Fiber-optic Sensor System for Multipoint Pressure and Temperature Measurement

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar
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Key Personnel: Ming Han, Ph. D.
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Program Manager: Daniel Nichols, Ph. D.
Department of Energy

Project goal and technology

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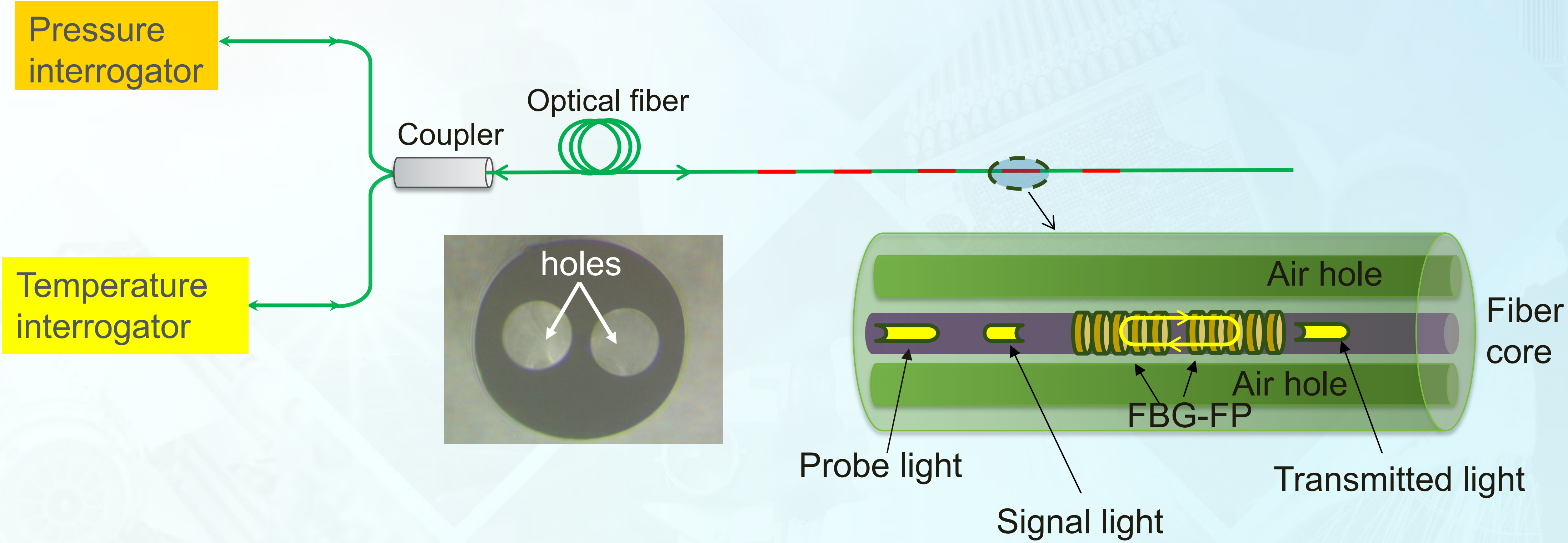
Goal: develop a quasi-distributed fiber-optic sensor system for multipoint pressure and temperature measurement for nuclear power plants.



Project schedule and Participants

Project Schedule		1 J	2 A	3 S	4 O	5 N	6 D	7 J	8 F	9 M	10 A	11 M	12 J
T1	Design and obtain side-hole fibers												
T2	Fabricate FBG-FP sensors on side-hole fibers												
T3	Construct sensor interrogator and perform laboratory test												
T4	Study an in-situ pressure sensor calibration method												
T5	Perform radiation testing on sensors												
T6	Prepare Phase II proposal and write final technical report												

Participants:

- PI: Dr. Qiwen Sheng (Senior Research Scientist)
- Research Scientist: Dr. Hasanur R. Chowdhury
- Key Personnel: Dr. Ming Han (Founder/President of Nusenics and Professor at MSU)

P/T Sensors for Nuclear Power Plants

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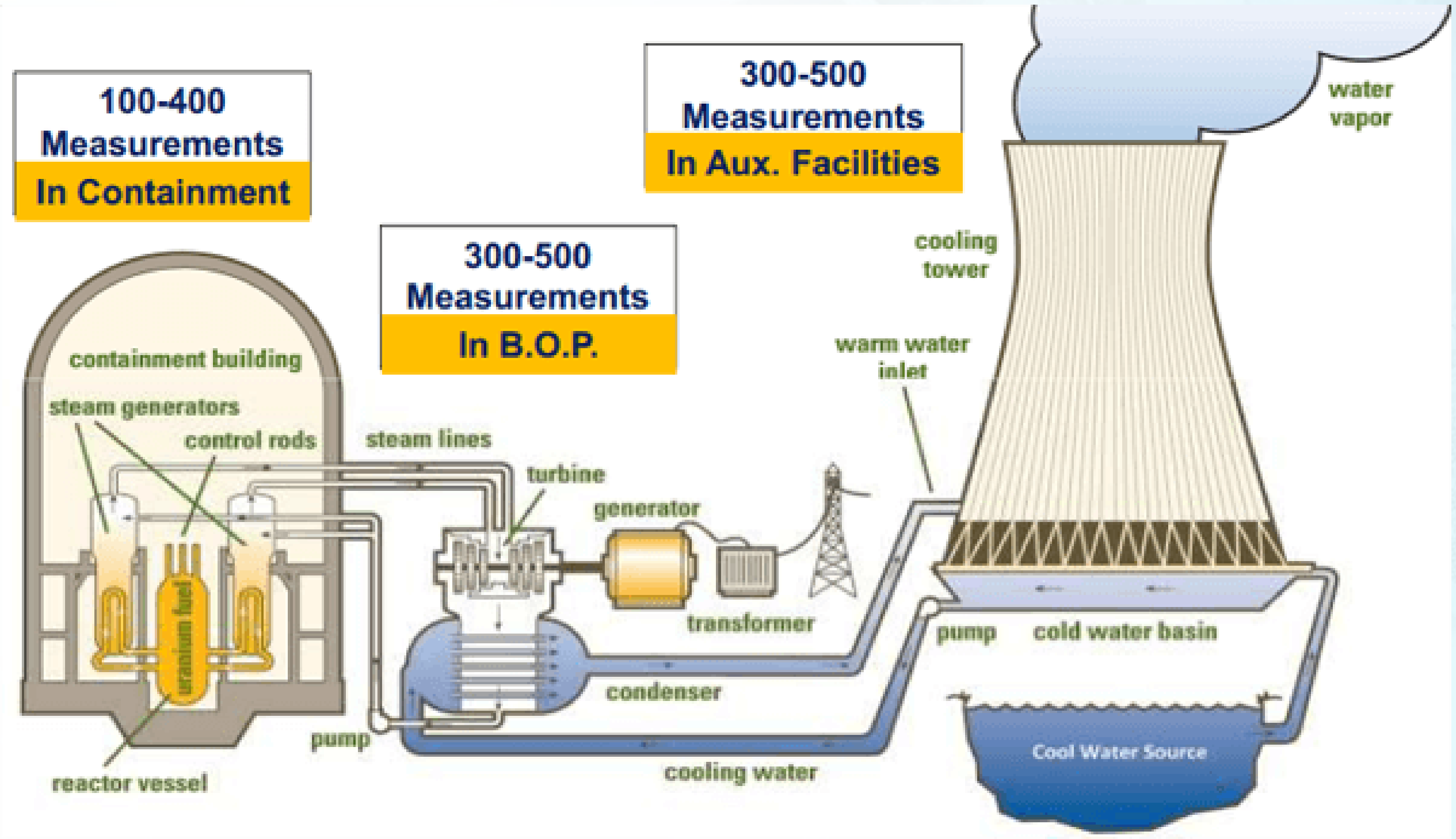
Pressure/temperature measurement – increase safety, improve efficiency, and reduce cost.



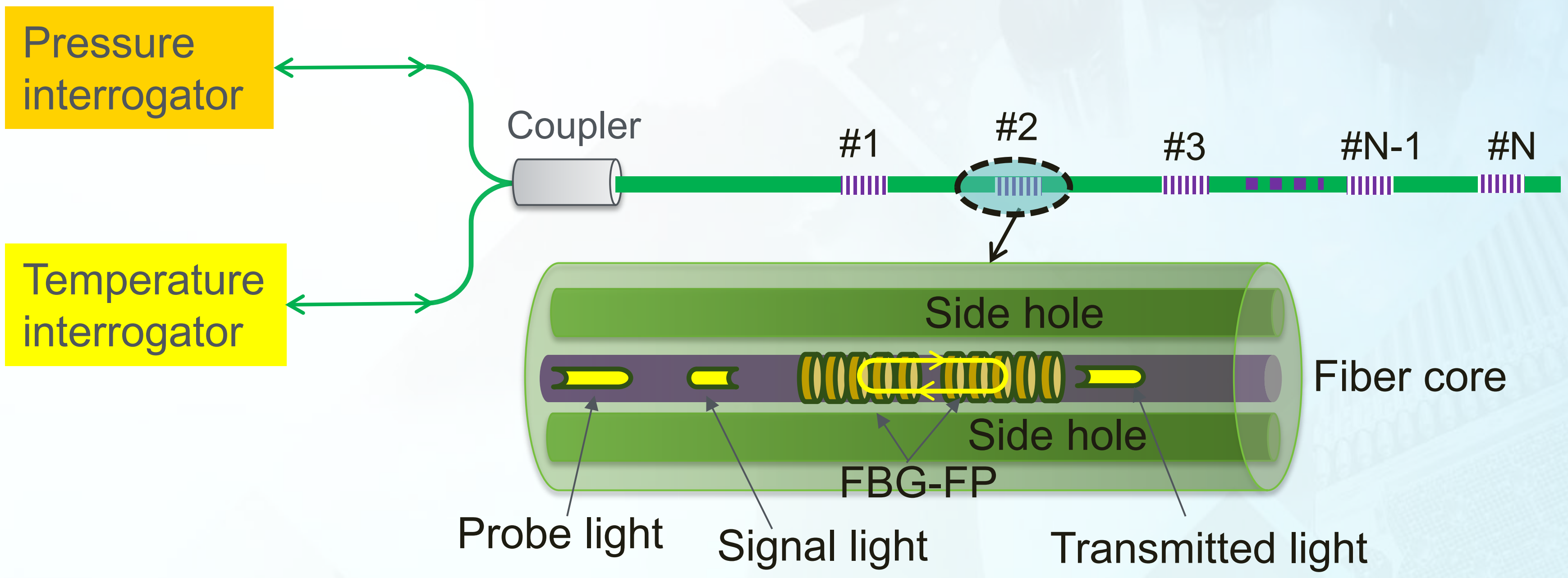
Typical nuclear power plant *(https://www.emersonautomationexperts.com/)*

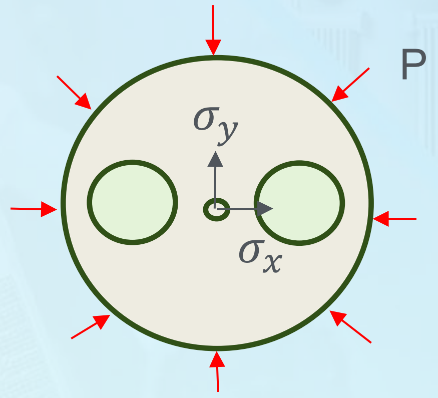
Advantages of Fiber-Optic Sensors

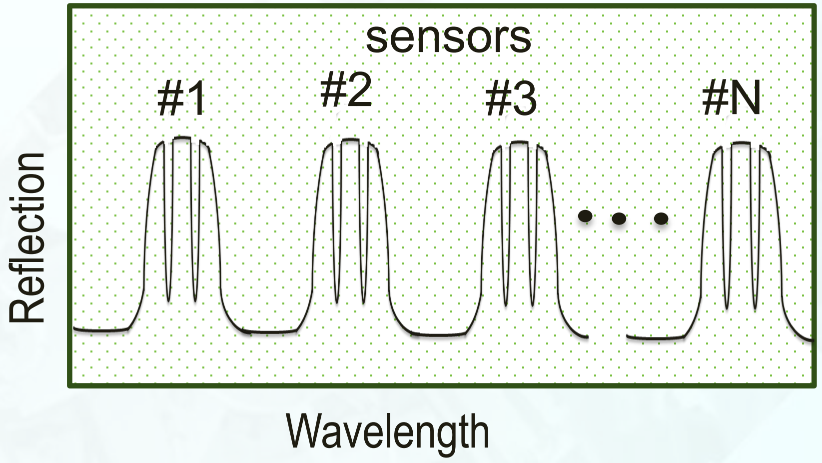
- Intrinsically immune to EMI
- Small footprint/light weight
- Long distance signal transmission
- Chemically inert
- High-temperature capability
- Multiplexing and multi-modal capability (minimizing # of feedthroughs; reducing assembly time)

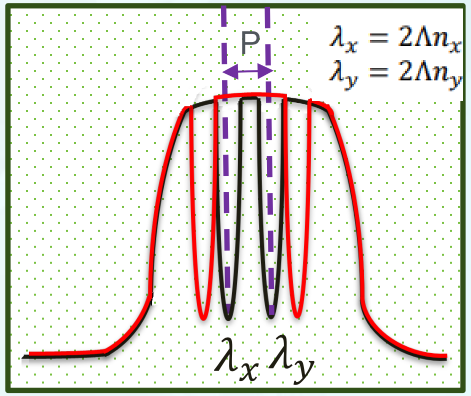
Fleming, Austin, et al. *Research plan for the development of optical fiber pressure sensors for nuclear applications.* No. INL/EXT-18-45711-Rev000. Idaho National Lab.(INL), Idaho Falls, ID (United States), 2018.

Fiber-Optic P/T Sensor – FBG-FP + Side-Hole Fiber

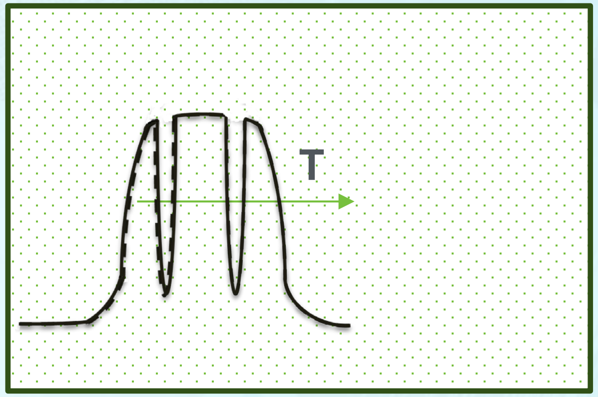








$\Delta\lambda = |\lambda_x - \lambda_y|$



Task 1: Design and obtain side-hole fibers

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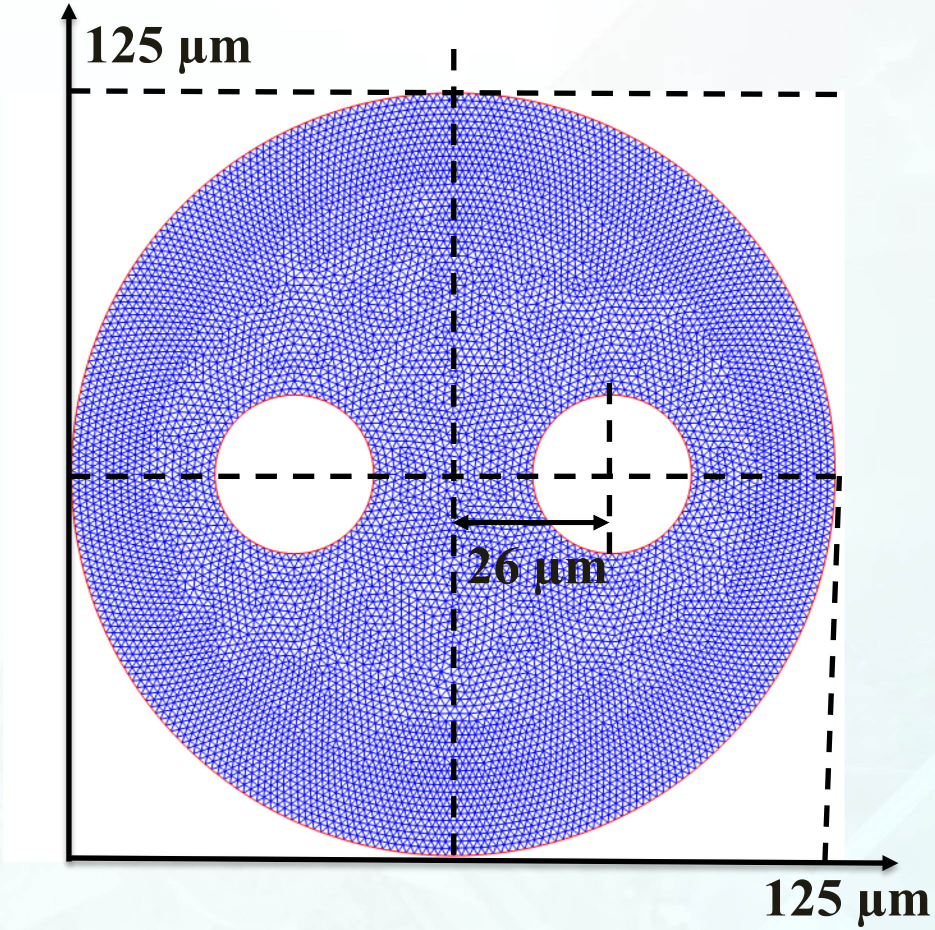
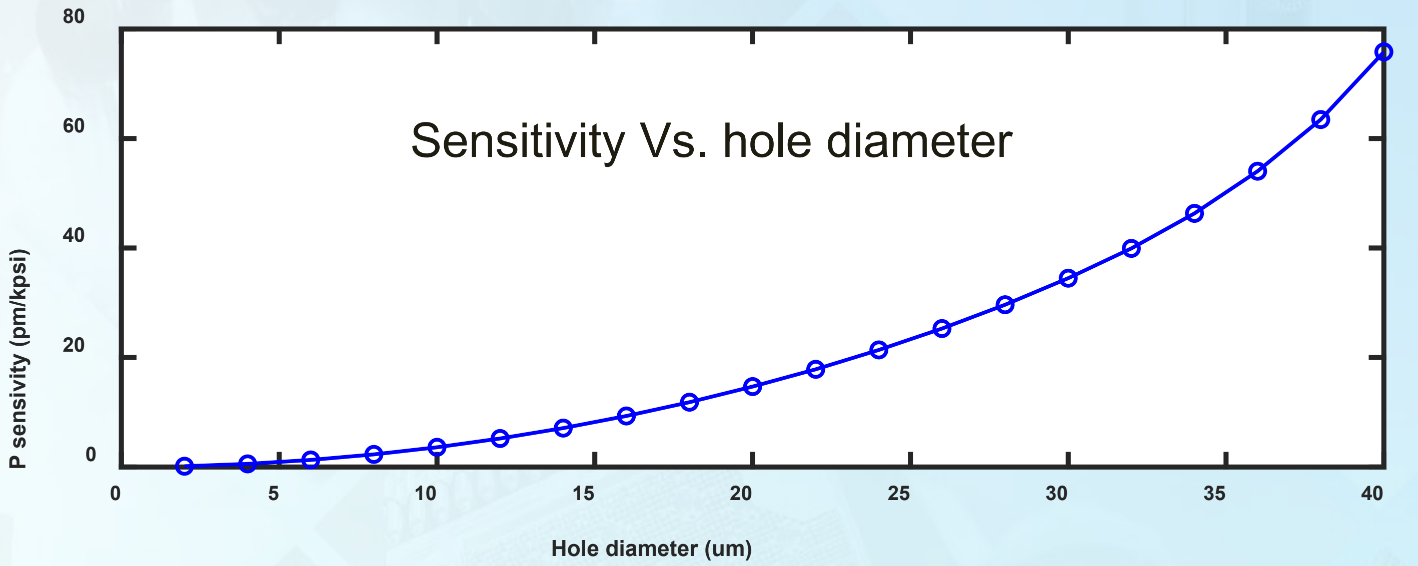
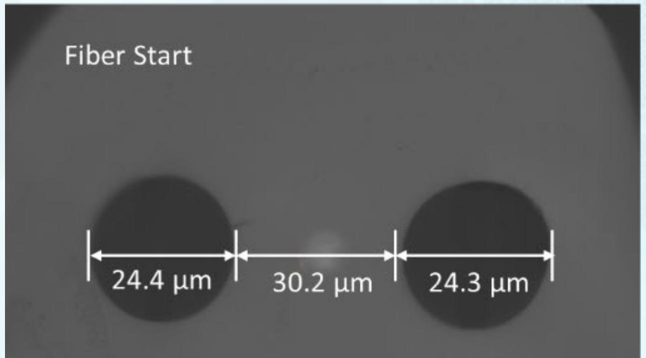
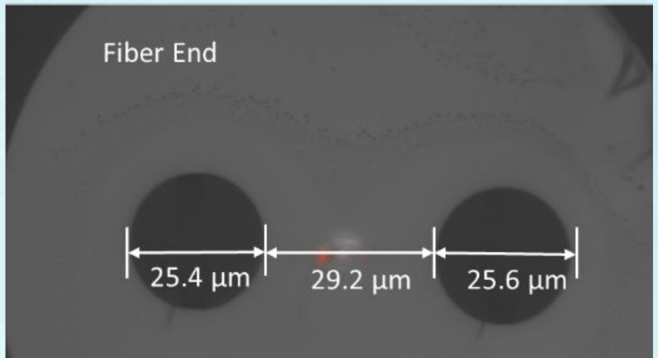
Simulation model (finite element)





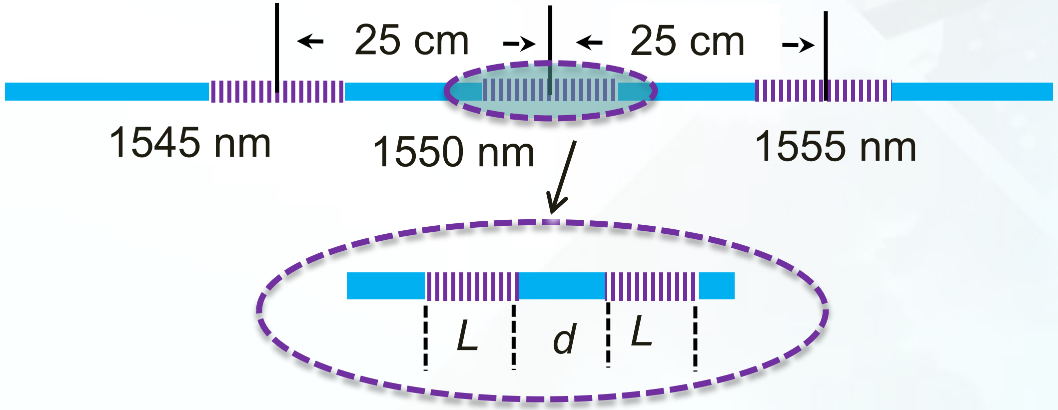


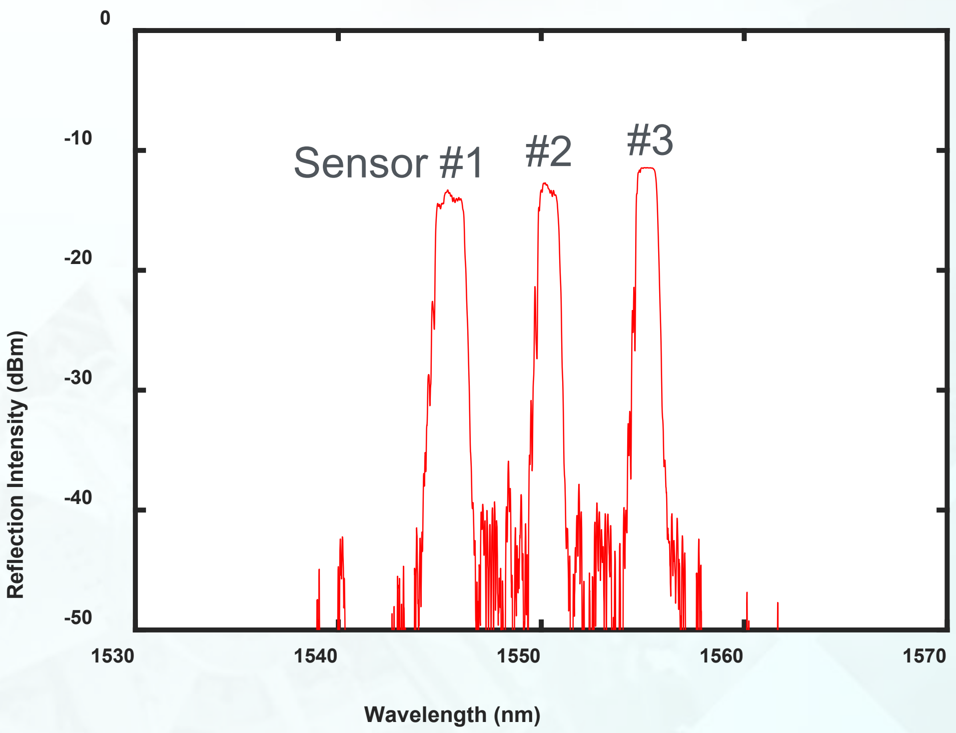
SM Side hole fiber with Ge-doped fiber core

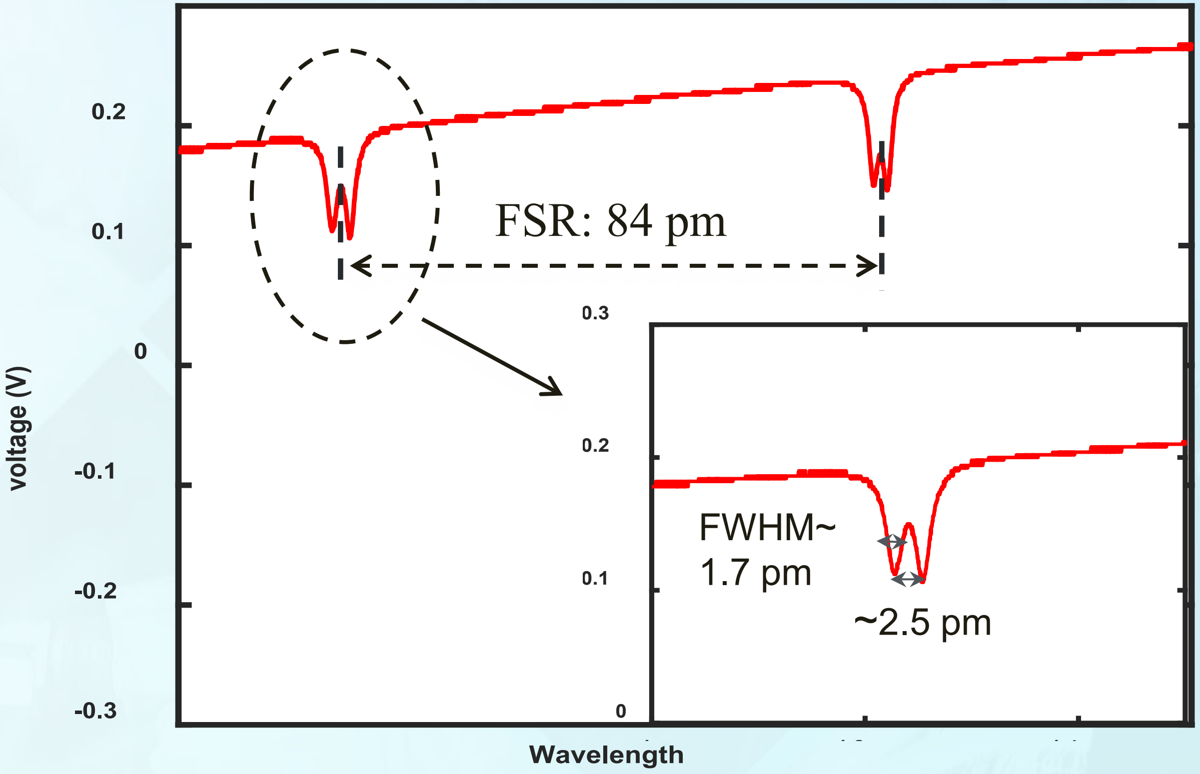


Simulation(hole D.~25 µm): 23.3 vs. experiments (18.7 pm/kpsi)

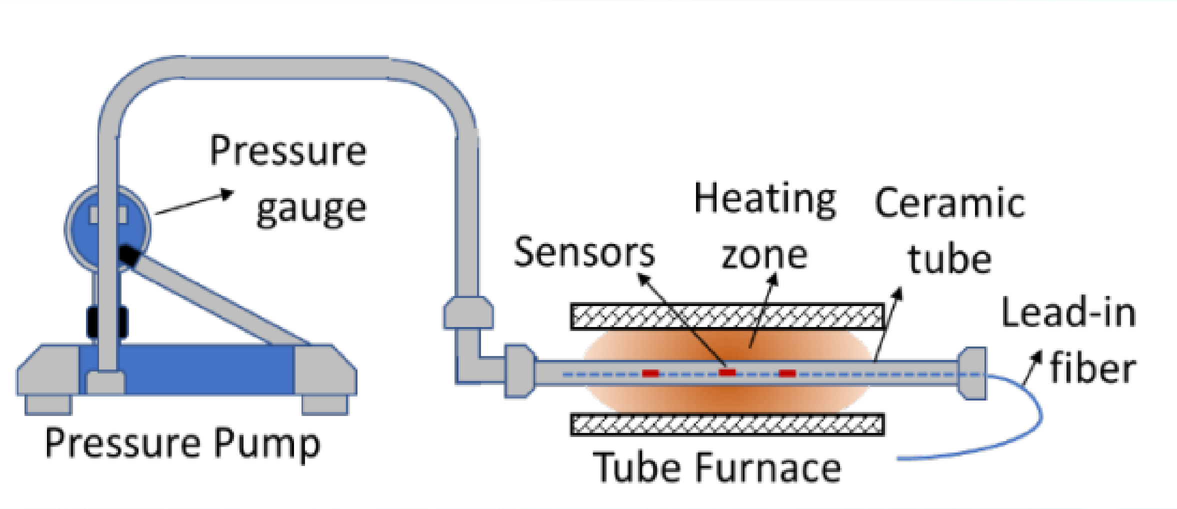
Task 2: Obtain FBG-FPs on side-hole fibers

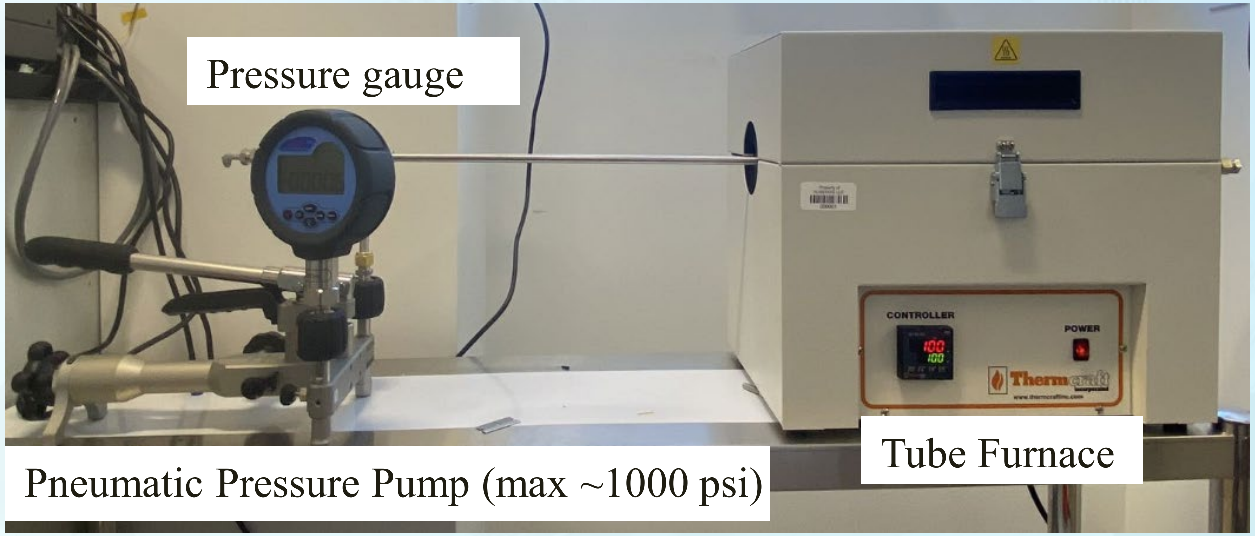




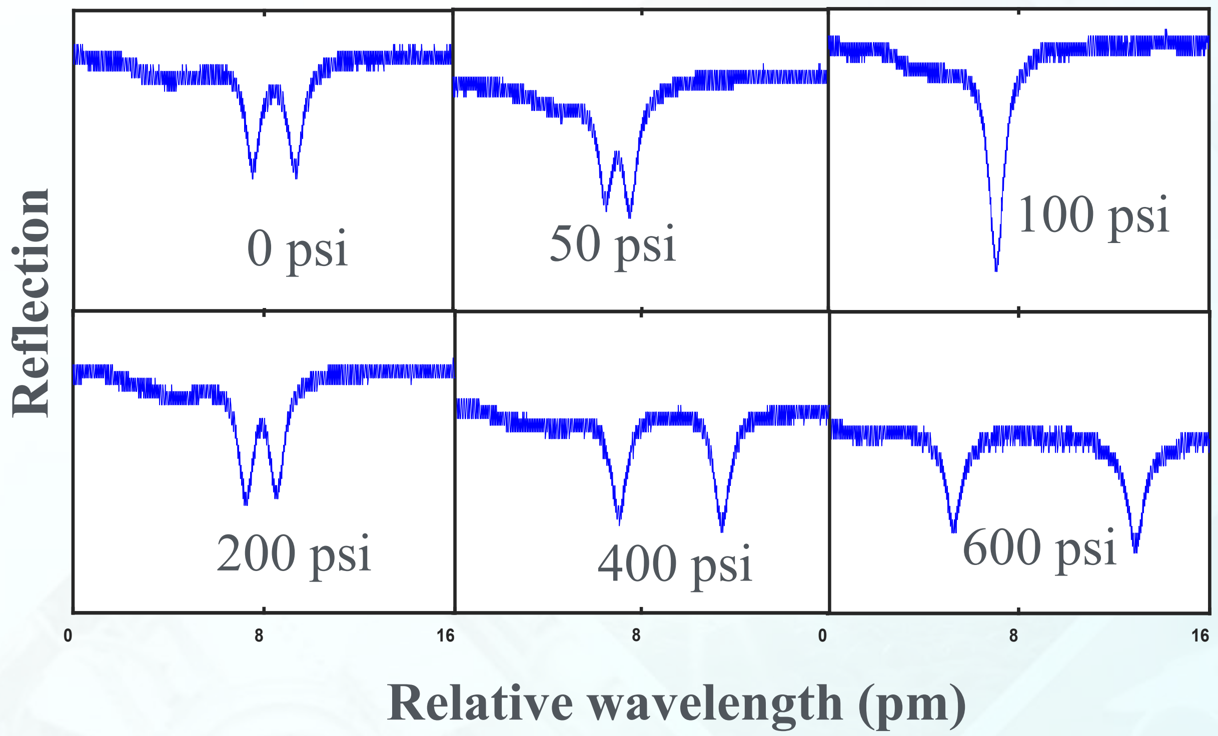


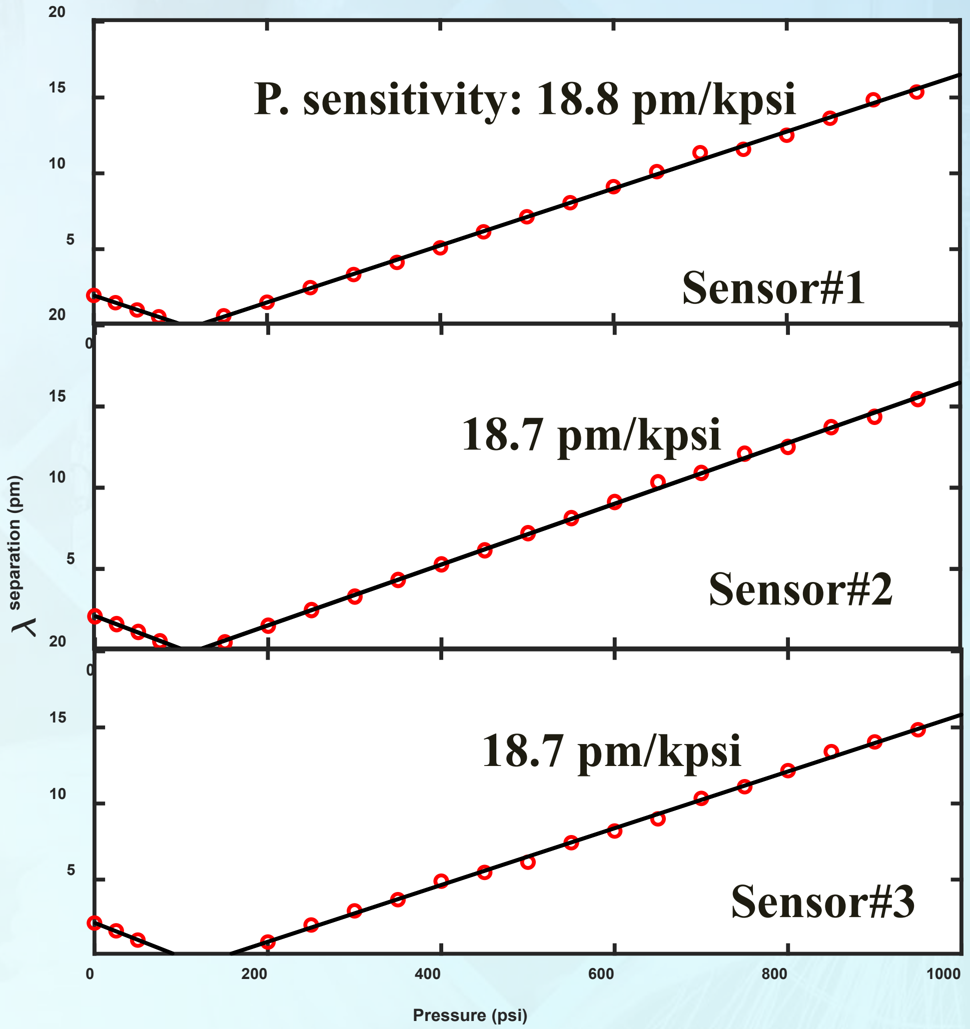
Task 3: Sensor interrogation and Laboratory Test





Sensor response to pressure at room temperature





Sensor response to pressure at elevated temperature

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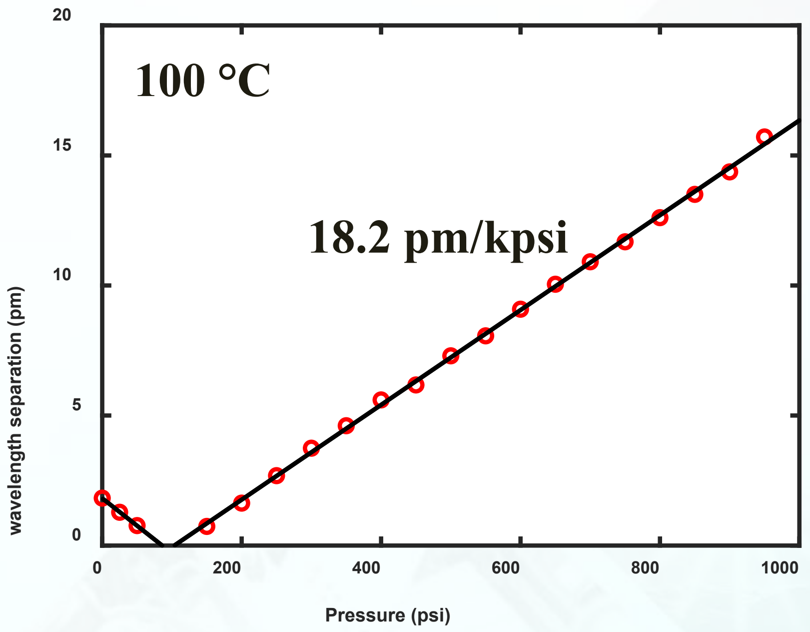
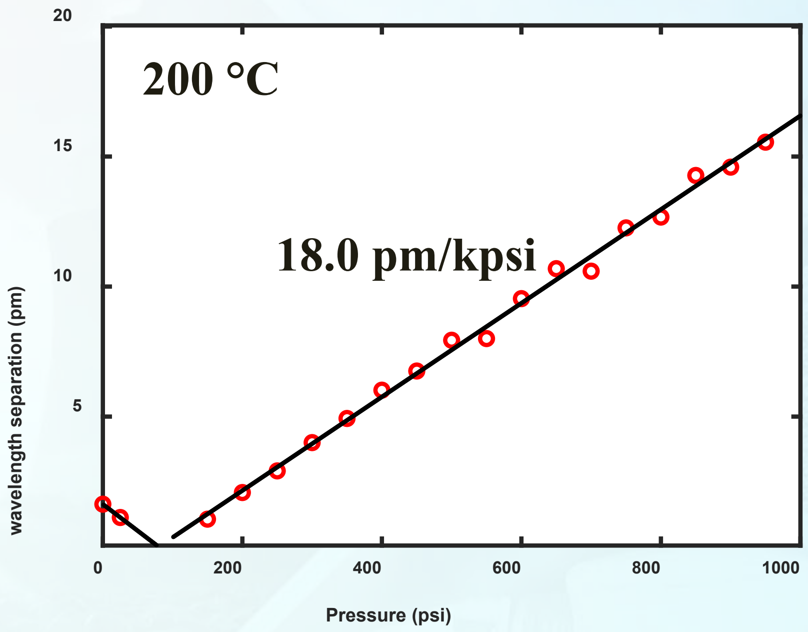
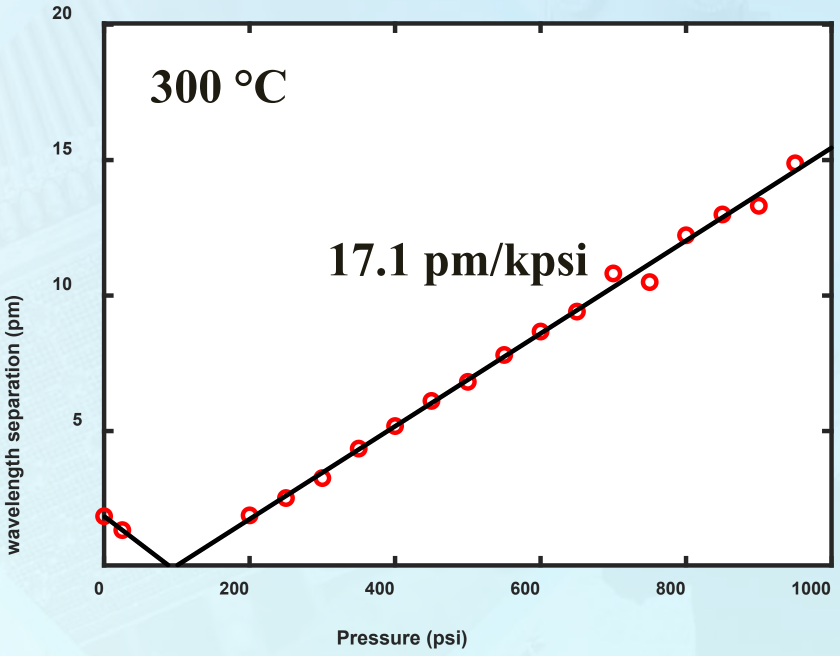
Sensor #2 was tested at given pressure and temperature.

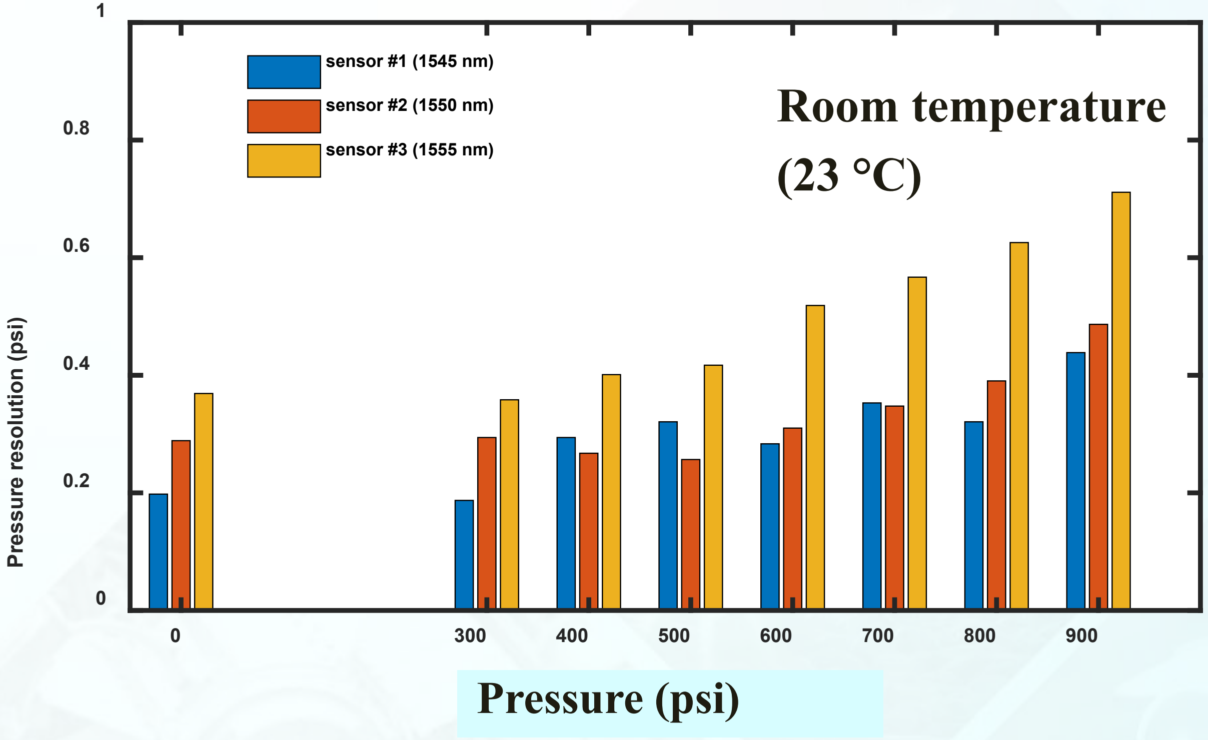


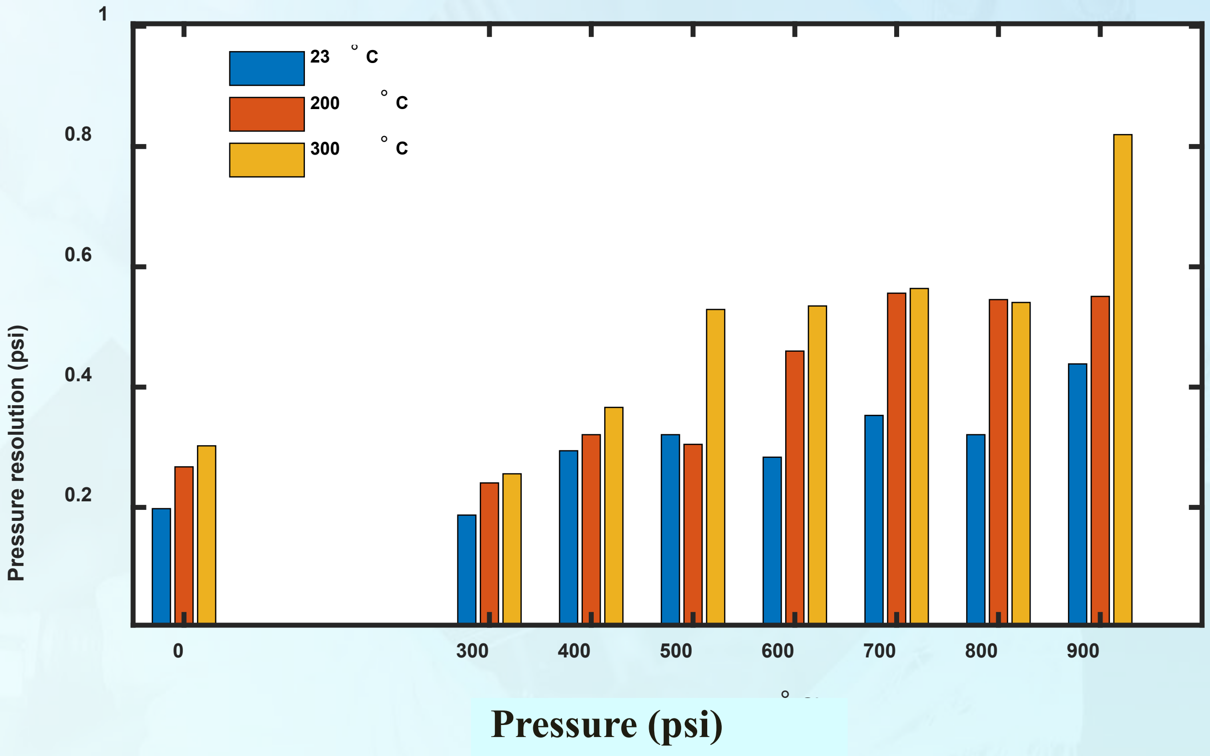




- Sensor shows similar pressure sensitivity at different given temperature.

Resolution was defined as the standard deviation (std) of pressure reading over a short time span (~ 1 min).





- All three sensors retained excellent resolution below ~1 psi at the tested pressure levels.
- The sensor stability remains <1 psi even at elevated temperatures of 300°C underscoring a good pressure resolution performance of the sensors.

Sensor response to temperature and temperature resolution

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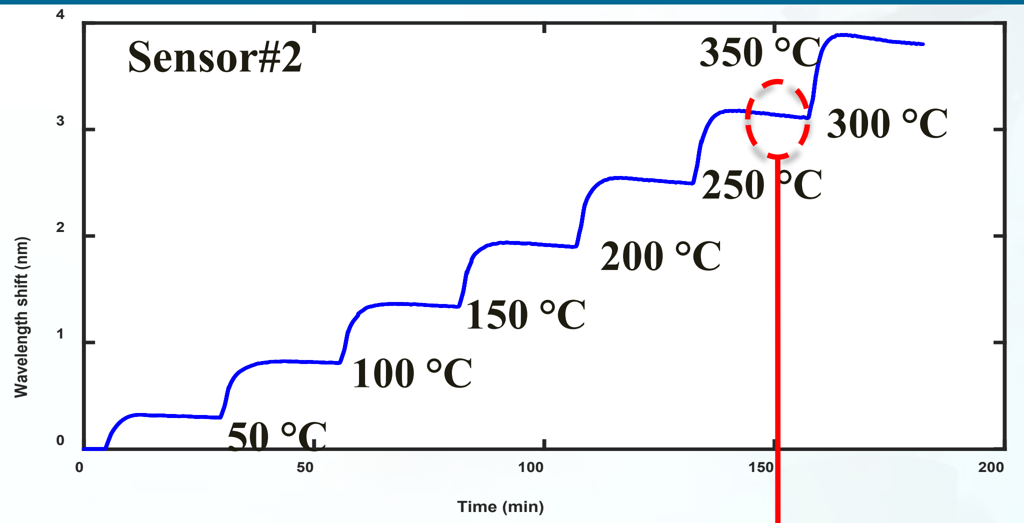

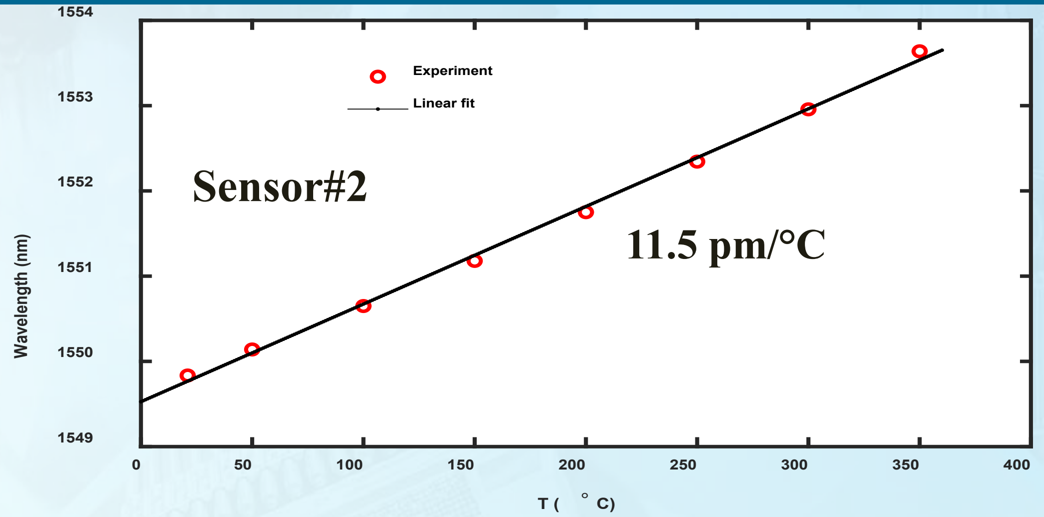

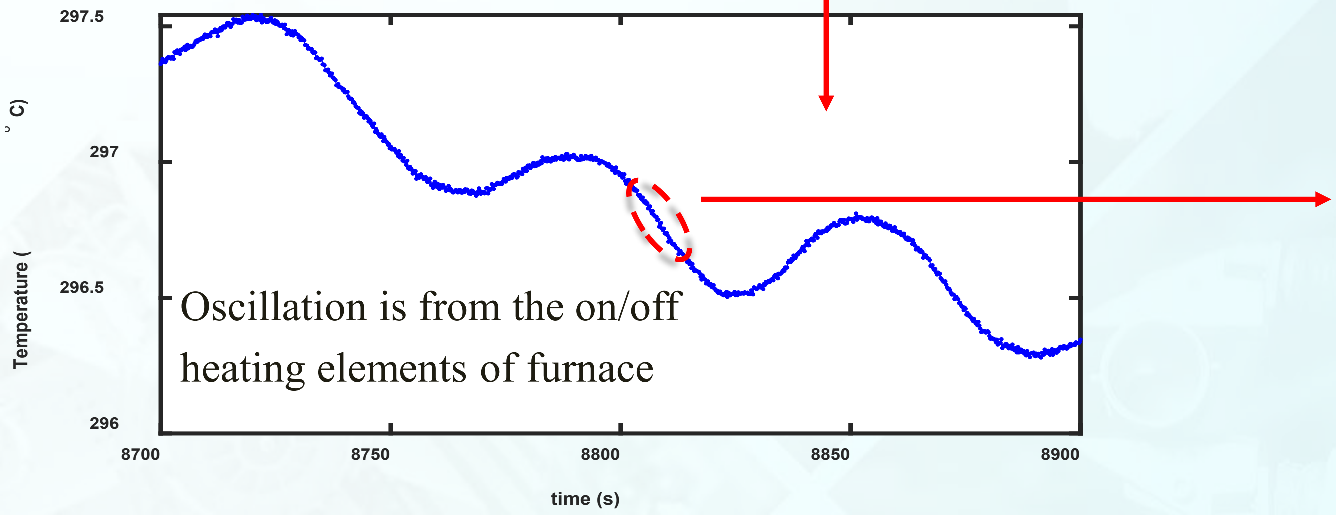

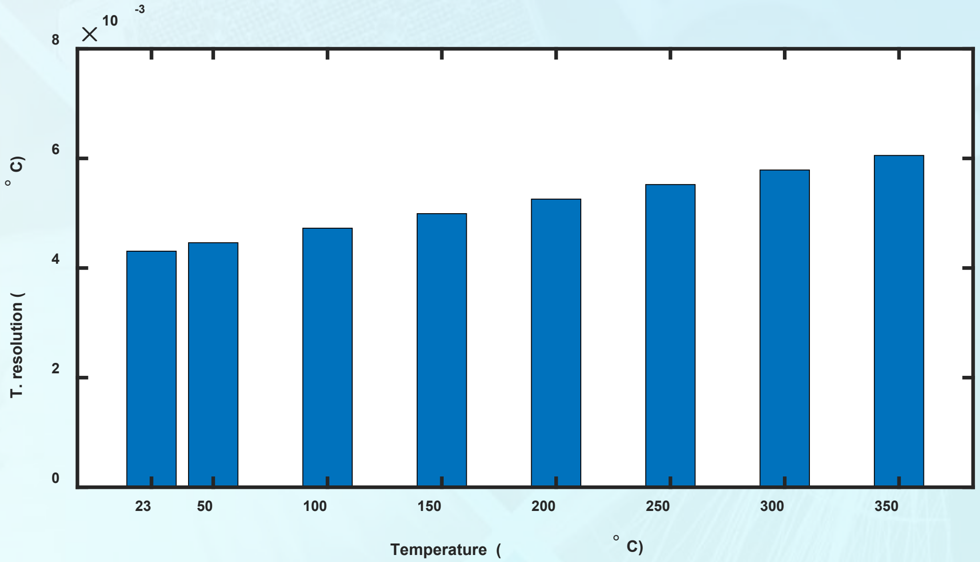

Sensor temperature cross-sensitivity

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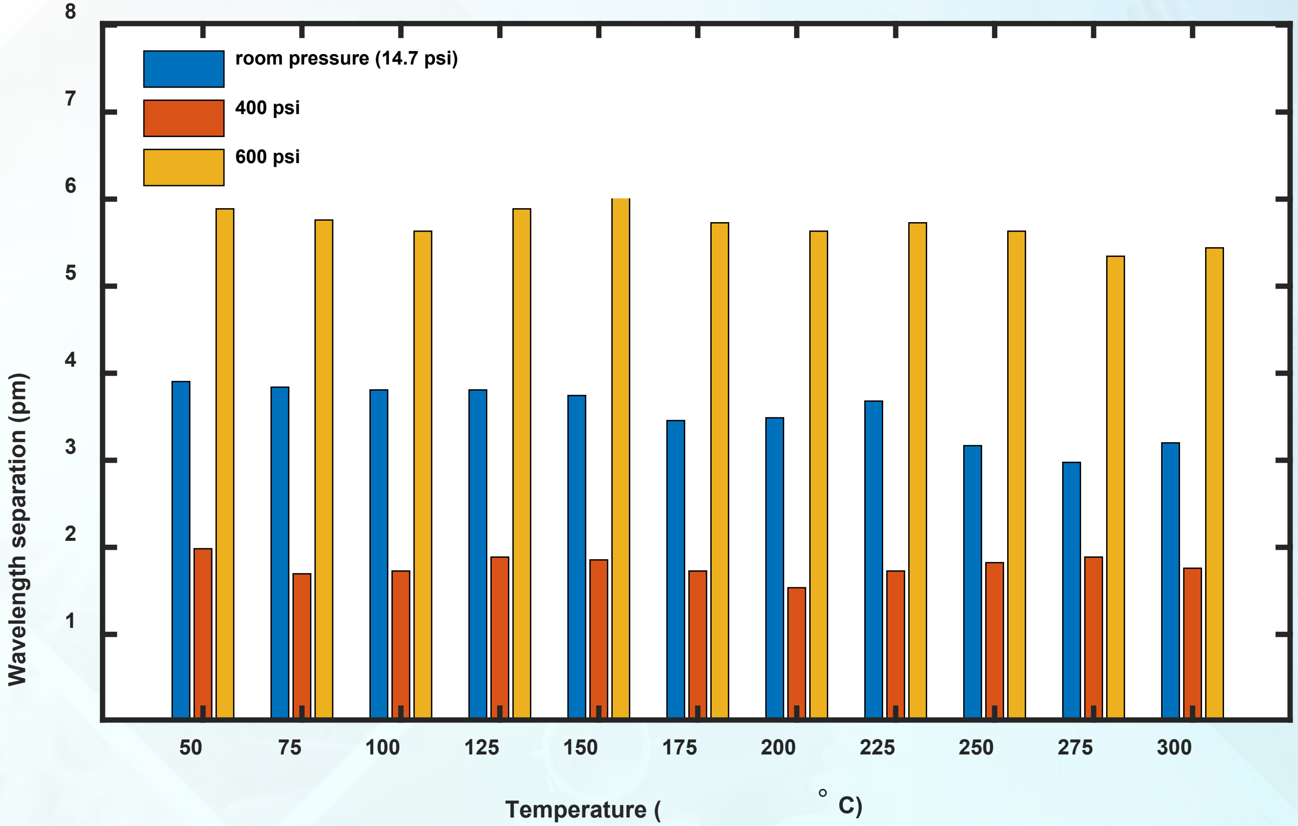
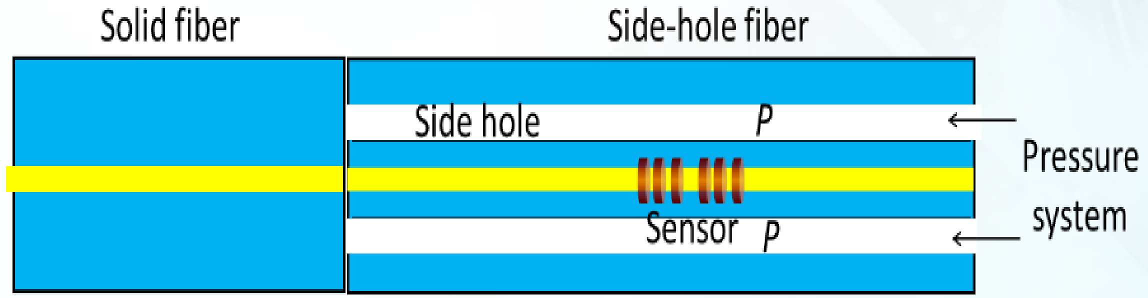
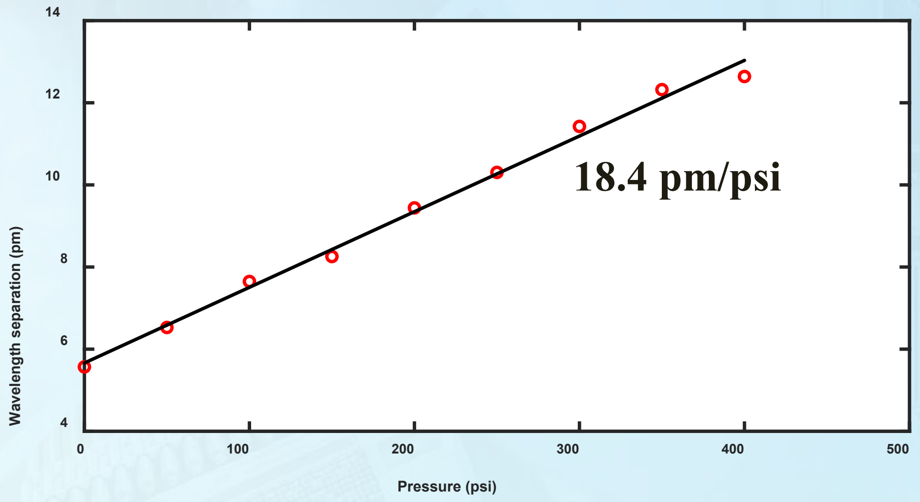
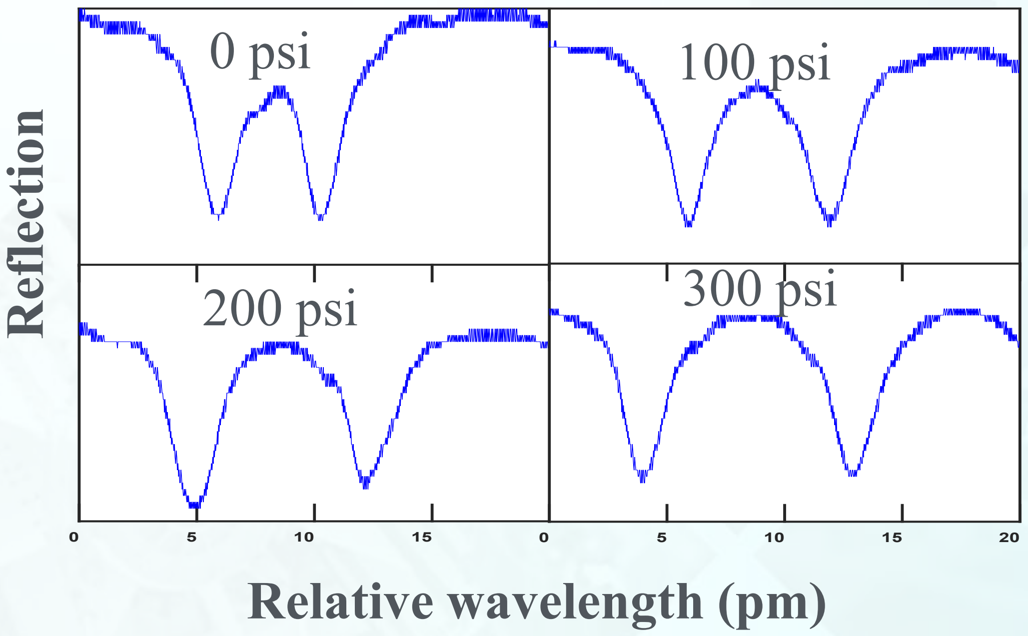
Sensor wavelength separation was measured at given pressure and temperature.



Task 4: Study an *in-situ* Pressure Sensor Calibration Method







Temperature (°C)	23	100	200	300
External P. sensitivity (pm/psi)	18.7	18.2	18.0	17.2
Internal P. sensitivity (pm/psi)	18.4	19.0	17.4	18.3

Task 5: Perform radiation testing on sensors

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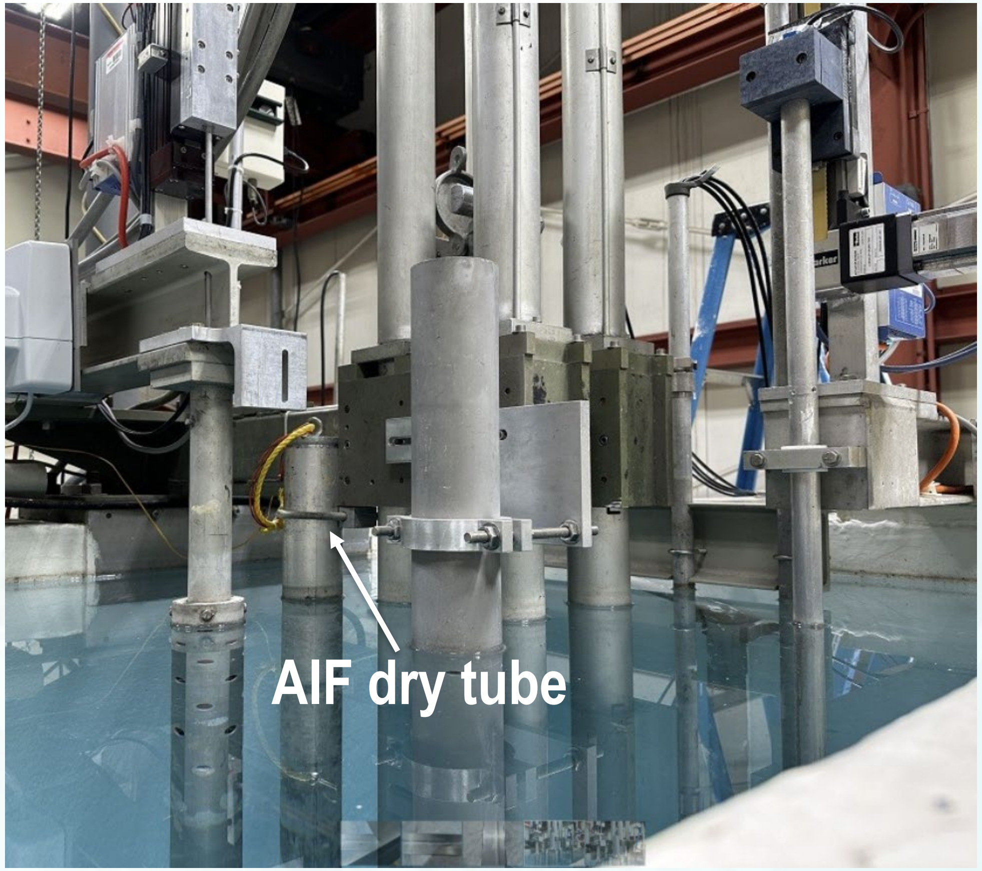
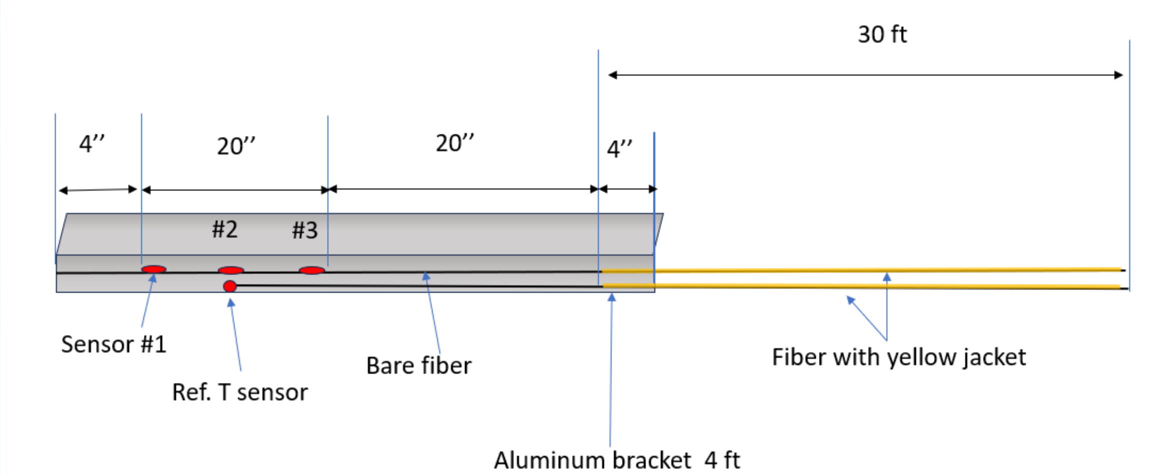
Nusenics performed radiation tests on the sensors in the Nuclear Reactor Laboratory (NRL) at the OSU (~ 7 hours)

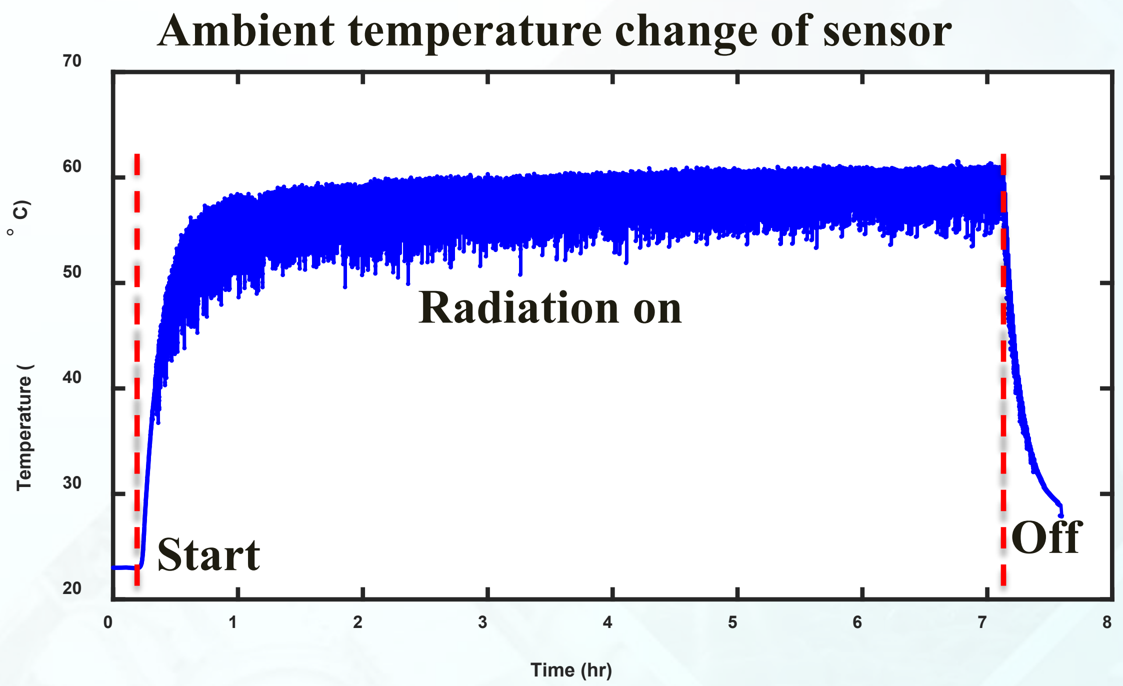


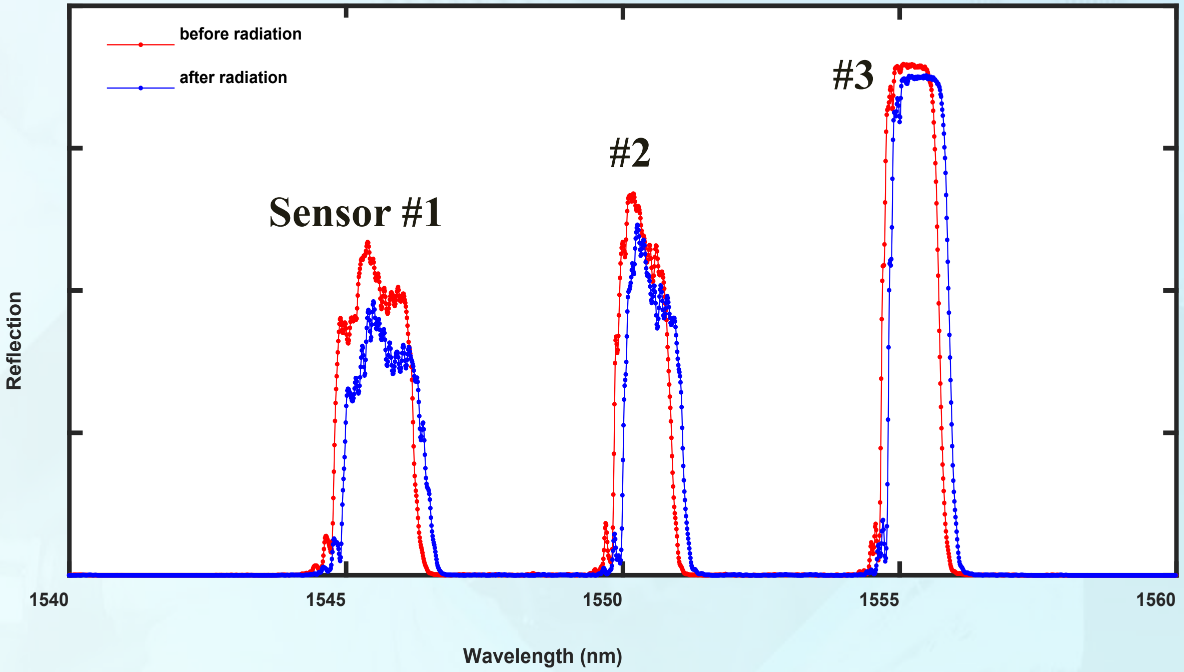


Sensors bonded on an aluminum bracket after radiation tests.

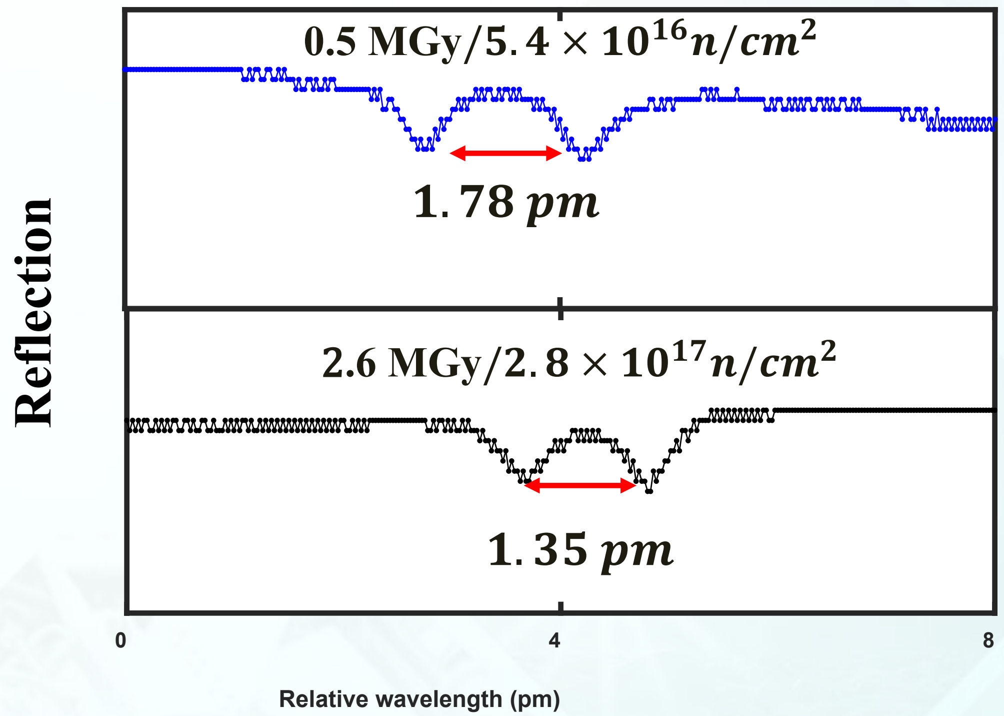
Sensor response to radiation

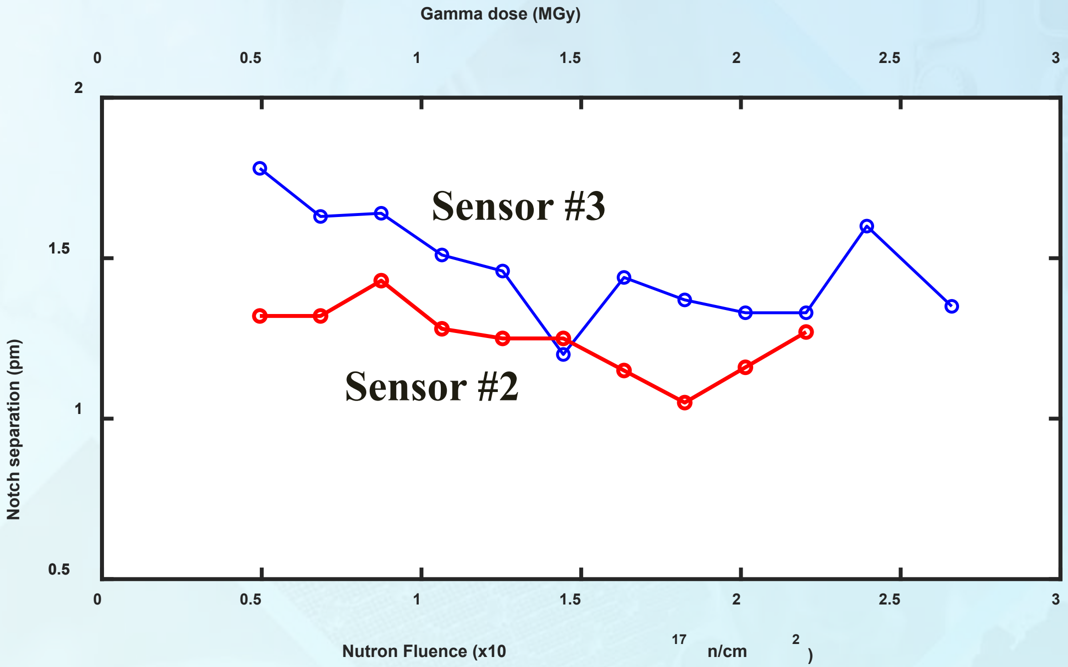
A silicon-equivalent gamma dose rate of 0.38 MGy/hr and a total neutron flux of 1.1×10^{13} n/cm²/s





Sensor response to radiation





- ❑ **Both sensors show similar trends that the notch separation distance decreases as the radiation dose increases, which could be attributed to the fiber core damage induced by the radiation.**

Conclusion

Nusenics did a thorough tests for the proposed fiber-optic pressure and temperature sensor system including the pressure and temperature sensitivity, resolution, temperature cross, and in-situ calibration. Nusenics also carried out radiation tests at OSU. The decrease of the notch separation distance could be attributed to the fiber core damage induced by the radiation. Radiation hardened fiber will be used in the future work.

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Thank You