Thursday Morning, November 12, 2026

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

The Future of Temperature Sensing IV

Moderators: Dr. Nikolai Klimov, National Institute of Standards and Technology, **Dr. Sesha Challa**, NIST-Gaithersburg

8:00am **TS-ThM-1 Magnomechanical Noise Thermometry***, **John Davis**,* University of Alberta, Canada **INVITED**

Virtually every quantum technology needs to be operated at some level of low temperatures to generate and protect low energy quantum states.As a result, cryogenics has become a critical enabling tool in the race to develop quantum technologies.Yet little attention has been paid to the thermometry that allows us to quantify these low temperatures.As an example, most users of a dilution refrigerator simply take for granted that the resistive temperature sensor they use to measure millikelvin temperatures is accurate (and actually represents their experimental temperature).A such, we believe that a renewed focus must be put on primary temperatures sensors in the sub-kelvin regime to ensure that quantum technologies and their enabling cryogenics can be accurately measured and compared between laboratories.To this end, we are working on a type of mechanical noise thermometry using the techniques of cavity optomechanics.I will provide the background and context of this temperature sensor and where we are in its development.

8:30am **TS-ThM-3 Compact Blackbody Radiation Atomic Sensor (CoBRAS)***, Eric Norrgard,* National Institute of Standards & Technology*; **William Newman**,* National Institute of Standards and Technology

The NIST Fundamental Thermodynamics group is leveraging the physical properties of atoms to provide accurate metrology of radiative temperature. Atoms are quantum systems whose interactions with electromagnetic radiation have been characterized with exquisite precision and, in many cases, are amenable to ab initio calculation. Compact Blackbody Radiation Atomic Sensor (CoBRAS) uses fluorescence detection of optically excited atoms in vapor cells to determine temperature. A CoBRAS temperature measurement is fast, with statistical uncertainty as low as 0.1% in one second. We provide an update on the temperature precision, range, and sensitivity of the CoBRAS. We also describe a new fiberized CoBRAS sensor with a form factor similar to traditional four-wire resistance thermometers.

8:45am **TS-ThM-4 Electro-Optic Frequency Comb Doppler-Broadening Thermometry***, **Sean Bresler**,* University of Maryland, College Park/National Institute of Standards and Technology (NIST)*; Erin Adkins,* National Institute for Science and Technology (NIST)*; Stephen Eckel,* National Institute of Standards and Technology (NIST)*; David Long,* National Institute for Science and Technology (NIST)*; Benjamin Reschovsky, Daniel Barker,* National Institute of Standards and Technology (NIST)

We demonstrate Doppler-broadening thermometry based on direct optical frequency comb spectroscopy of an 85Rb vapor with a chirped electro-optic frequency comb (EOFC). The direct EOFC Doppler-broadening thermometry measurements are accurate to within their approximately K statistical uncertainty. We experimentally compare direct EOFC spectroscopy with conventional Doppler spectroscopy using a single-frequency, step-scanned laser probe. Our results show that direct EOFC spectroscopy mitigates transit-induced optical pumping distortion of the atomic lineshape, which is the dominant systematic temperature shift in alkali atom Doppler-broadening thermometry. Optical Bloch equation simulations of conventional and direct EOFC Doppler spectroscopy confirm that EOFC spectroscopy can use higher optical power to reduce statistical noise without optical pumping distortion. Our results indicate that EOFC Doppler-broadening thermometry is a promising approach to realizing a primary thermometer with size and measurement rate sufficient for applications including pharmaceutical manufacturing and nuclear waste monitoring.

9:00am **TS-ThM-5 Towards Practical Integrated Primary Thermometry with Optomechanical and Photonic Techniques***, **Olga Kozlova**,* LNE-Cnam, France **INVITED**

Temperature is one of the most commonly measured physical quantities and influences nearly every physical, chemical, and biological process. Photonic and quantum-based approaches have the potential to transform practical thermometry by enabling *in-situ* traceability without requiring sensor removal for recalibration. A further advantage of these optical methods is their compatibility with silicon photonics, allowing on-chip integration thus to have the potential to radically improve thermal management of semi-conductor devices.

In this presentation, I will give an overview of the progress of European Partnership in Metrology Joint Research Project: Photonic and Quantum Sensors for Practical Integrated Primary Thermometry (PhoQuS-T) [1]. This project aims to develop integrated optical practical primary thermometry from 4 K to 500 K to enable *in-situ* traceability for practical applications.To achieve this, we combine several techniques: photonic thermometry using ring resonators; optomechanical noise thermometry and quantum correlation thermometry with opto-mechanical resonators. In addition, key challenges such as robust packaging over a wide temperature range are being addressed, along with metrological validation of the developed sensors and the exploration of future application possibilities.

At the current stage of the project, recent progress in photonic thermometry and optical noise thermometry from 4 K to 300 K, using 1D- and 2D- optomechanical sensors, will be presented. The next steps toward self-calibration using quantum thermometry (quantum correlation techniques [2]) will also be discussed. An overview of advances in high-resolution photonic sensors based on ring resonators operating over an extended temperature range (80 K to 500 K) will be given, along with updates on the development of a novel active thermometry approach [3]. Progress in packaging techniques (including gluing, welding, and mechanical support) for the developed sensors will also be presented.

Finally, developments toward practical application of such photonic sensors (including temperature monitoring of photonic integrated chips for optical clocks and assigning temperature in quantum-based pressure measurements) will be discussed.

References:

[1] https://www.mdpi.com/2673-8244/5/3/44

[2] https://www.science.org/doi/10.1126/science.aag1407

[3] https://doi.org/10.1098/rsta.2024.0459

9:30am **TS-ThM-7 Two-Dimensional Silicon Optomechanical Crystals for Quantum-Referenced Temperature Sensing***, **Daniel Ramos**,* CSIC, Spain*; María José Martin Hernandez,* CEM, Spain*; Irene Castro,* CSIC, Spain*; Iago Sanchez,* CEM, Spain

Accurate temperature sensing at the nanoscale remains a central challenge for emerging quantum, photonic and nanomechanical technologies, where local heating, weak thermal anchoring and limited calibration accuracy can strongly affect device performance. Optomechanical systems offer a route to temperature sensing based on the thermal occupation of mechanical modes, enabling local, contactless and potentially self-calibrated thermometry through the optical readout of mechanical motion.

Here we present the design and first experimental realization of a two-dimensional silicon optomechanical crystal engineered as a platform for temperature sensing across the transition from the classical thermal regime toward the quantum regime. The device integrates a telecom C-band optical cavity and a co-localized GHz radial-breathing mechanical mode within a two-dimensional phononic shield. This architecture combines strong optical–mechanical confinement with improved thermal anchoring to the substrate compared with conventional one-dimensional optomechanical cavities, reducing absorption-induced heating while preserving high displacement sensitivity.

The geometry was optimized using three-dimensional simulations and machine-learning-assisted parametric sweeps to achieve operation in the resolved-sideband regime, high optical and mechanical quality factors, and strong optomechanical coupling. These characteristics enable sensitive monitoring of the mechanical noise spectrum as a function of temperature and provide the basis for sideband-resolved thermometry at low phonon occupation. In this regime, the Stokes and anti-Stokes sidebands provide a direct route to absolute quantum thermometry, since their asymmetry is determined by the mean phonon population rather than by an external thermal calibration.

We discuss how this two-dimensional optomechanical platform can be used for temperature sensing from elevated temperatures down to cryogenic conditions, with particular emphasis on quantifying local optical heating, calibrating phonon occupation, and approaching the quantum ground state. By combining heterodyne sideband readout, optomechanical cooling and sideband-asymmetry thermometry, the device provides a route toward quantum-referenced nanoscale temperature sensing. These results position two-dimensional silicon optomechanical crystals as a promising integrated platform for future temperature sensors operating beyond conventional calibration limits.

9:45am **TS-ThM-8 Developing Thermal Magnetic Imaging for Advanced Semiconductor Packaging**, ***Frank Abel****,* *Thinh Bui, Mahadi Rajib,* National Institute of Standards and Technology (NIST)*; Brian Donovan,* United States Naval Academy*; Solomon Woods,* National Institute for Science and Technology (NIST)

As the number of transistors on a single chip has approached its physical limit, the architectural complexity of semiconductor packaging in the form of heterogeneous 3D integrated components has been developed to meet the demand for high performance computing. However, with increased complexity comes significant thermal management issues, which are a crucial factor in designing new high-density semiconductor packages. These challenges require new measurement techniques to quantify temperature and heat flow during operational conditions through opaque materials with greater than 1 mm of depth penetration. For the past 5 years, our team at NIST has been developing magnetic imaging instrumentation and magnetic nanoparticle thermometers for 3D temperature imaging. Here, we present our progress in designing temperature- and signal-sensitive magnetic nanoparticle tracers integrated into proxy semiconductor materials, including silicon substrates, thermal interface materials (TIMs), and underfills. Along with the demonstration of solid-state imaging of embedded tracers in silicon imaging phantoms.

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