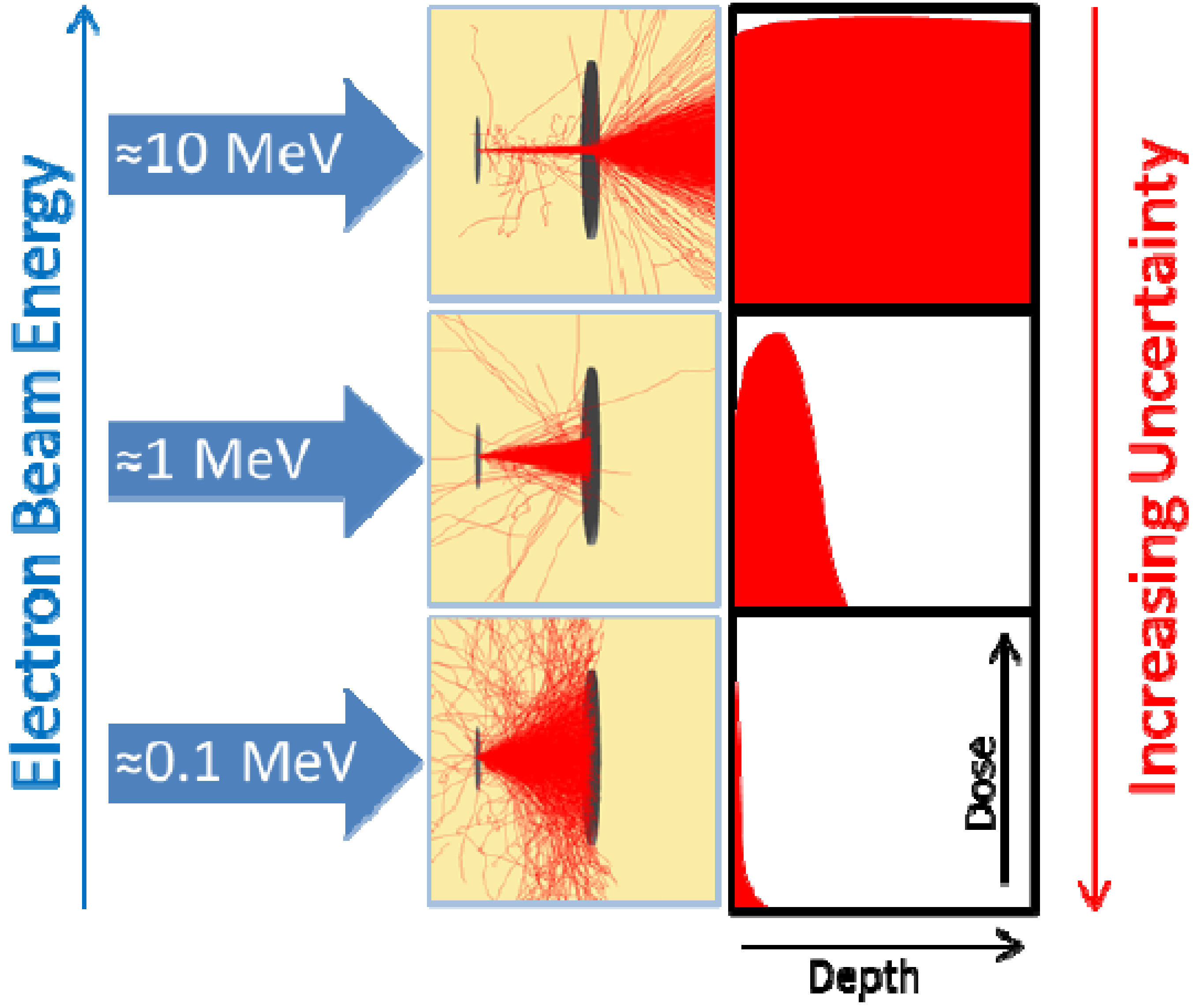


Direct traceability

?

Depth-dose distribution of electrons

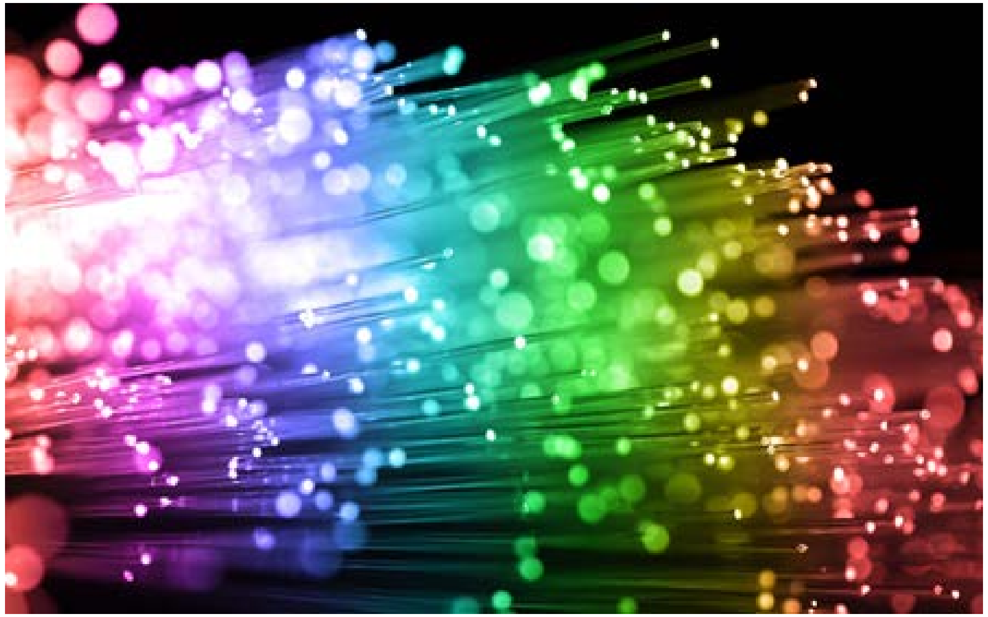
Monte Carlo simulations
of electron beams on
2 mm graphite wafer
Fred Bateman, NIST



Photonic sensors

NIST-on-a-Chip: Collaborative project on photonic dosimetry between **Radiation Physics** and **Sensor Science** Divisions

Telecom revolution made the underlying technology (lasers, detectors and fiber optics) easily available

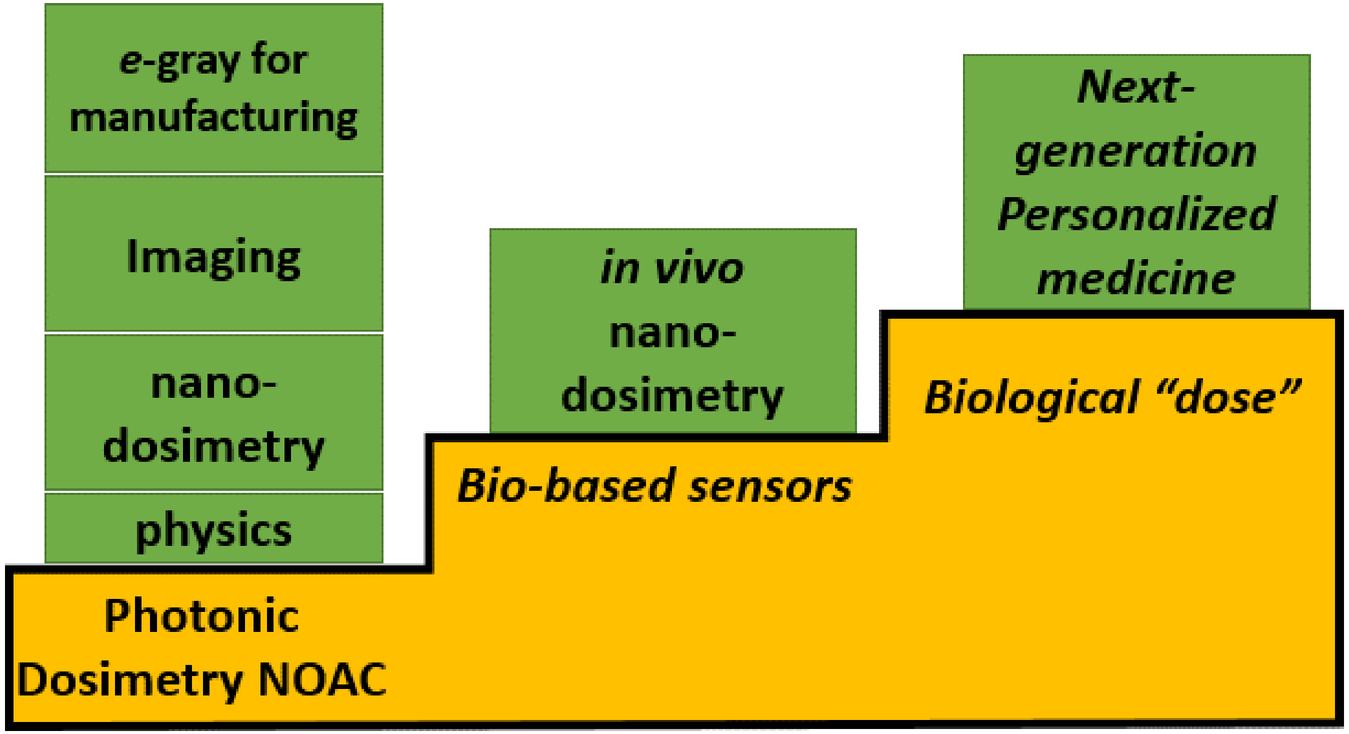


- Photonics is concerned with the generation, transmission, modulation and detection of light.

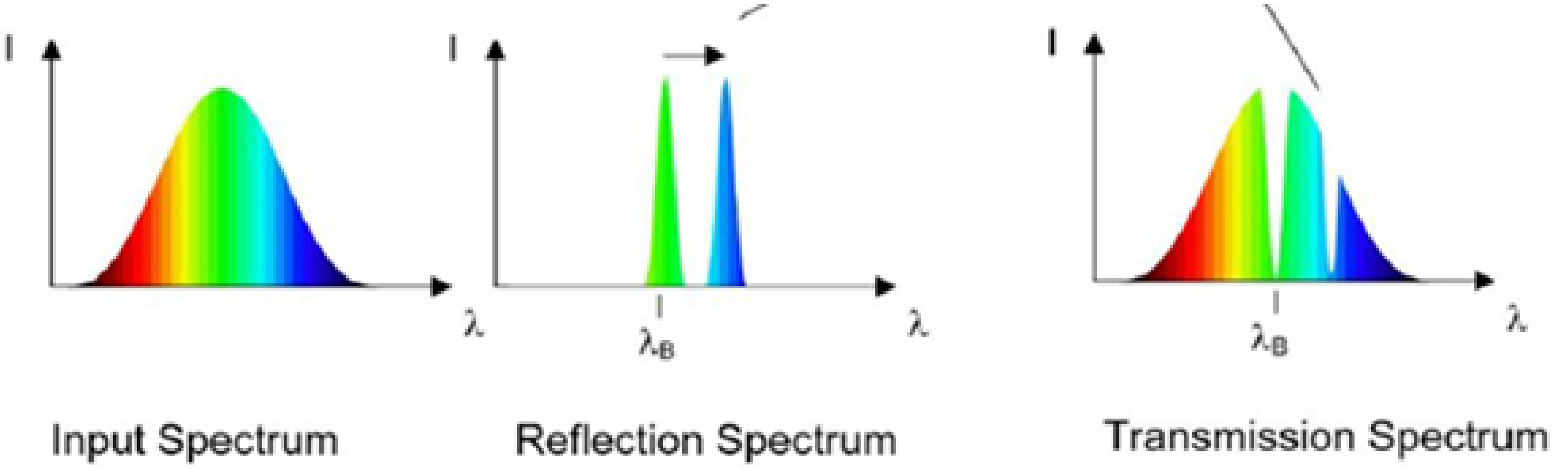
*Photonic sensors can be used to measure **strain**, **temperature** and **humidity** changes in concrete using sensors*

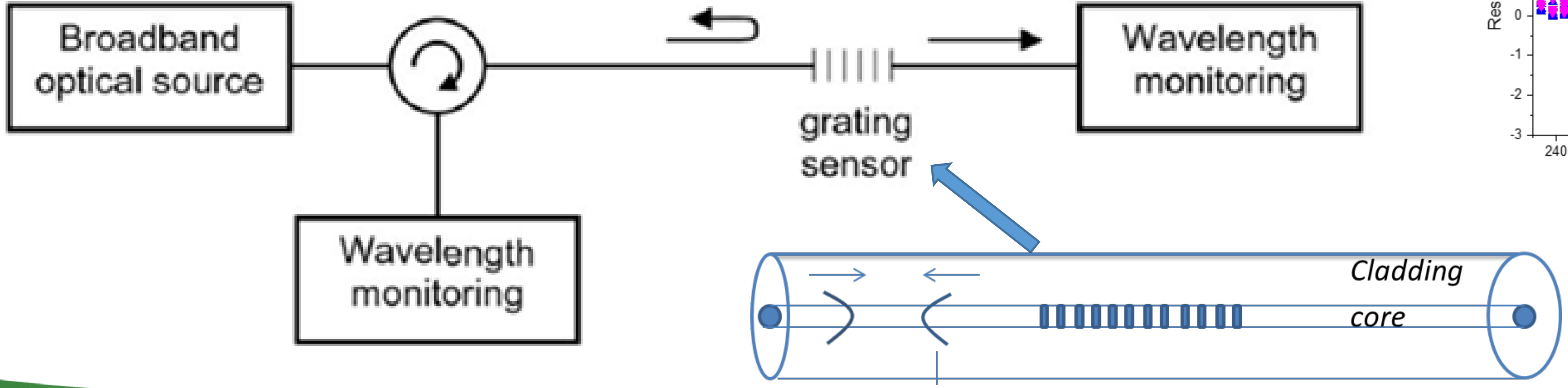
Photonics as radiation sensors

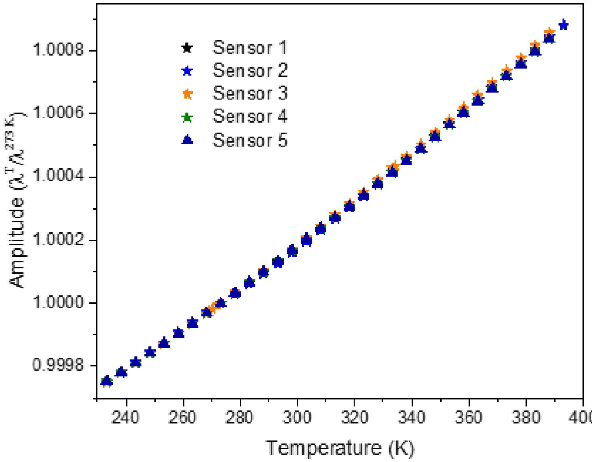
- Vastly extend NIST-traceable radiation dosimetry
  - 1000x improved spatial resolution
  - Ionizing radiation of different energies
  - Highly non-uniform radiation fields
- Developing a high-precision photonic nano-sensor platform
  - Thermal response can be used for calorimetry
  - Accumulated point defects can be used for dosimetry



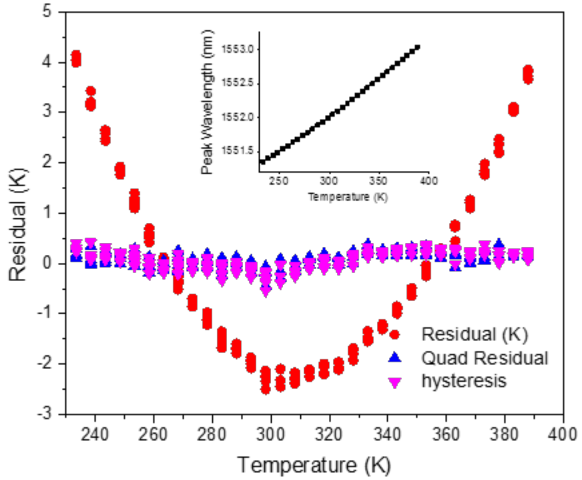
Fiber Bragg Gratings (FBG)







Sensitivity: 10 pm/K

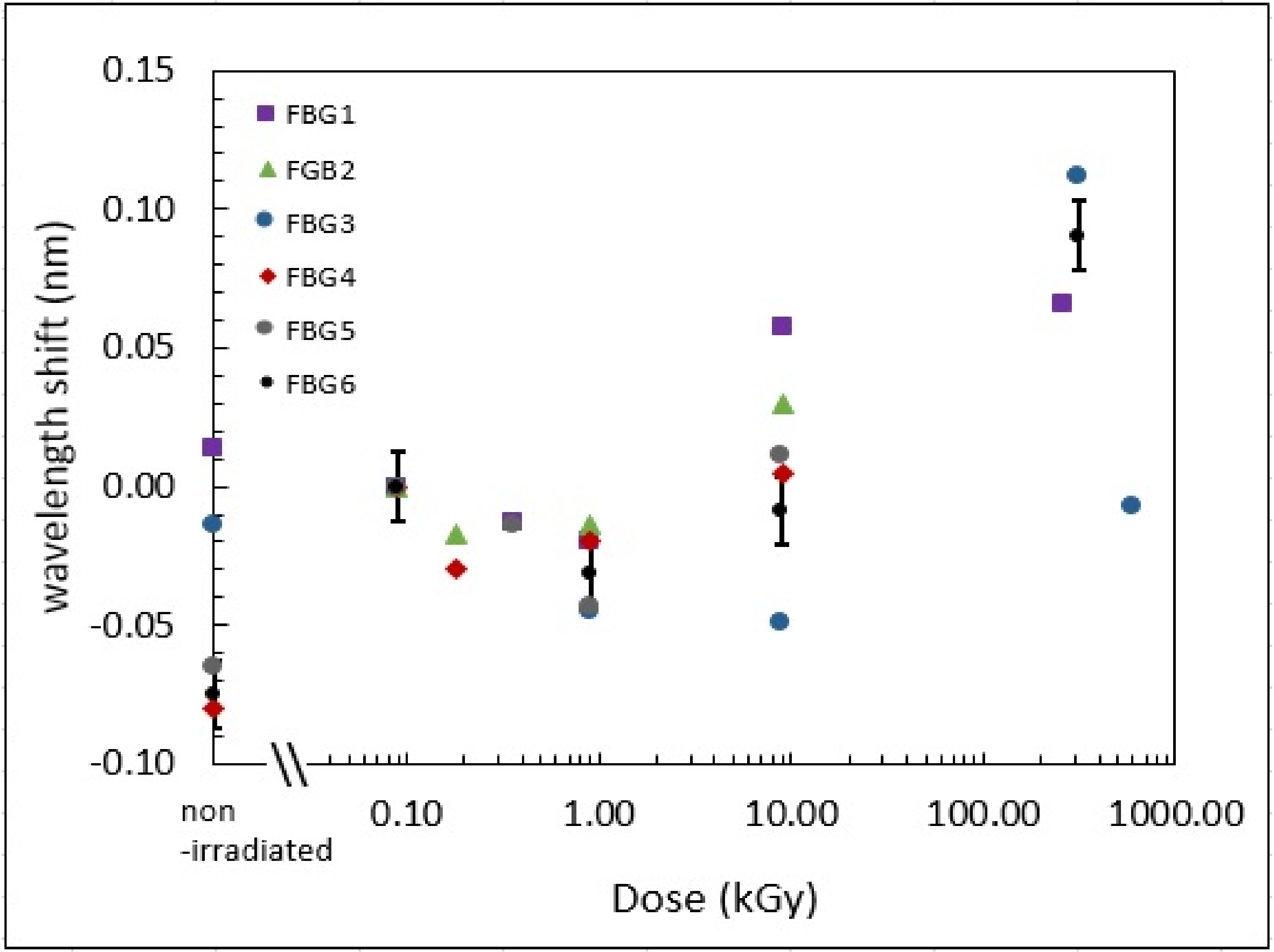


Uncertainty ≈ 500 mK

Radiation Hardness of Fiber Bragg Gratings

- The impact of the temperature response after γ-ray exposure on FBG:

- Exposures of up to 600 kGy result in complex dose-dependent drift in Bragg wavelength
  - Inflates the uncertainty in temperature measurements

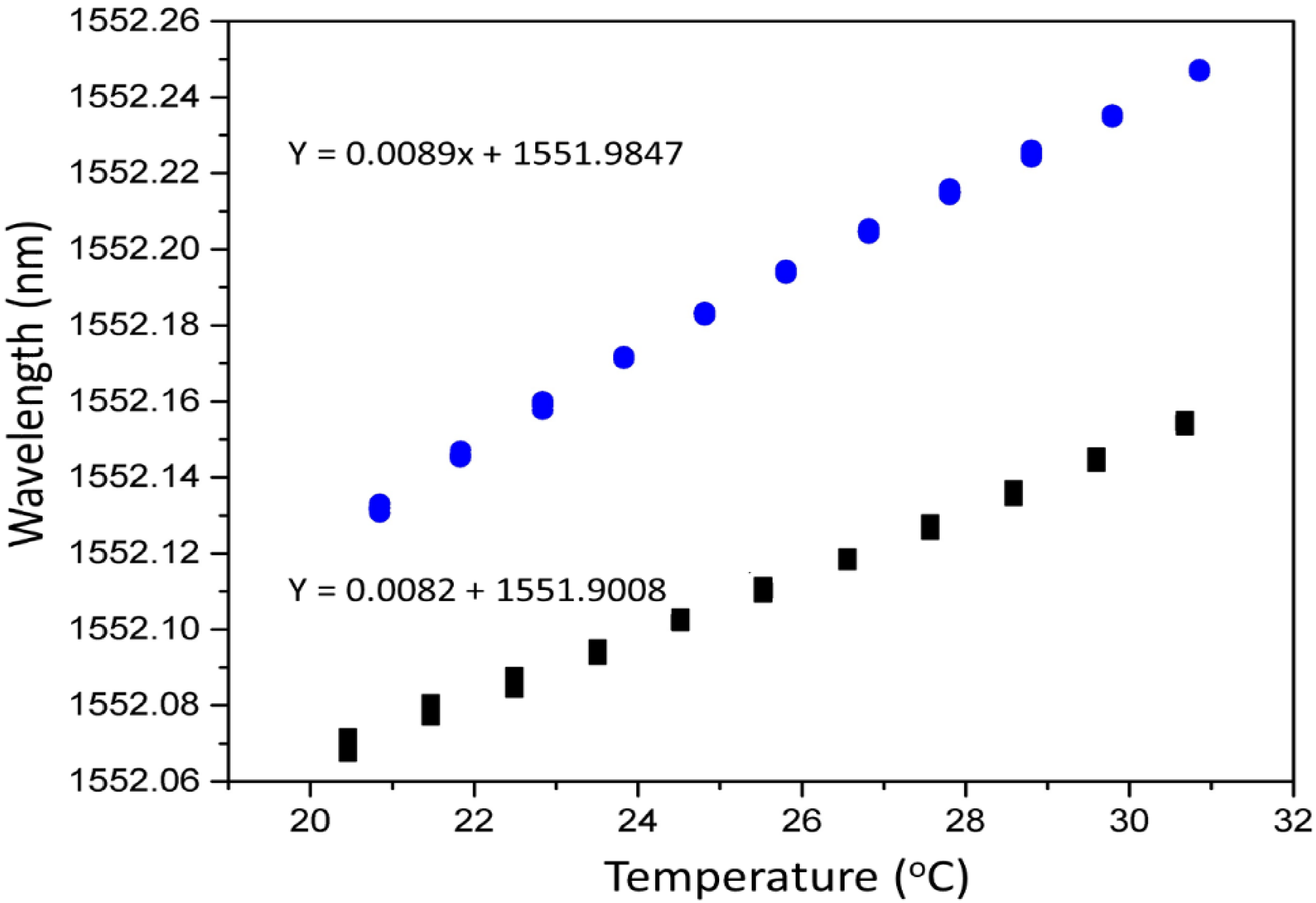


Manuscript submitted to NCSL International

Radiation Hardness of Fiber Bragg Gratings

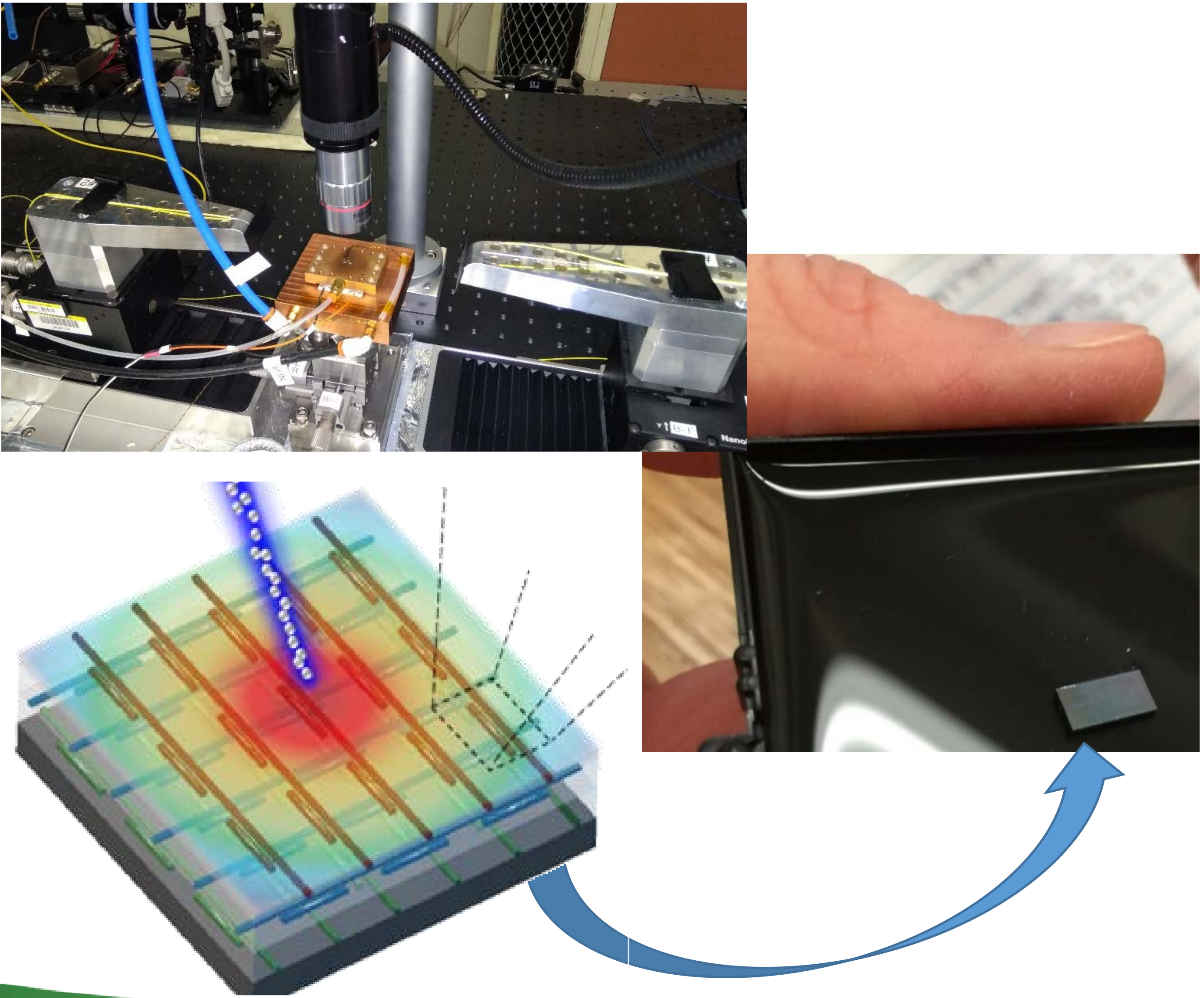
- The impact of the temperature response after γ-ray exposure on FBG:

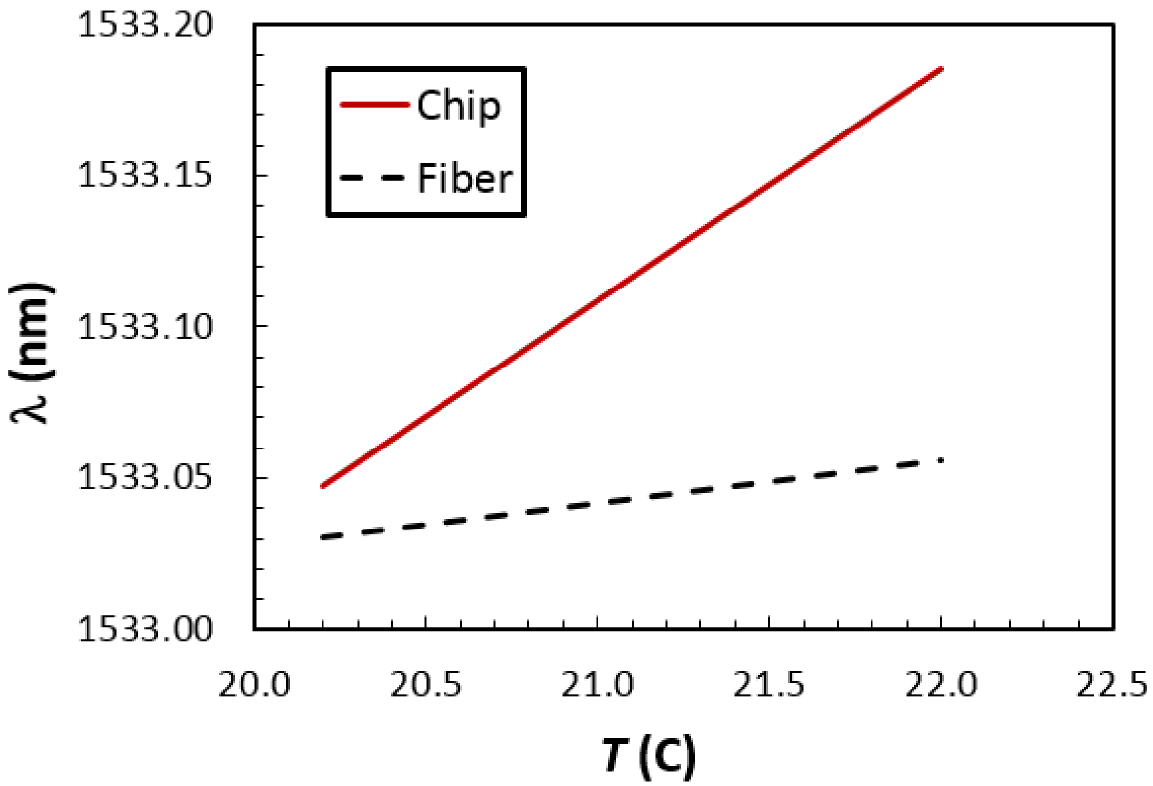
- The temperature sensitivity is not impacted by the integrated dose
  - Suggests devices could be used to measure relative changes in temperature
- 11 pm/K



Manuscript submitted to NCSL International

Chip-based photonic thermometry





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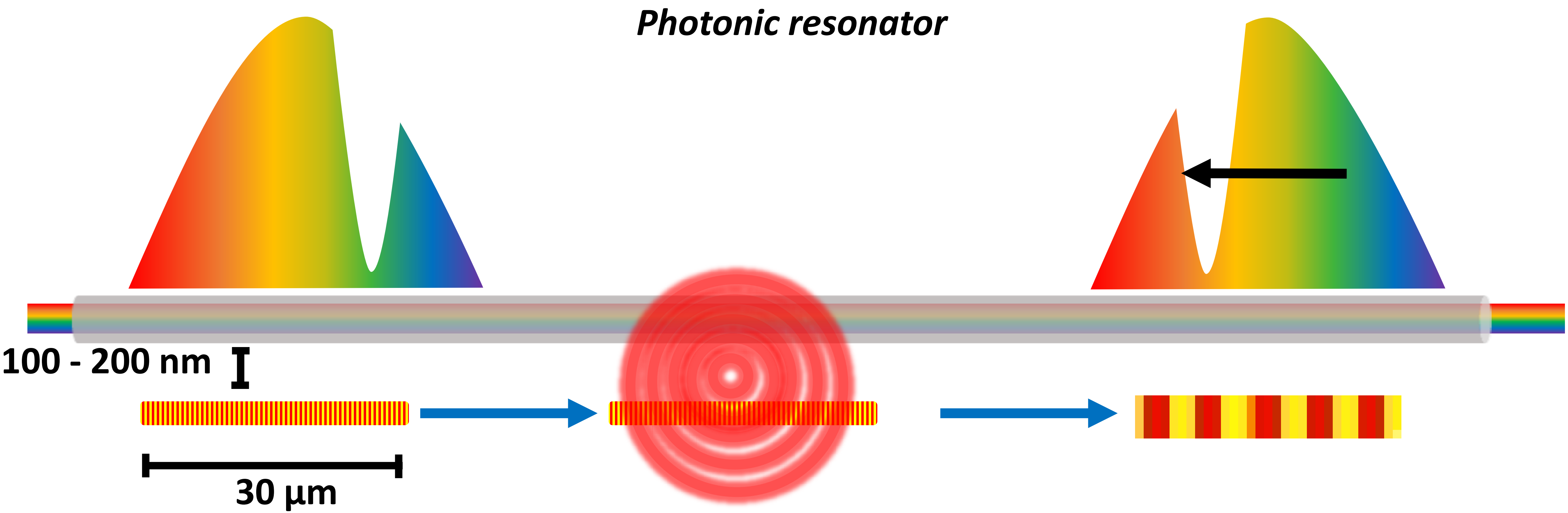
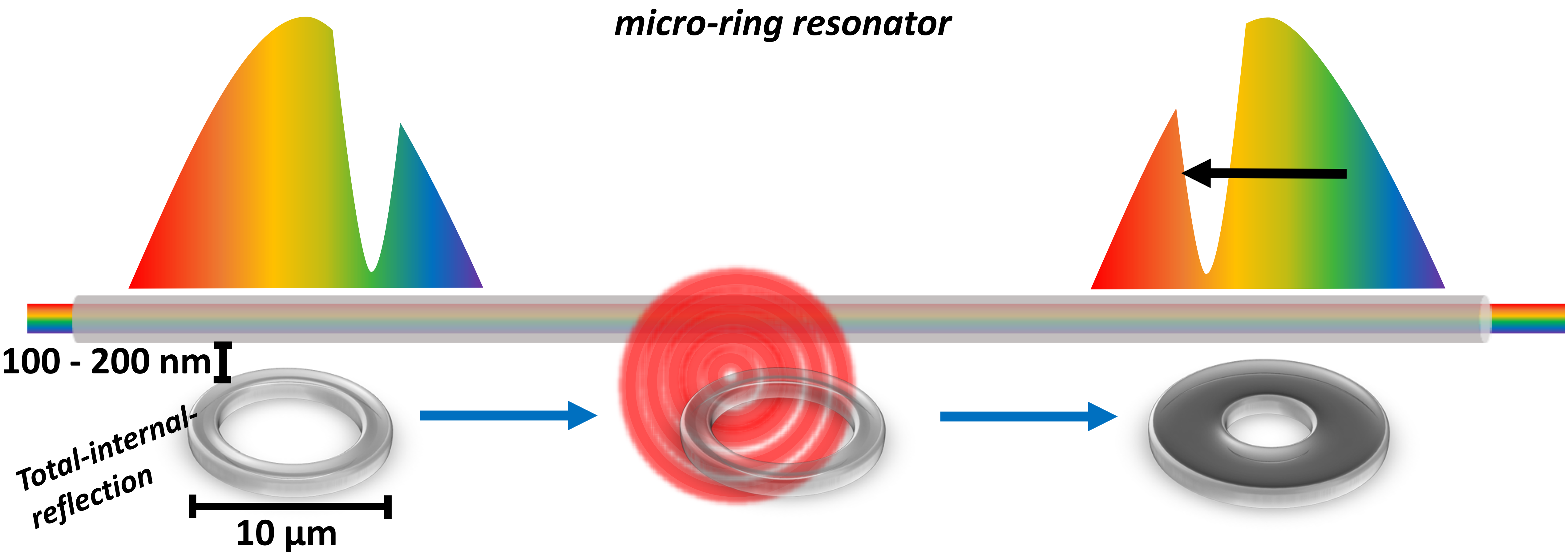
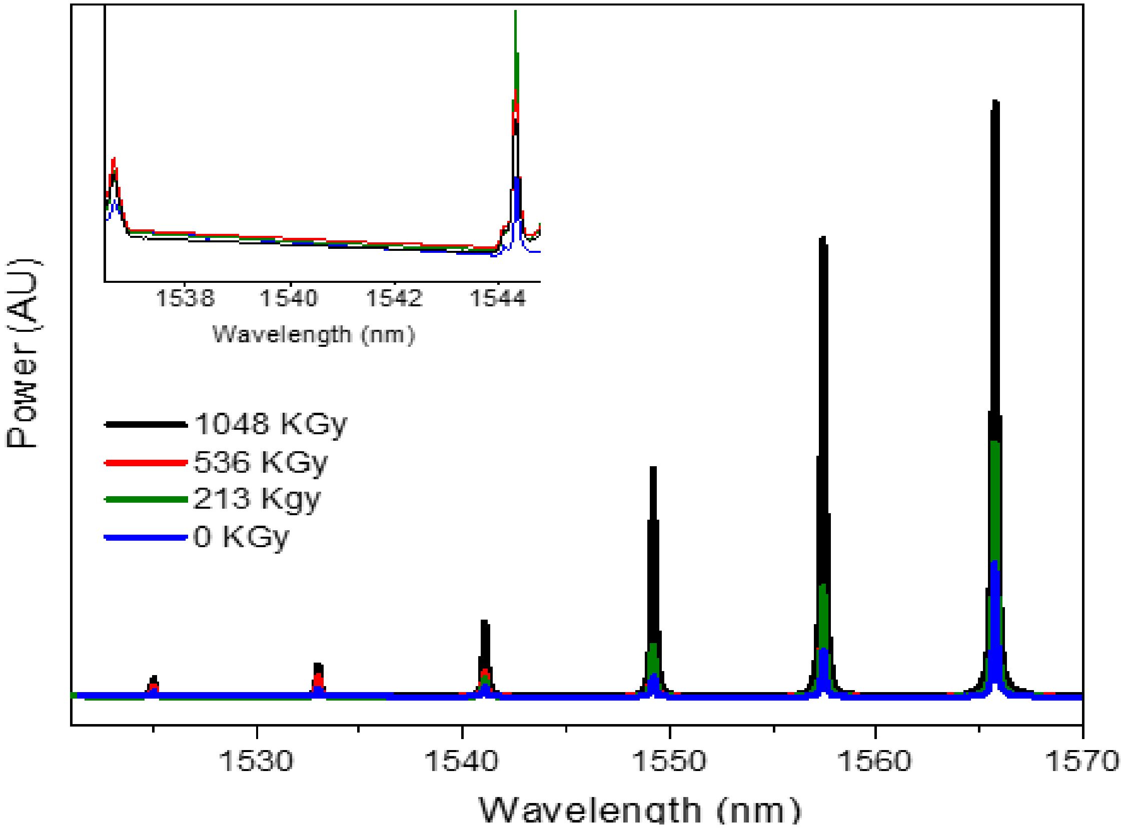


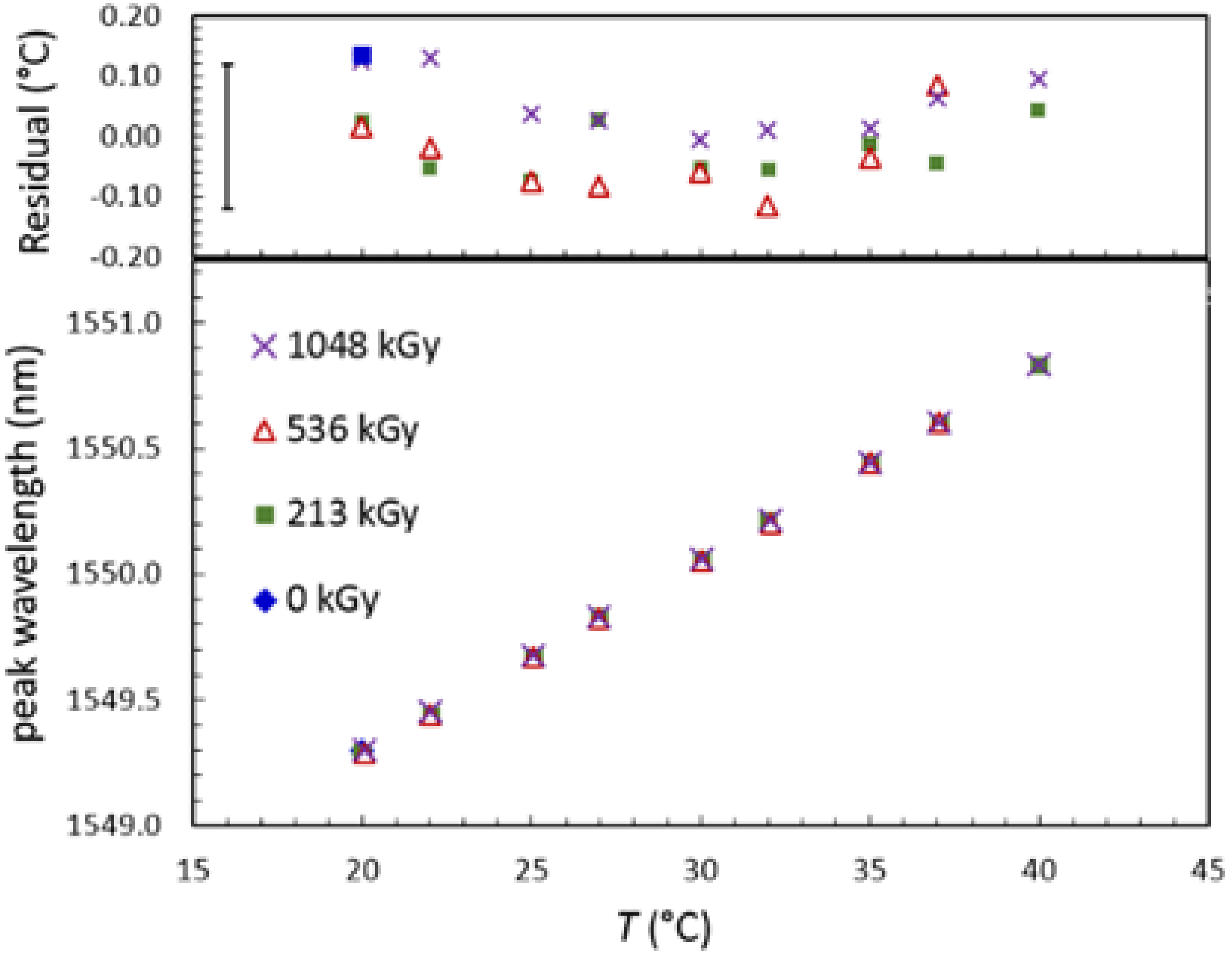
Chip-based photonic thermometry



Assessing Radiation Hardness of Photonic Sensors

No systematic impact of radiation (up to 1 MGy dose) were found on passivated silicon chip devices, indicating the extreme durability under harsh conditions.





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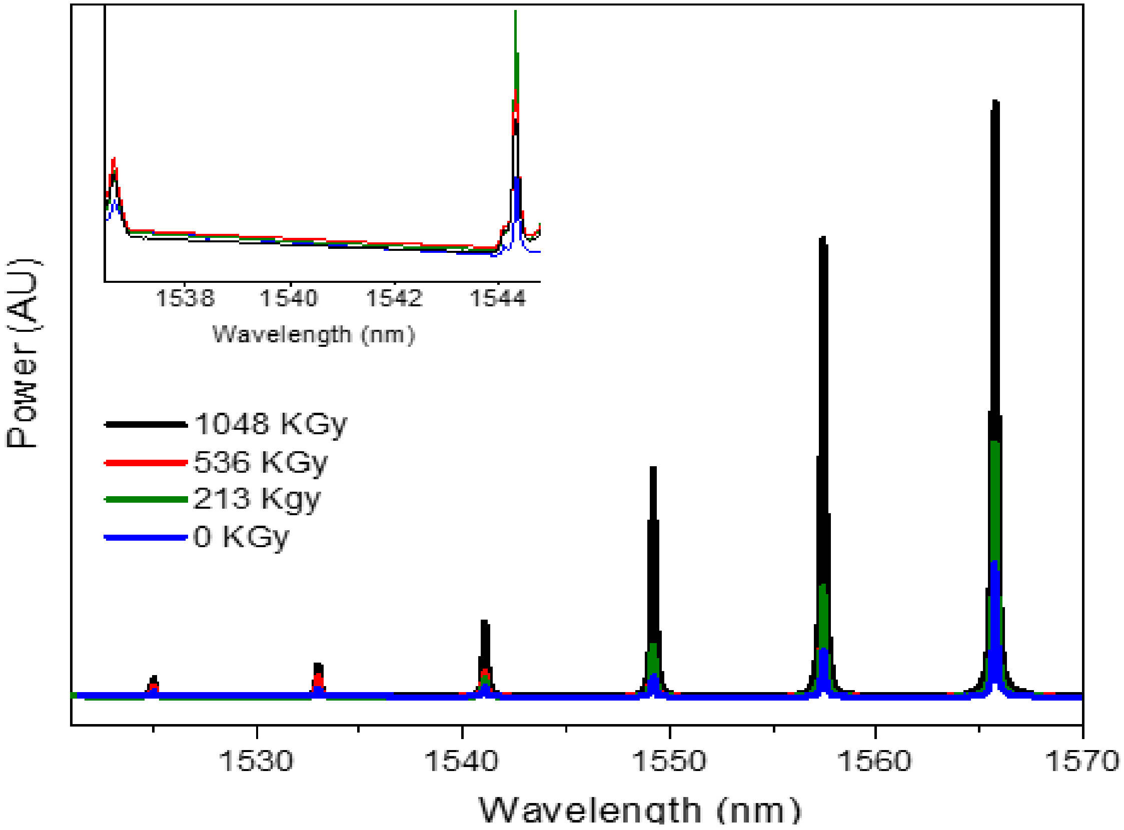

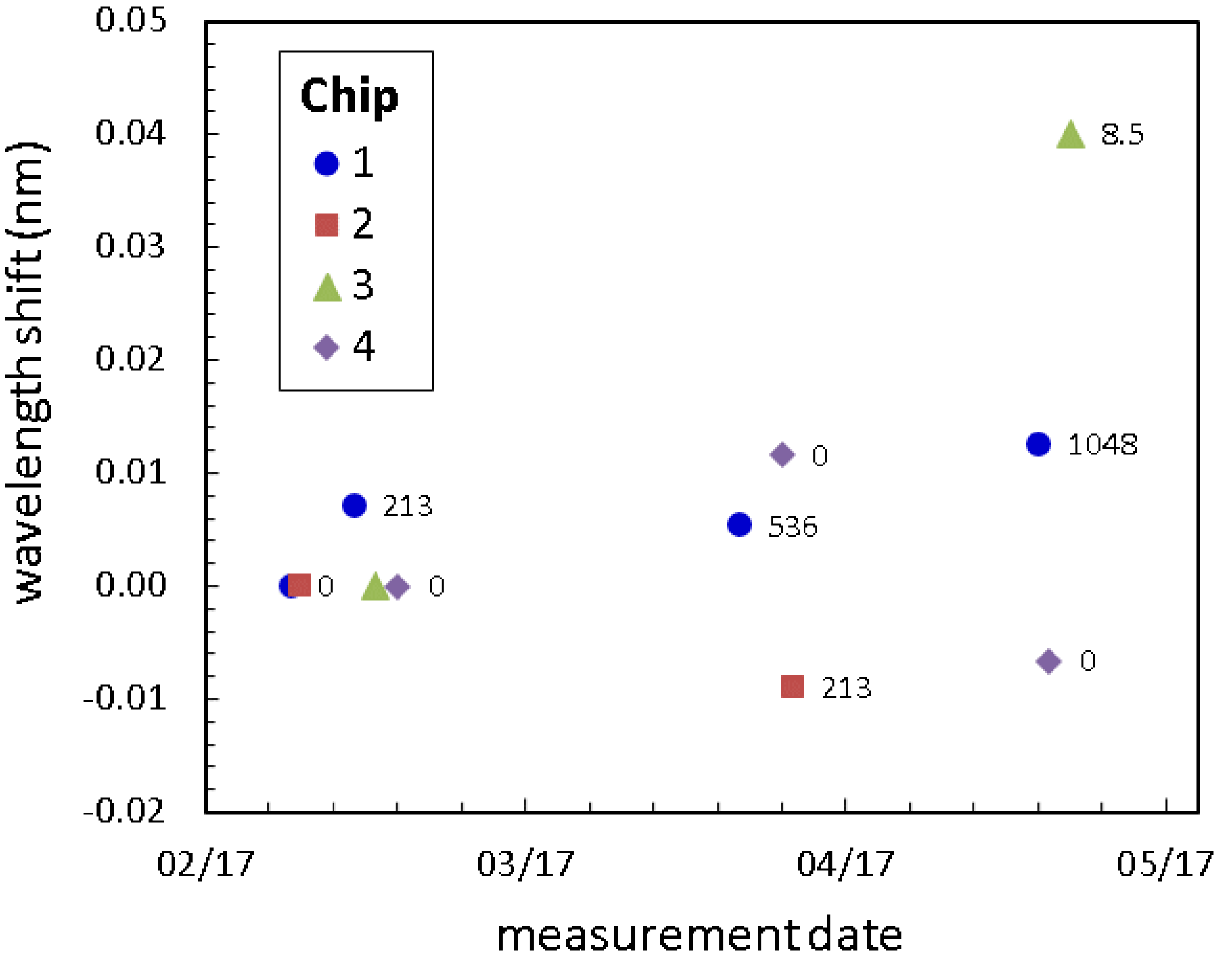

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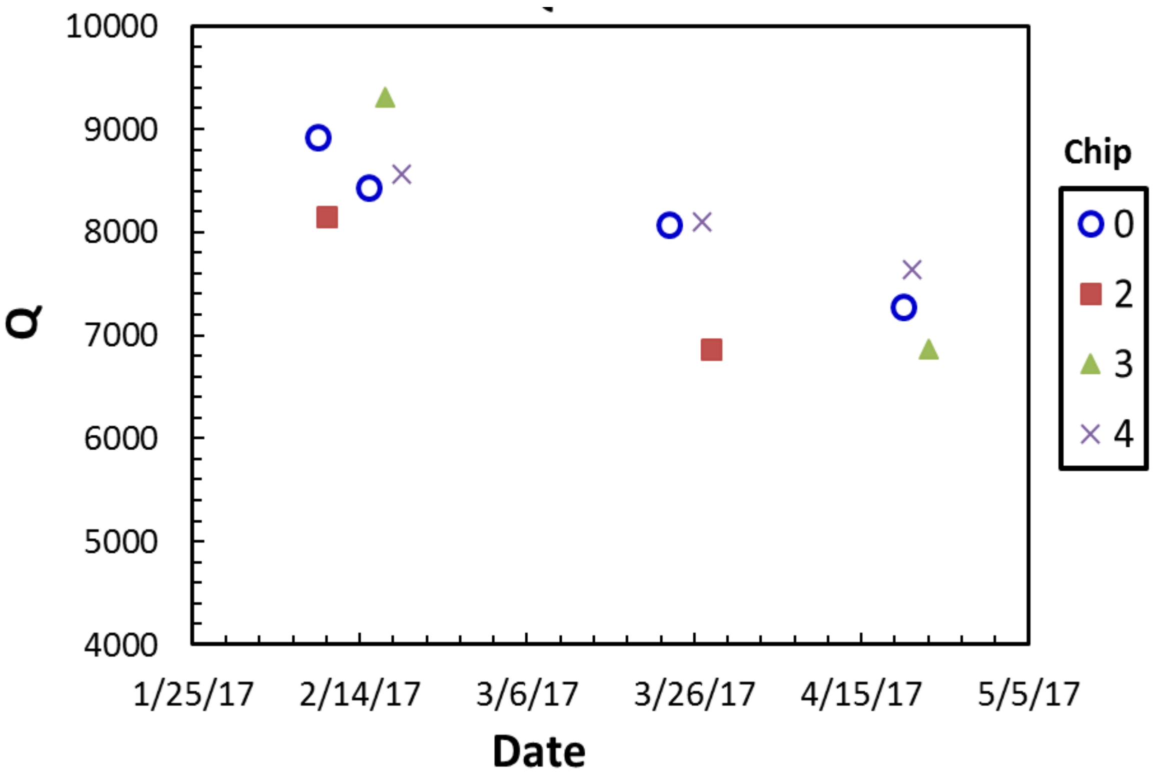
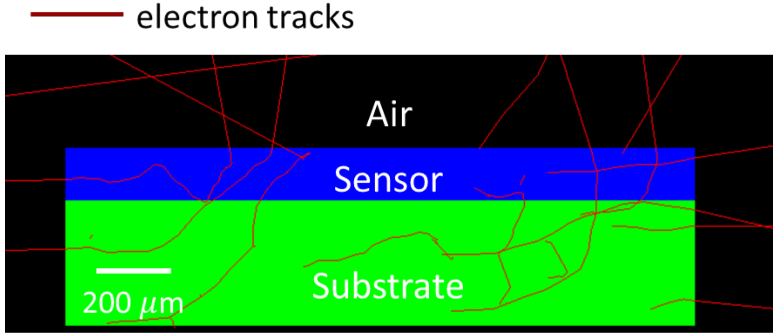
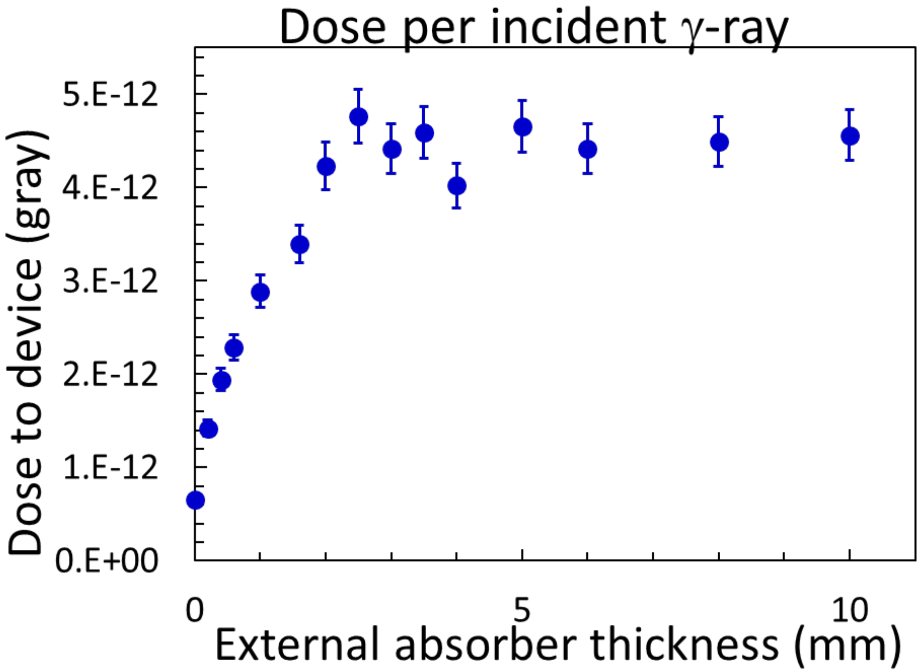
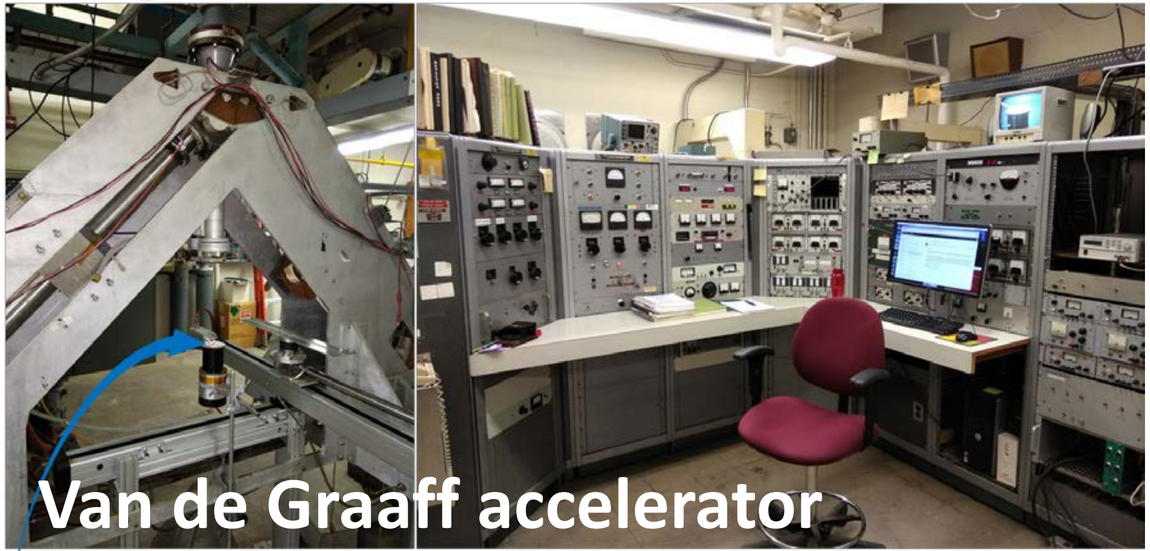






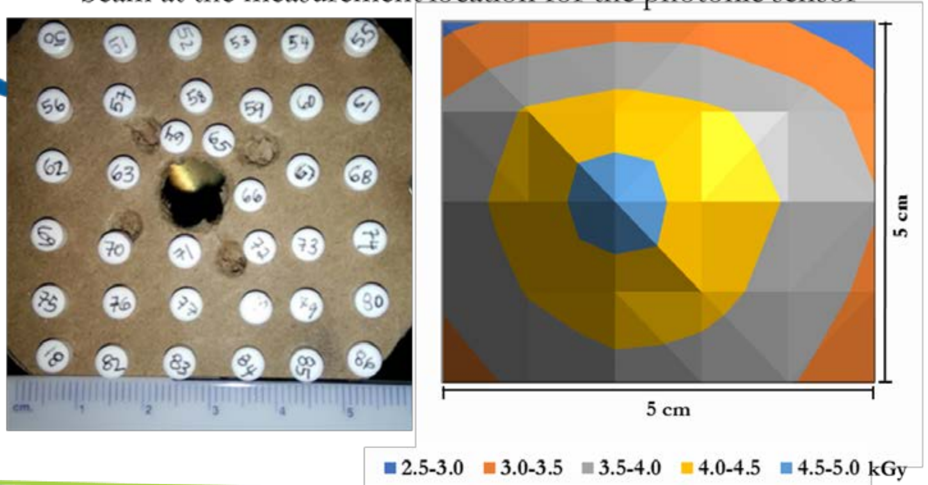
Manuscript submitted to Scientific Reports

Live calorimetry testing of photonic sensors

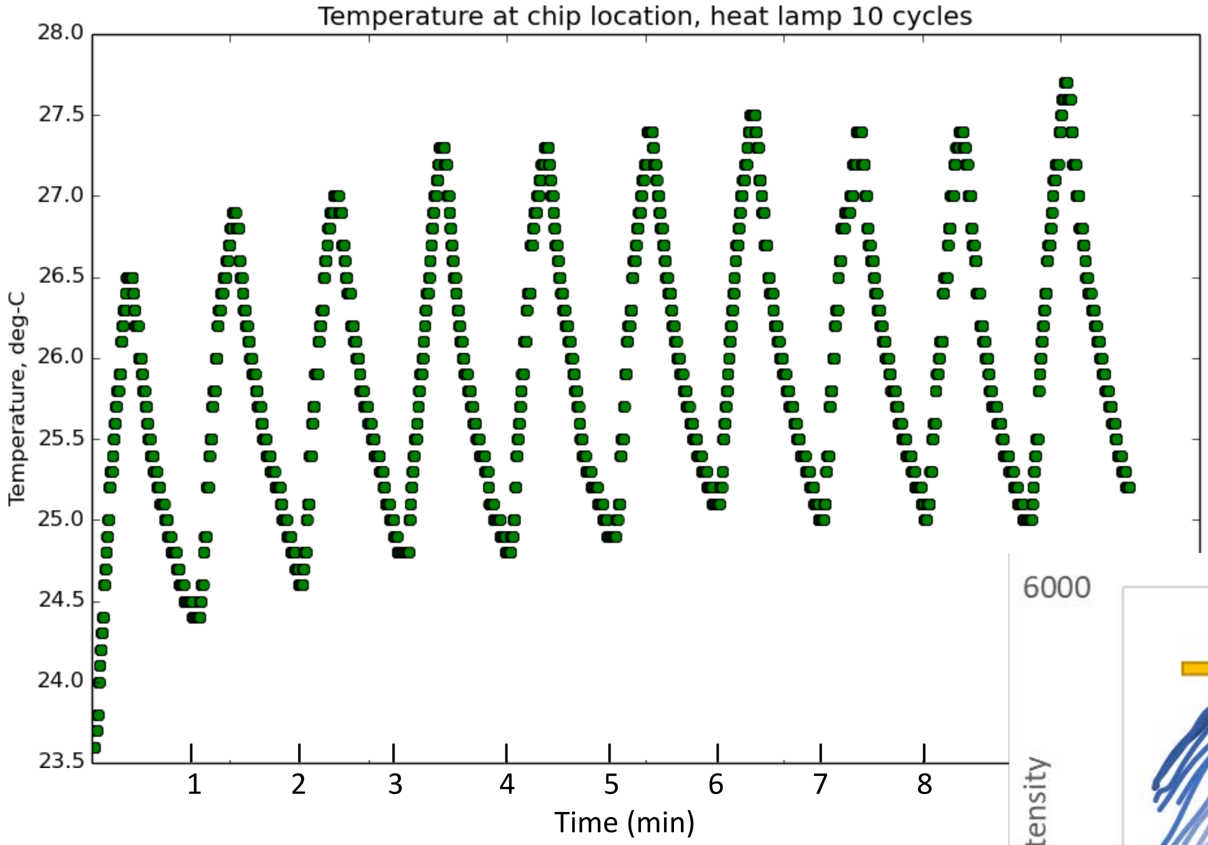


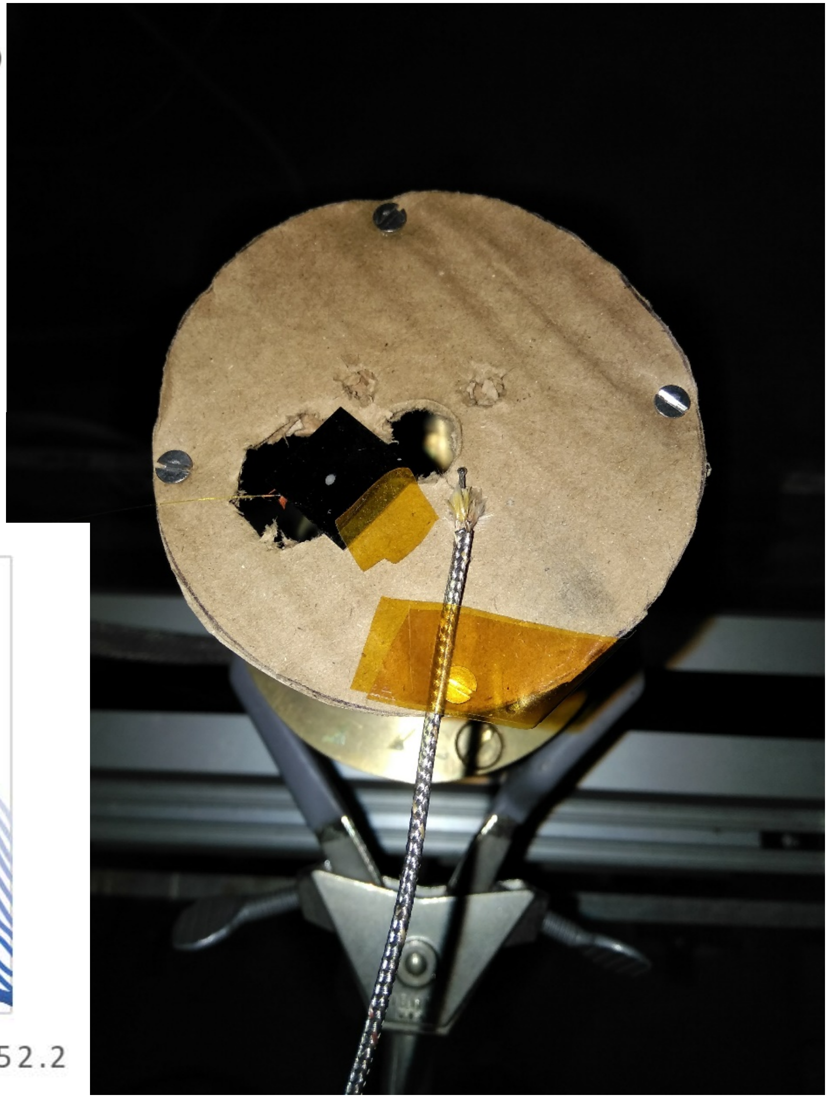
Alanine dosimetry

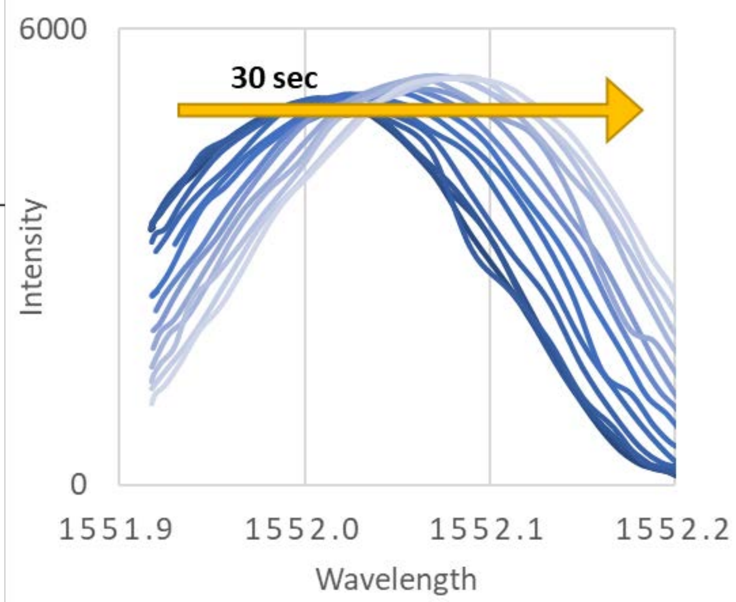
Dose calibration and lateral profile of a 1.8 MeV electron beam at the measurement location for the photonic sensor



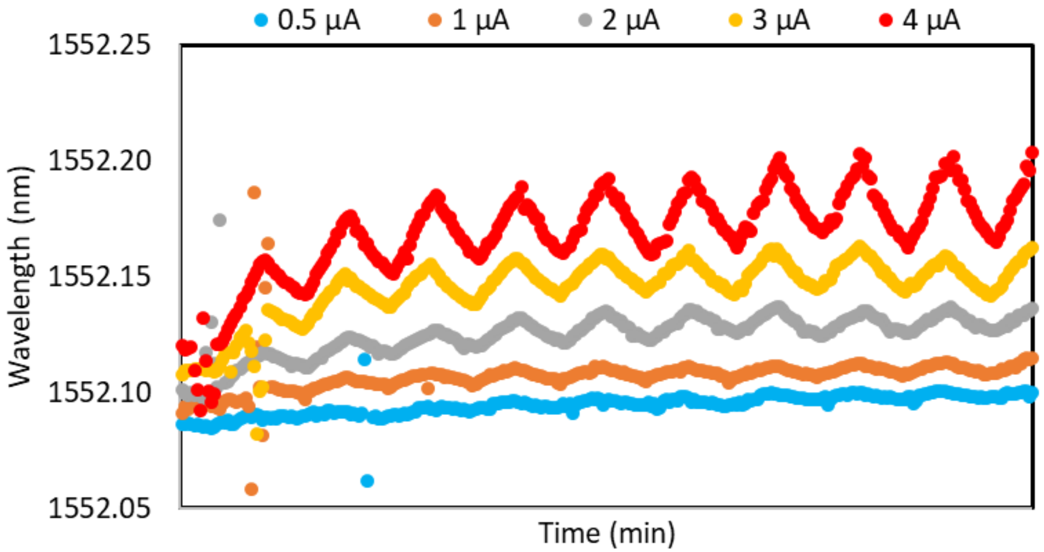
Live calorimetry testing of fiber Bragg grating

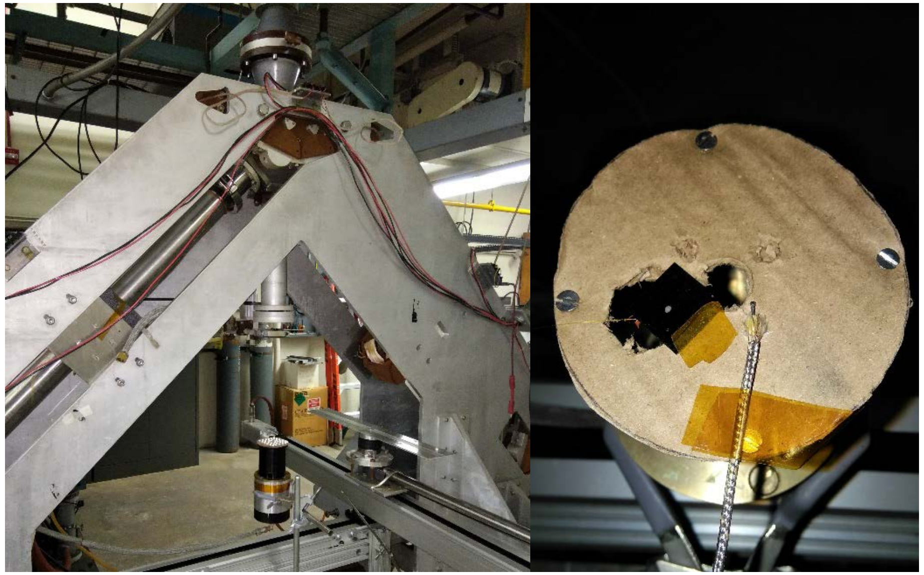




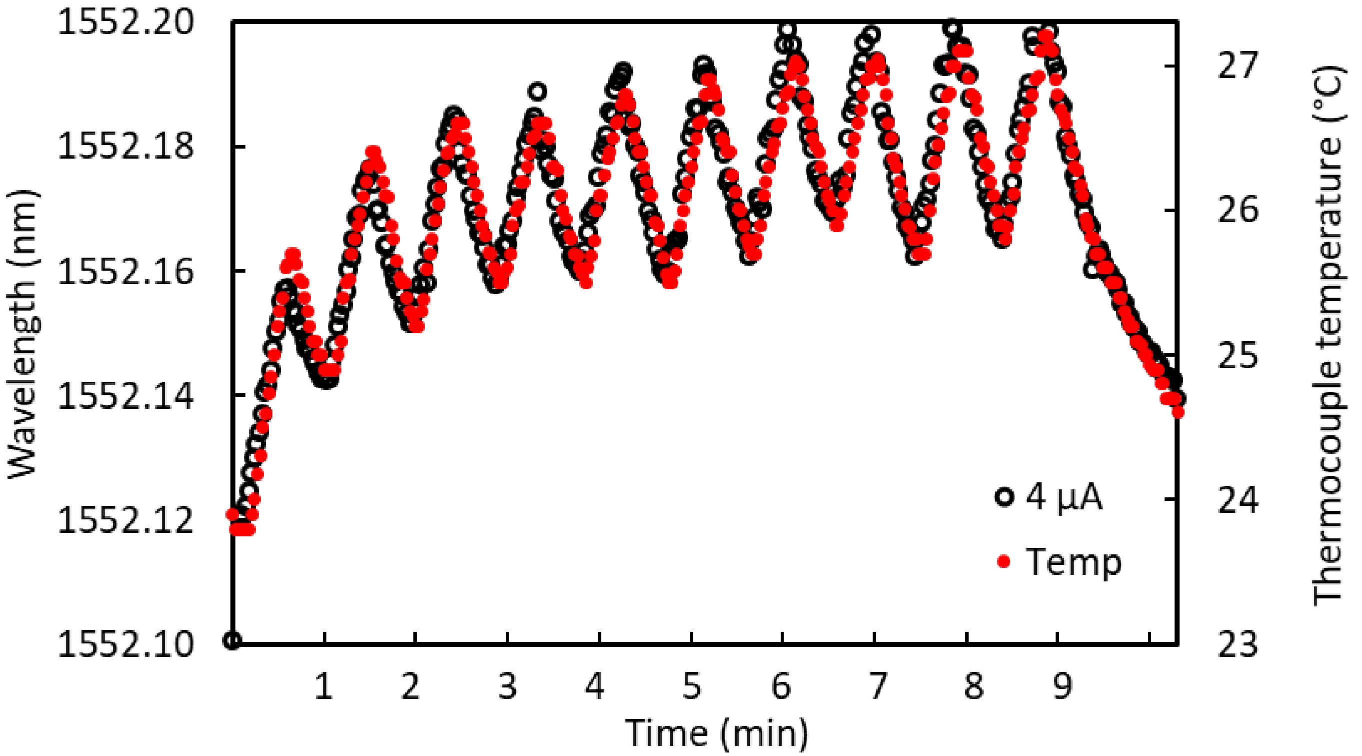


Live calorimetry testing of fiber Bragg grating

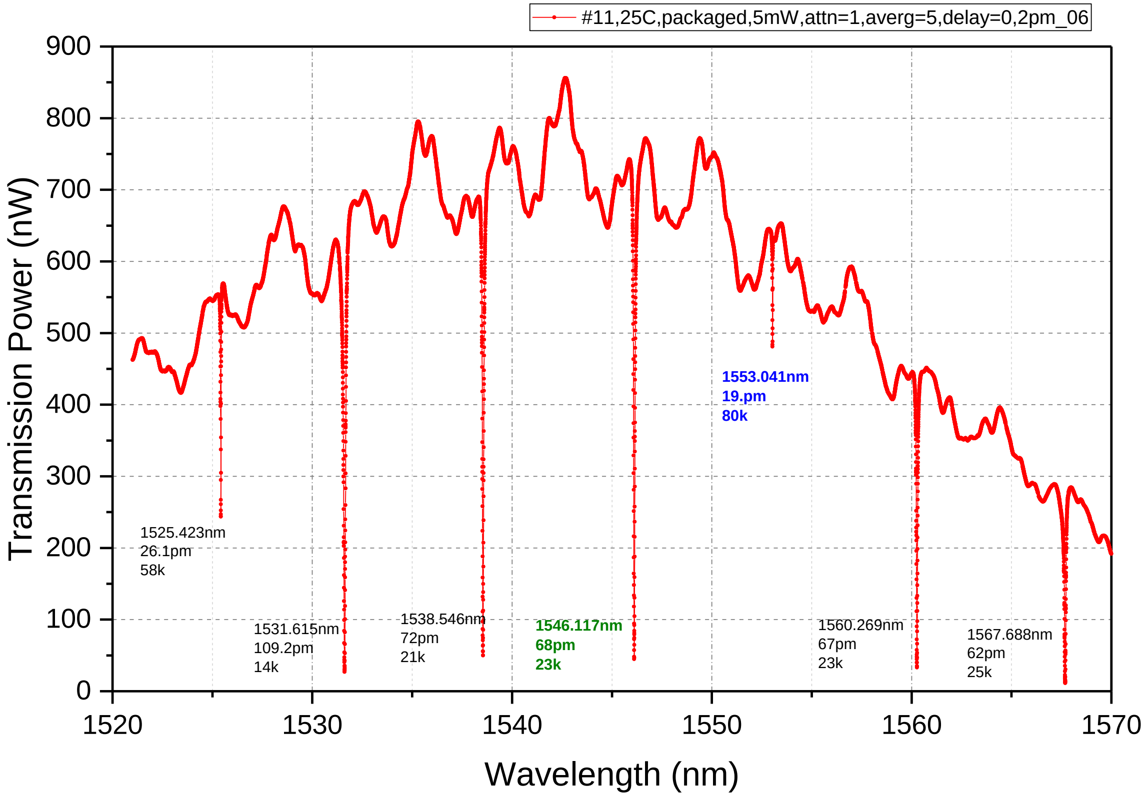


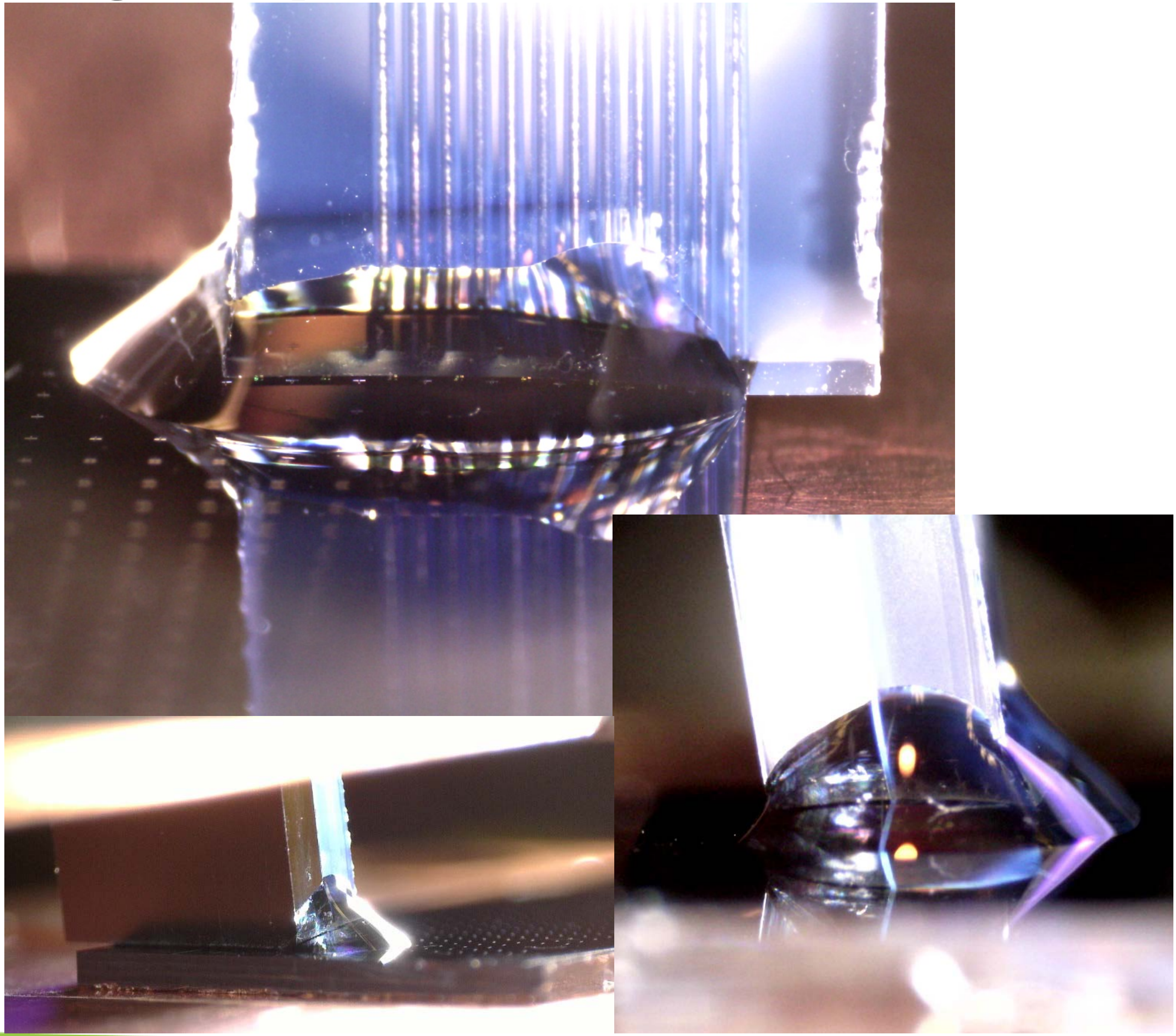


~ 10 pm / ˚C

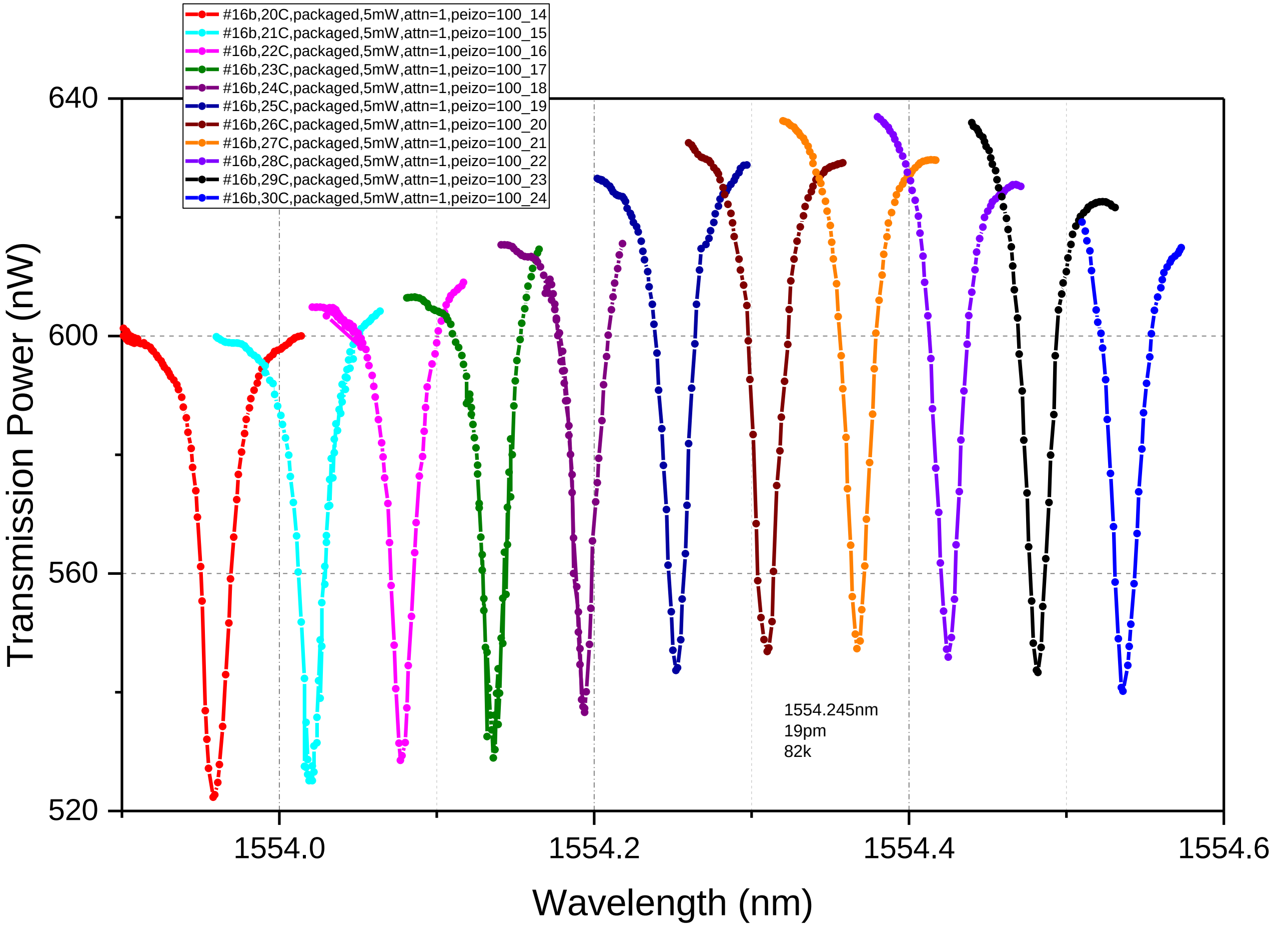


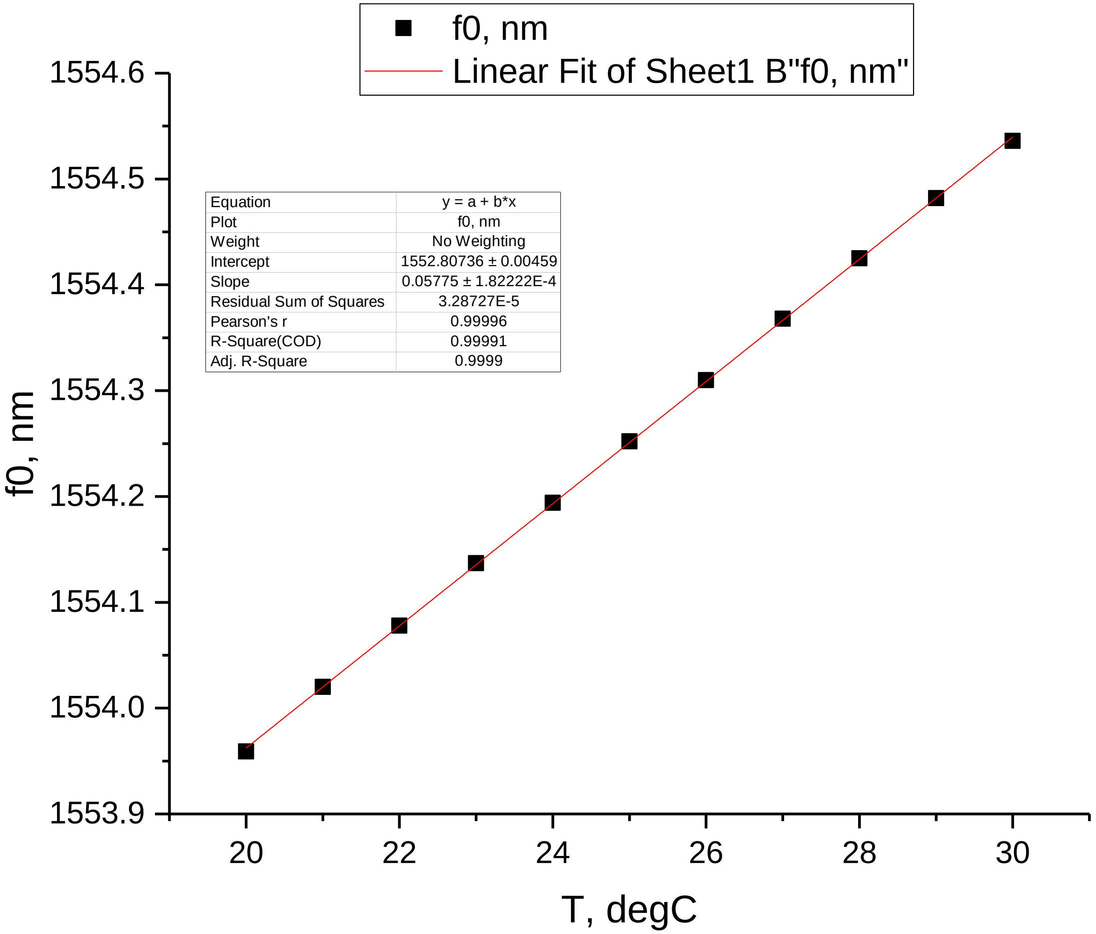
Live calorimetry testing of photonic sensors





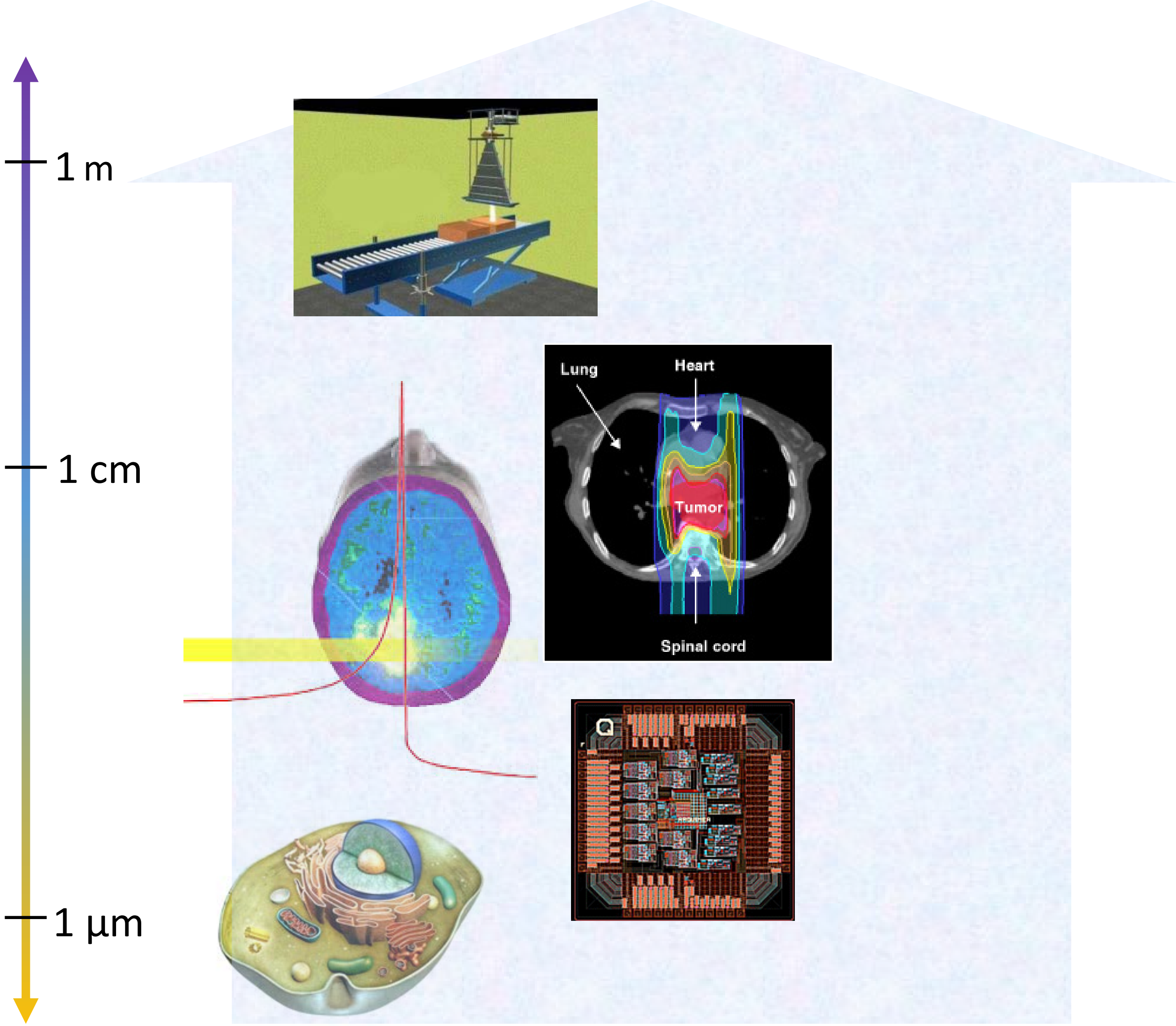
Live calorimetry testing of photonic sensors





Equation	y = a + b*x
Plot	f0, nm
Weight	No Weighting
Intercept	1552.80736 ± 0.00459
Slope	0.05775 ± 1.82222E-4
Residual Sum of Squares	3.28727E-5
Pearson's r	0.99996
R-Square(COD)	0.99991
Adj. R-Square	0.9999

Goal: Micro-Scale Calorimetry



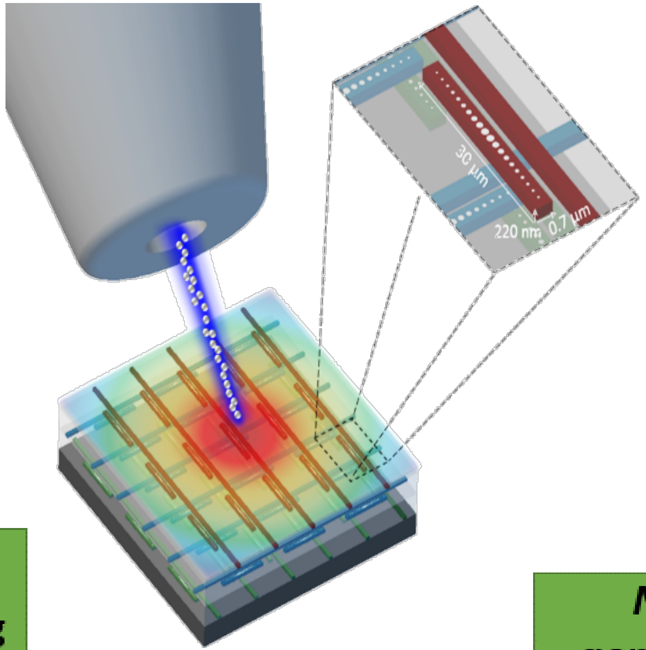
- **Photonic thermometer embedded in a radiation-resistant substrate**
- **Calibration in electron beams at all energies used in industry**
- **Field-deployable chip-scale dosimeters**
- microbeam therapy
- microelectronics
- cellular dosimetry

Challenges: micro-scale calorimetry

☑ Radiation resistance of sensors
  - Nanofab controls material doping

☑ All materials are radiation resistant
  - Calorimetry and integrated dose
  - Reproducible damage could act as a dosimeter

- Temperature to dose
  - Monte Carlo modeling and scaling
- Multiplexing
  - Independently measure temperature from 1000s of sensors in a large array



e-gray for manufacturing

Imaging

nano-dosimetry

physics

Photonic Dosimetry NOAC

in vivo nano-dosimetry

Bio-based sensors

Next-generation Personalized medicine

Biological "dose"

Acknowledgements

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Dr. Ron Tosh

Sensor Science Division

Dr. Zeeshan Ahmed

Dr. Nikolai Klimov

Dr. Kevin O Douglass

NIST on a Chip Program