Ultrasonic Multipoint Waveguide Temperature Sensor for Divertor Diagnostics in FPPs

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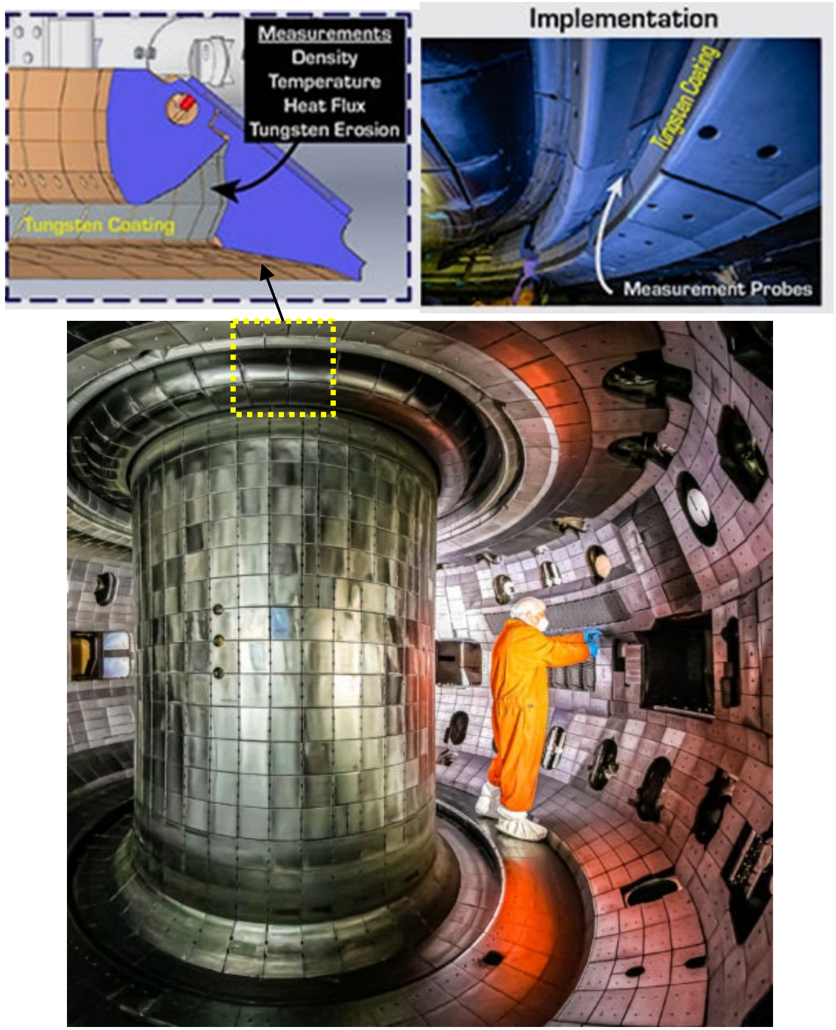
Ultrasonic Waveguide Thermometry for Fusion Divertor Diagnostics

- The divertor removes heat and particles, protecting the reactor vessel.
- Accurate, real-time temperature monitoring prevents damage and supports stable plasma operation.
- Conventional sensors (thermocouples, IR, probes) degrade rapidly under extreme heat, radiation, and erosion.
- Diagnostics must be compact, heat- and radiation-tolerant, and reliable for long-pulse operation.
- The ultrasonic waveguide sensor enables multipoint, radiation-hardened temperature measurement in harsh divertor environments for long-term operations.

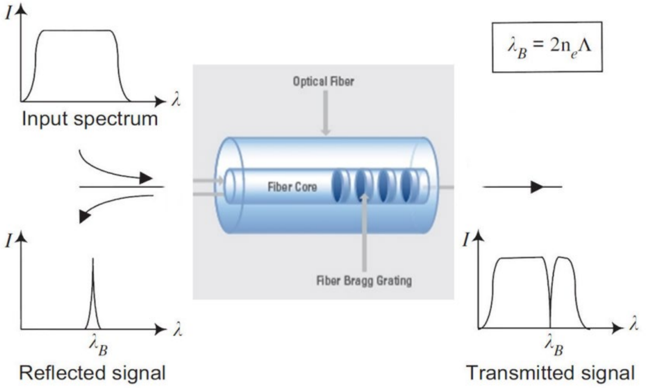


https://www.ga.com/diii-d-facility-adds-tool-resolve-heat-handling-future-fusion-power-plants

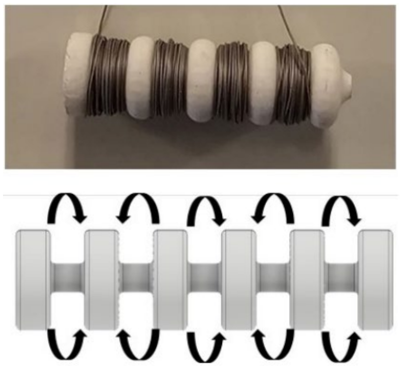
ULTRASONIC MULTIPOINT WAVEGUIDE TEMPERATURE SENSOR (UMWTS)

- UMWTS: Combines XII's grating-based waveguide with INL's magnetostrictive thermometry.
- Grating waveguide: Multiple gratings reflect distinct frequencies for localized temperature sensing.
- Rugged transducer: High-temperature, irradiation-resistant magnetostrictive driver.
- Smart processing: Algorithms extract temperature from grating reflection frequency shifts.
- Complete system: Includes interrogation unit, software, and GUI for real-time divertor monitoring in FPPs.

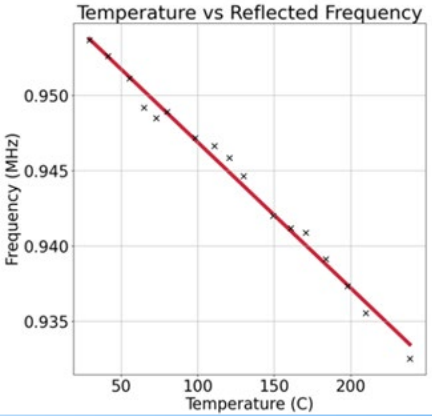
*Working principle of a Fiber Bragg Grating (FBG) sensor**



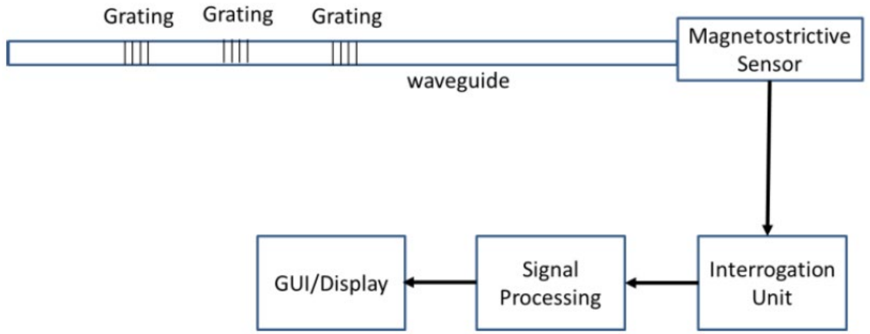
INL's Magnetostrictive transducer#



Results form previous SBIR effort



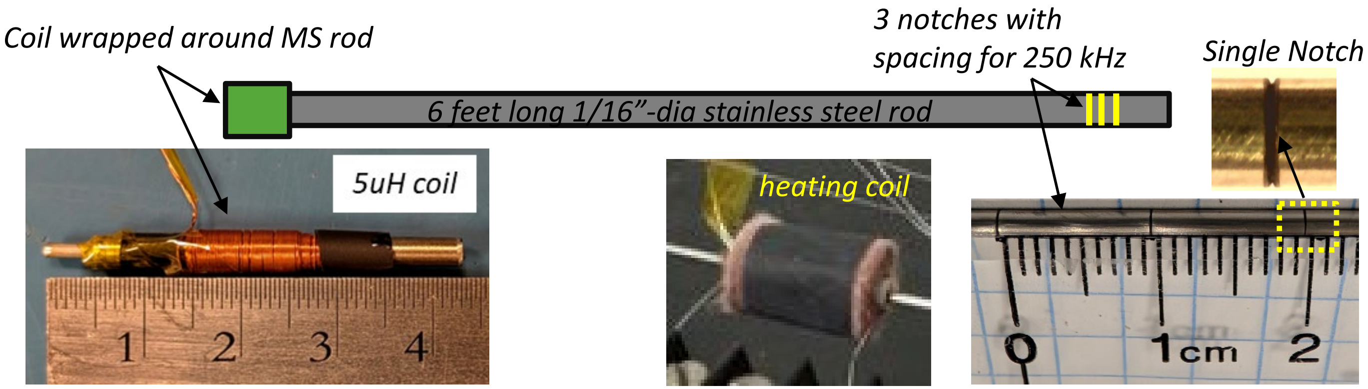
XII's proposed solution

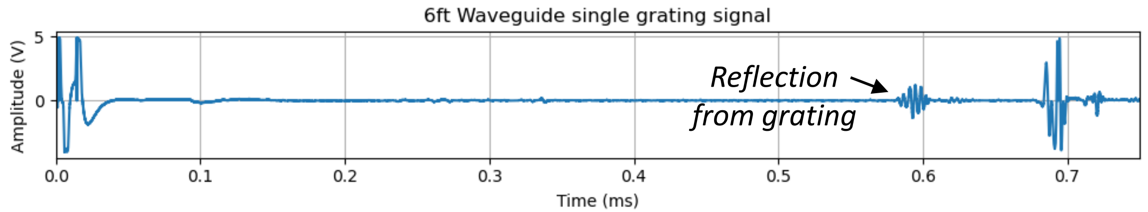


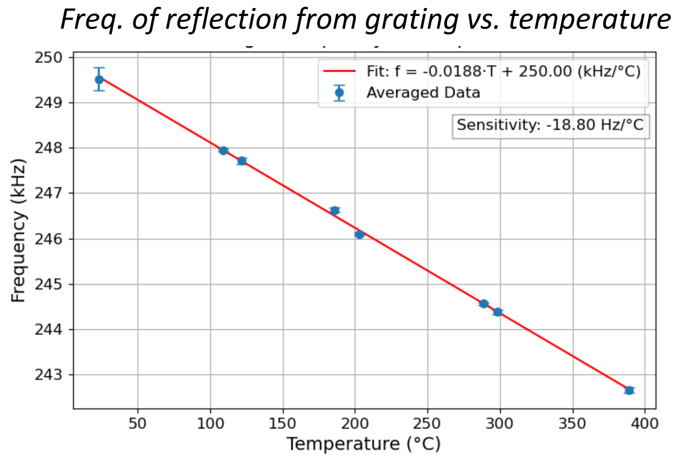
*https://www.worldscientific.com/doi/pdf/10.1142/S2010194512003807
#Joshua Daw & Bibo Zhong, "Development of INL Ultrasonic Thermometer", INL Report 2024

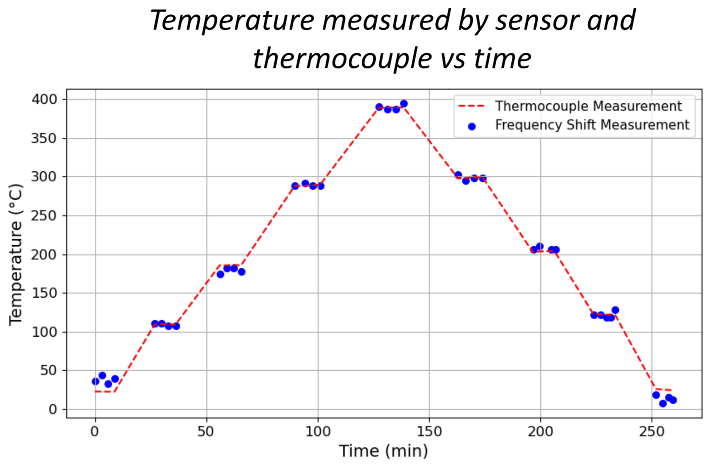
Magnetostrictive UMWTS

- Three notches (λ/2 spacing for 250 kHz) machined on a 6 ft, 1/16″ stainless steel rod.
- Magnetostrictive rod welded to one end and driven by a 5 µH coil using a 200 V, 2 µs square pulse.
- Heating coil applied around grating region, temperature raised up to 400 °C.
- Reflections from gratings recorded using the waveguide signal.
- Linear frequency-temperature response observed with a sensitivity of ≈ –18.8 Hz/°C.
- Frequency shift measurements closely matched thermocouple readings.



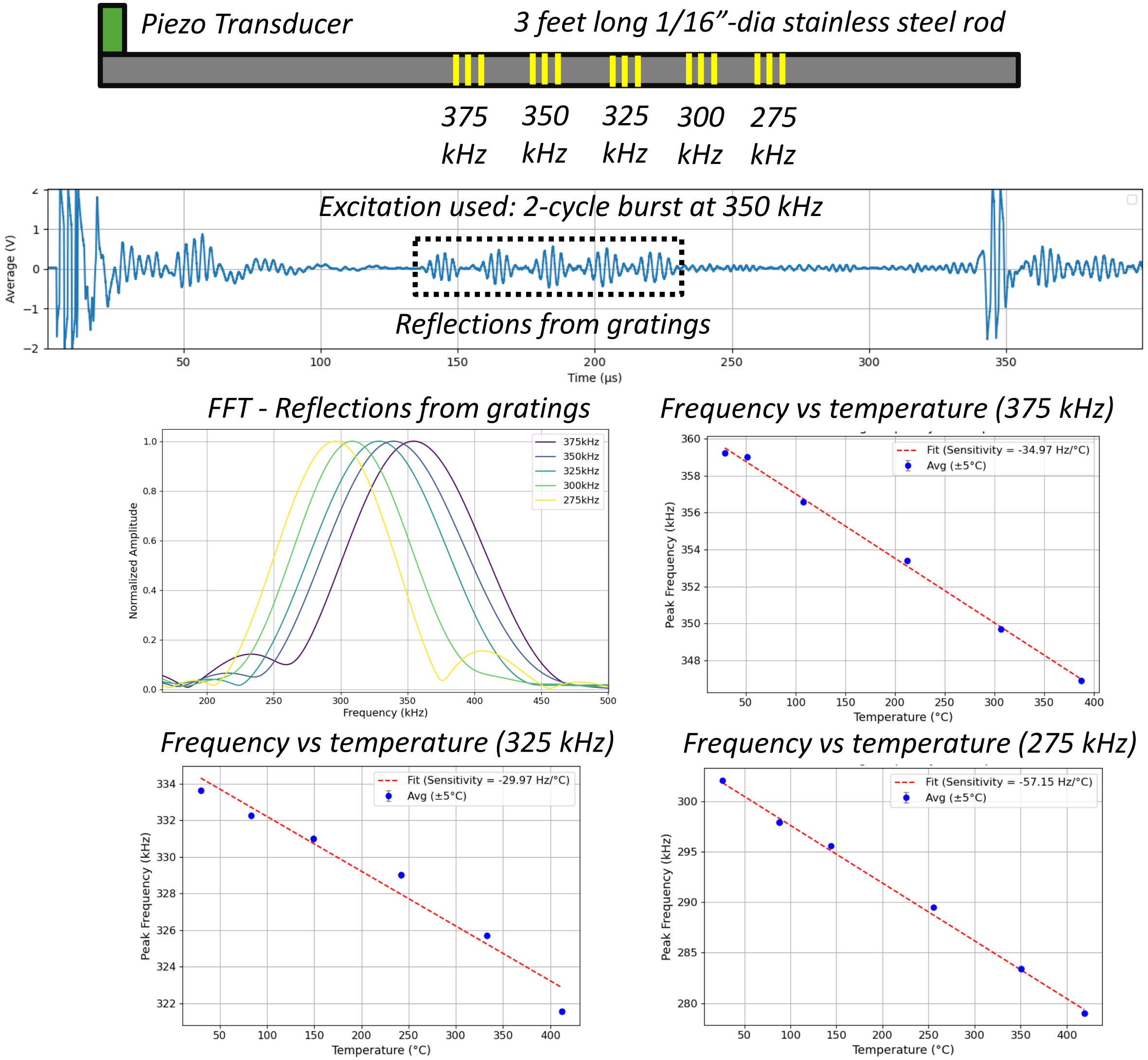






Multi-Grating UMWTS

- Five gratings (λ/2 spacing for 375–275 kHz) fabricated on a 3 ft, 1/16″ stainless steel rod, with 5 cm spacing between gratings.
- Excitation: 2-cycle burst at 350 kHz; reflections recorded from each grating.
- Odd gratings (375, 325, 275 kHz) heated up to 400 °C.
- Reflected frequencies showed linear to slightly nonlinear temperature response with varying sensitivities.
- Filtering effects from downstream gratings influence reflection amplitudes.
- Ongoing work: Developing signal-processing algorithms to isolate each grating response for accurate temperature mapping.



Ultrasonic Waveguide Thermometry for Fusion Divertor Diagnostics

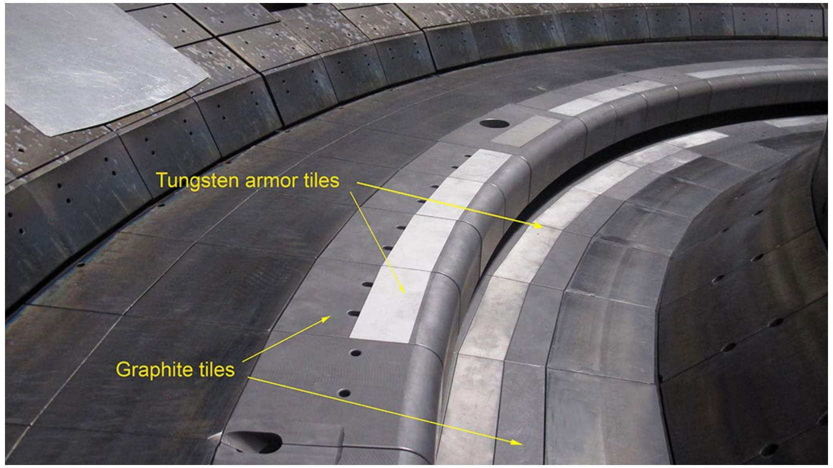
UT waveguide materials tested at INL.

Material and Diameter	Max Temp ℃	Comments
1.6 mm SS 316	≈1380	Excellent performance. High temperature sensitivity. Tested to melting point, phase change obvious via acoustic signal.
0.25 mm SS 316	≈1050	Excellent performance to 1000℃, then attenuation becomes excessive. High temperature sensitivity.
1 mm Tungsten	≈2500	Excellent performance to the maximum temperature limit of furnace. High neutron capture cross section.
1.6 mm Molybdenum	≈2500℃	Excellent performance to the maximum temperature limit of furnace. Low temperature sensitivity.
0.25 mm Molybdenum	≈1800℃	Excellent performance to ~1400℃. Excessive attenuation of signal at 1500℃. Low temperature sensitivity.

Joshua Daw & Bibo Zhong, "Development of INL Ultrasonic Thermometer", INL Report 2024

- Embedding concepts in W tiles: shallow micro-slot/trench behind plasma face.
- Transducer placement: keep magnetostrictive driver off-tile in a cooler, shielded region; route waveguide through a back-side feedthrough.

View of the divertor region on the floor of the DIII-D tokamak



https://www.ga.com/diii-d-scientists-pinpoint-mechanism-responsible-for-wall-erosion-in-fusion-devices