The Future of Temperature Sensing
Room 320 - Session TS-WeA

The Future of Temperature Sensing III

Moderators: Dr. Olga Kozlova, LNE-CNAM, **Dr. Nikolai Klimov**, National Institute of Standards and Technology

2:15pm **TS-WeA-1 Enabling New Measurement Capabilities with Fiber-Optic Thermometry***, **Stephan Krenek**, René Eisermann,* Physikalisch-Technische Bundesanstalt (PTB), Germany*; Guillaume Failleau,* Laboratoire National de métrologie et d'Essais (LNE), France*; Xin Lu,* Bundesanstalt für Materialforschung und -prüfung (BAM), Germany*; Peter Thomas,* Norwegian Research Centre AS (NORCE), Norway*; Henrik Kjeldsen,* Danish Technological Institute (DTI), Denmark **INVITED**

Accurate temperature measurement and control are fundamental to advancements in industry and the energy sector. Transitioning to a clean industry is essential for ensuring future competitiveness. This transition necessitates not only the reduction of carbon emissions but also the assurance of reliable and affordable clean energy. Accurate thermometry is an enabling technology that facilitates the optimization of energy safety, storage, and transmission. It also contributes to the enhancement of industrial efficiency. Fiber optic thermometry has emerged as a promising solution for applications where conventional electrical temperature sensors are impractical. This technology offers unique advantages, including immunity to electromagnetic interference and the ability to make spatially distributed measurements over long distances. However, the lack of metrological characterization, and thus SI traceability, currently hinders its widespread adoption. As with all sensors, fiber optic sensors exhibit cross-sensitivities and aging effects that must be investigated, quantified, and minimized to ensure low uncertainty temperature measurements.

Over the past three years, the European project INFOTherm has begun to unlock the full potential of fiber optic thermometry by addressing current limitations and implementing calibration methods and infrastructure. A key aspect of this project was demonstrating fiber optic thermometry in real-world scenarios. Industrial case studies examined the ability of fiber optic thermometry to optimize energy infrastructure and improve the efficiency of processes in high-temperature industrial environments.

Case studies have been performed in thermal energy storage in molten salt tanks, geothermal systems, submarine cable monitoring, high-voltage component diagnostics, and silicone and glass production. These successful case studies were made possible by improving fiber optic thermometry throughout the project, particularly by enabling the traceable calibration and reducing measurement uncertainties, while extending the operational temperature range.

This presentation will provide a comprehensive overview of the INFOTherm project, with a focus on the practical implementation of fiber optics in the energy and industrial sectors. Recent progress will be highlighted. This includes improved calibration techniques for distributed sensing methods and advancements in fiber optic sensors for high temperatures.

2:45pm **TS-WeA-3 Distributed Fiber-Optic Thermometry for High-Fidelity Temperature Metrology in Harsh and Thermally Heterogeneous Environments***, KOUSTAV DEY, Grant Whitham, **Laura Bartlett**, Rony Kumer Saha, Farhan Mumtaz, Ronald J. O'Malley, Jeffrey D. Smith, Rex E. Gerald II, Jie Huang,* Missouri S&T

Recent advances in distributed optical fiber sensing are enabling transformative approaches for high-resolution temperature metrology in harsh manufacturing environments. In this work, we developed a scalable, high-resolution distributed thermometry platform based on Rayleigh backscattering (RBS)-enabled optical frequency domain reflectometry (OFDR) for real-time spatial thermal mapping during the aluminum casting process. The system utilzed silica optical fibers (UHNA1, Thorlabs) interrogated with a high-speed OFDR platform, enabling high-density thermal metrology with a resolution of approximately 0.65 mm (~1538 points m^{-1}) and acquisition rates up to 62 Hz. The sensing approach was successfully integrated into elevated-temperature casting environments, including the casting of AA356 aluminum in 3D-printed investment shells. Distributed thermal data were acquired throughout the full casting cycle, including shell preheating, molten metal pouring, and subsequent solidification at temperatures approaching 700 °C, showing trends consistent with thermocouple measurements. The platform effectively captured localized thermal gradients, transient heat-transfer phenomena, and the spatio-temporal evolution of temperature during solidification, while the optical fiber remained intact after molten metal pouring and was reusable for subsequent measurements, demonstrating the robustness of the sensing platform in harsh casting environments. Unlike conventional thermocouple-based systems, the distributed fiber-optic approach provided near-continuous thermal measurements along the length of a single optical fiber, significantly improving spatial sensing capability while remaining minimally invasive. The results demonstrate the strong potential of RBS-enabled distributed fiber-optic sensors as robust thermometry platforms for metal casting and other advanced manufacturing applications operating in extreme environments. This work further establishes a foundation for intelligent process monitoring, real-time thermal diagnostics, and digital twin-enabled manufacturing systems, while highlighting the broader applicability of distributed fiber-optic thermometry for next-generation harsh-environment sensing technologies.

3:00pm **TS-WeA-4 Toward SI-Traceable Photonic Thermometry using Dual-Comb Spectroscopy***, **Peter Chang**, Nathan Brooks, Tsung-Han Wu,* Chi3 Optics

Precise measurements of temperature are an important requirement in many fields, with functions ranging from process control in manufacturing, to disease treatment in medicine, to military applications. Whereas the Standard Platinum Resistance Thermometer (SPRT) is a robust and simple method to measure temperature to uncertainties less than 10mK, their sensitivity to mechanical shock and need for routine calibration has motivated research to establish platforms based on photonic thermometry [1]. A photonic thermometer is composed of an element highly sensitive to temperature (a photonic thermistor), and a means to reference the device to a primary standard. For example, a prominent platform is the silicon photonic thermometer (SPoT), which uses the narrow resonance of a photonic crystal cavity that can be calibrated against the thermal Brownian motion of its nanomechanical resonator [2]. Here, we propose a platform based on dual-comb spectroscopy (DCS), where the absolute frequency axis retrieved in DCS is used to provide a primary standard. In particular, by leveraging developments in low SWaP and compact fully self-referenced frequency combs, we aim to employ a high resolution 50MHz dual-comb spectrometer covering 30nm of optical bandwidth in the C-band. This spectrometer can be paired with a fiber Bragg grating [3] or a NIST standard reference gas-cell [4] to resolve temperature-dependent frequency shifts below 100MHz with direct SI traceability. Its high resolution targets the 10 mK sensitivity range, while SI traceability can be provided either in the RF by locking the repetition rate to a reference oscillator, or in the optical domain by locking a comb line to an optical standard. Together, these capabilities point toward a compact and fieldable thermometry platform relevant to precision metrology in demanding environments.

References:

1. N. Klimov, T. Purdy, and Z. Ahmed, "Towards replacing resistance thermometry with photonic thermometry," Sens. Actuators Phys. 269, 308–312 (2018).
2. T. P. Purdy, K. E. Grutter, K. Srinivasan, and J. M. Taylor, "Quantum correlations from a room-temperature optomechanical cavity," Science 356, 1265–1268 (2017).
3. A. J. Fleisher, Z. Ahmed, T. Herman, and M. R. Hartings, "Dual electro-optic frequency comb photonic thermometry," Opt. Lett. 48, 2210 (2023).
4. Y. Pang, L. Xu, X. Zhang, Z. Cao, Y. Ding, and G. Wang, "Accurate gas temperature measurement via iterative fitting of dual-comb spectral absorbance versus lower-state energy dependence," Opt. Express 33, 37913 (2025).

3:15pm **TS-WeA-5 A Practical Approach to Johnson Noise Thermometry***, Robert Crabtree,* Isothermal technology Ltd, UK*; **Carl Baines**,* Isothermal Technology Ltd, UK

Johnson Noise Thermometry (JNT) offers a primary, electrically traceable approach to temperature measurement.

Achieved by directly linking the Johnson noise voltage across a resistive probe to temperature as defined by the Johnson-Nyquist equation. Presented is aconcise overview of JNT from its theory, through prior arts to modern techniques, and outlining real-world applications. Topics include noise signal acquisition and processing, andpractical challenges of implementation across laboratory and industrial environments. Recent advances in JNT development to realise a practical Johnson noise thermometer will also be examined, with a discussion of its evolving role within the broader landscape of precision thermometry.

3:30pm **TS-WeA-6 Validated Dissemination: What Makes a Primary-Standard Bridge Trustworthy in a Post-Redefinition Traceability Chain***, **Abhishek Sengupta**,* WIKA Group, UK

Since the 2019 kelvin redefinition, thermodynamic temperature can be realized directly through methods anchored to the Boltzmann constant. Realization, however, is not dissemination - and dissemination determines whether a primary realization becomes a deployable, qualified measurement in the field. A calibrated kelvin still reaches accredited laboratories and industrial processes through standard platinum resistance thermometers and the ratio bridges that read them.

This contribution is from the manufacturer of one such instrument: the WIKA CTR9000, an AC resistance ratio bridge built on the ASL technology deployed at most national metrology institutes for ITS-90 realization and dissemination. One reason it occupies that role at parts-per-billion scale is architectural. Top-tier bridges derive accuracy from transformer-based ratio determination set by integer winding counts that cannot drift. The CTR9000 implements this in AC - continuously alternating excitation, inductive voltage divider ratio determination, quadrature balancing - where thermal EMFs sit at DC and never enter the measurement bandwidth, so each reading is a continuous measurement rather than a composite of two opposite-polarity readings combined by symmetry.

What gives the 20 parts-per-billion specification its standing is the framework of independent validations behind it: zero and unity checks, complement measurements by swapping resistors and evaluating the reciprocal, ratio test units against a calculable network, resistance bridge calibrators against a combinatorial standard, and long-term stabilization during manufacture. Each catches an error the others would miss, each works by physical manipulation of real ratios, independent of internal references. This carries the instrument from factory specification to qualified field deployment.

Drawing on a current cooperation with PTB on the CTR9000, the talk frames the AC bridge as the interface between primary realization and accredited dissemination. Of the methods enabled by the redefined kelvin, Johnson noise thermometry sits closest: a quantum voltage noise source provides the reference against which a sense resistor's thermal noise is compared, and the resistance contributes directly to realized temperature. As photonic, optomechanical, and noise-based primary thermometers move from laboratory demonstration toward deployable, qualified systems, each will face the question the bridge has answered over decades: not how accurate it can be in principle, but what architecture and framework will make the trust transferable.

4:15pm **TS-WeA-9 Fiber Optic Phosphor-Based Temperature Sensors: Can It Replace Industrial Platinum Resistance Thermometers (IPRTs)?***, Noah J.J. Johnson, **Michael Goldstein**,* Accelovant Technologies Corporation, Canada

IPRTs are the industrial standard for highly accurate, reliable and repeatable temperature measurement in the range of -200°C to 650°C. Despite their rugged construction, IPRTs do suffer from drift due to mechanical shock and vibration necessitating costly routine recalibration. Fiber optic phosphor-based temperature sensors can potentially achieve drift free performance that require no recalibration over time. These sensors are also unaffected by electromagnetic fields, RF, MRI, and microwave radiation making them attractive for medical and high-voltage environments. The all optical sensing tip eliminates sparking and electrical hazards making them suitable for oil, gas, and mining industries. In this talk, we will present our successful effort towards commercializing fiber optic phosphor-based temperature sensors that outperform the tolerance specification of commercial IPRTs. Temperature measurement range (-200°C to 650°C), drift (<0.05°C for 1000 hours at 450°C) and repeatability (within ±0.01°C) measurements show they can potentially match current industrial performance standards. The presentation will highlight the technology and its overall suitability as an easily scalable, cost effective replacement of IPRTs in various industrial applications.

4:30pm **TS-WeA-10 Industry Panel Discussion - Scaling Up Temperature Innovation: Challenges, Opportunities, and Global Adoption -- Panelists: Isotech, WIKA, Fluke, Chi3 Optics, U.S. Air Force**

Panelists: Isotech, WIKA, Fluke, Chi3 Optics, U.S. Air Force

This industry panel brings together leaders from Isotech, WIKA, Fluke, Chi3 Optics, and the U.S. Air Force to examine how next–generation temperature–sensing technologies can move from laboratory innovation to broad industrial deployment. Panelists will discuss commercialization challenges, key roadblocks, and practical strategies to accelerate worldwide adoption of advanced temperature–metrology solutions.

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