

CCT member and observer Activity Report

Period: April 2024 to April 2026

Institute: National Institute of Metrology

State economy: P. R. China

Number of persons involved in thermometry of the institute:20

Short summary of research and development:

1. Contact Thermometry

1.1 Primary Contact thermometry

- Acoustic Gas Thermometry

The primary experiments for the determination of the difference between the thermodynamic temperature and ITS-90 from 319 K to 1303 K were carried out using two sets of cylindrical acoustic gas thermometry experimental (c-AGT) systems. A bolted cavity of c-AGT system is developed for application from 319 K to 823 K. The bolted resonator was hung in a pressure vessel surrounded by a radiation shield, a heat pipe, and a furnace. The acoustic resonant frequencies were measured in argon with the relative standard uncertainty $(3\sim 5)\times 10^{-6}$ from 580 K to 809 K. Each microwave resonance frequency was measured with a relative standard uncertainty of 3×10^{-7} . The inconsistency between four independent microwave modes was 2.2×10^{-6} at 809 K. A welded cavity of good gas-sealing performance is developed to test the microwave and acoustic measurements up to 1303 K. Although the gaps and cavity-distortions caused by welding deteriorate the measurement performance of the resonator, it shows the possibility to extend the c-AGT up to the copper point and to compare the thermodynamic temperature with primary radiometric thermometry at high temperature range if a bolted resonator was set in a welded pressure vessel.

- Noise Thermometry

Subsequent to our previous work on measuring the melting point of gallium with the fully differential superposition Johnson noise thermometer (SJNT) in 2022 [JNT,Han,2022], efforts have been focused on extending the temperature range and improving system integration and robustness for industrial applications. Recently, high-temperature measurements at 673.15 K (400 °C) were performed using our newly developed, highly integrated SJNT while the furnace temperature was concurrently monitored by a 25 Ω standard platinum resistance thermometer (SPRT) to assess measurement consistency. With the SJNT operating under a measurement bandwidth of 200.8 kHz and a cross-correlation integration period of 500 s, the difference between the SJNT and SPRT was found to be less than 0.05 K, with an associated uncertainty of

less than 0.4 K ($k=1$).

1.2 Replacement of Hg point

Over the past four years, we have conducted a comparative investigation of the three CO₂ triple point cells. In order to exclude auxiliary influences, we selected a single thermometer of high stability to be used in this work. The first cell has been measured for tens over the four-years span. That cell demonstrate a long-term stability of 0.04 mK with a standard deviation of 0.04 mK. The other two cells exhibit the annual differences of 0.02 mK and 0.08 mK with the first cell, respectively. The standard deviations of measurements are of less than 0.065 mK with the other two cells. The frequently regular weighing of the cells shows minor leaks of the sample in cell. The cumulative leak of the first cell in the four-years span is 50 g. Nevertheless, the long-term measurements account for no systematic drift. In summary, NIM's work demonstrates a perspective of long-term stability and consistency with the realizations of the CO₂ TP.

1.3 Pilot for APMP K9, APMP-S15

APMP.T-K9 piloted by NIM and supported by NMIJ, KRISS and NMIA is designed to compare the realization of the ITS-90 through the calibration of SPRTs. The range of temperature covered in this comparison is from the triple point of Ar (83.8058 K) to the freezing point of Zn (692.677 K), link to the CCT -K9. Ten labs in the Asia-pacific region participate in the comparison. At present, all the data from all participating institutes have been received, and the draft A of APMP.T-K9 comparison report has been completed.

A comparison of radiance temperature scales for clinical infrared ear thermometers (APMP.T-S15) have been performed successfully over the temperature range from 35.5 °C to 41.5 °C using one travelling blackbody in APMP. The radiance temperature of the travelling blackbody cavity has been compared directly to the standard blackbodies of the participating NMIs using ear thermometers with high resolutions and good short-term stabilities. There are some outliers in the results, but, in general, the radiance temperatures realized by the participant NMIs agree to well within ± 0.03 °C, which is agreeing with each other within the measurement uncertainties. The results also demonstrate comparable quality of the blackbody cavities recommended for the ear thermometer calibration in the ASTM, JIS, EN and CN standards. The results of this comparison can be used to underpin the Calibration and Measurement Capabilities (CMCs) of the participants, both for the calibration of ear thermometers and the ear thermometer blackbodies.

1.4 ITS-90

- Temperature scale

An important application of Ga-based alloys is the use of their eutectic point as temperature fixed points for thermometer calibration at room temperature. NIM has developed a highly reproducible Ga-In eutectic fixed point and successfully realized its melting plateau. The results show that the duration of the Ga-In eutectic melting plateau lasted for more than 80 h with a temperature change of less than 1.5 mK. The temperature of the plateau changed within 1 mK during the middle of 55 h, and within 0.5 mK during the middle 30 h. By repeatedly realizing Ga-In eutectic melting plateaus, the melting point temperature was determined to be 15.6479 °C, with a reproducibility of less than 0.14 mK. The corresponding realization uncertainty of Ga-In eutectic was also analyzed and was found to be 0.90 mK ($k = 2$). These results are consistent with those of previous studies within the associated uncertainties and will help better understand the phase diagram and the corresponding thermal properties of the Ga-In eutectic.

NIM designed and tested a cryostat based on a two-stage closed-cycle Gifford-McMahon cryocooler for the calibration of capsule standard platinum resistance thermometers (c-SPRTs) or standard rhodium-iron resistance thermometers (RIRTs) from 3.4 K to 273 K. After 550 hours experiments in the cryostat, the drift for a c-SPRT at the triple point of water was measured to be 0.07 mK. The temperature fluctuation was measured with the standard resistance thermometers from 3.4 K to 273 K within $\pm(0.1\sim 0.3)$ mK per 30 minutes. We used two RIRTs to measure the temperature inhomogeneity of the copper blocks at 3.4 K. The temperature difference from the two thermometers was less than 0.1 mK at 3.386 K. Two c-SPRTs were used to measure the temperature inhomogeneity at higher temperature, and 0.56 mK temperature difference was observed at 237.369 K. NIM realized the cryogenic fixed points (e-H₂, Ne, O₂, Ar) and compared the inconsistencies between different c-SPRT and RIRTs near 17 K and 20 K. Long-term good stability (better than 0.5 mK/40 years) were found for RIRTs. The system for realizing PLTS-2000 is also under building.

- Photonic thermometry

NIM has continued to promote the progress of micro-nano scale temperature measurement based on nitrogen-vacancy centers in diamond thermometer. Firstly, the heating effects generated by microwave and laser power have been extensively studied. We independently designed double open loop resonant and broadband large-area irregular microwave antennas, which effectively improved the effective microwave power and signal-to-noise ratio. Moreover, a new method for calibrating solid-state quantum thermometers using the zero method of thermoelectric potential of micro-thermocouples is proposed. By tracking the temperature of the measurement end and the reference end using the thermoelectric potential null method, accurate measurements of the temperature at the measurement end were achieved using a standard platinum resistance thermometer. This established a traceability chain between the NV center and the International Temperature Scale of 1990 (ITS-90). Finally, the

uncertainty of temperature measurement is better than 0.05 K ($k=1$) by optimizing the parameters of laser and microwave. In the future, we will be committed to the development of miniaturized temperature measurement standard devices and promote their application in chip manufacturing and biomedical fields.

NIM proposed a photonic sensor with sub-milli-kelvin resolution and broad range utilizing frequency-locked silicon nitride microring resonator combined with a wide spanning soliton microcomb. The approach leverages the microcomb-microring beatnote for temperature measurement of on-chip devices with an ultra-high resolution of 58 μ K. Moreover, a feedback voltage gradient based ambiguity resolving method was proposed to eliminate the non-ambiguous temperature range caused by two symmetry beatnotes between comb-lines, which ensures the ultra-high resolution over the measurement range of 45 K in the proof-of-concept experiment.

- Thermocouple

NIM has promoted the implementation of calibration specification for gold/platinum thermocouples in China, and officially implemented on September, 2025. Moreover, the report of APMP regional comparison of type R thermocouples calibration at Cu, Co-C and Pd fixed points has been completed. Based on the comparison results, we have applied to add CMCs for type S and R thermocouples at Cu, Co-C and Pd fixed points. Meanwhile, CMC related to type B thermocouples is also being applied for. In the future, we will also expand the temperature upper limit of calibration capabilities and promote technological applications in fields such as low altitude economy and integrated circuits.

2. Radiation Thermometry

2.1 Primary Radiation Thermometry

The relative spectral responsivity of photoelectric pyrometers at NIM has been enhanced to support the thermodynamic temperature measurements based on the relative primary method. The tungsten halogen lamp was replaced with a supercontinuum laser source, which, operating in feedback mode at 50% power, provides an output 2–3 orders of magnitude higher than the original lamp while achieving a stability of up to 0.01%. A dual-reflection output beam path was designed to replace the original transmissive configuration, incorporating a dark box to significantly improve luminous energy utilization and effectively suppress stray light. These modifications reduced the dark current of the pyrometer under test from 10^{-12} A to 10^{-14} A and enhanced the measurable transmittance in the cutoff region to the 10^{-8} level. Additionally, the output wavelength of the double monochromator was cross-verified using a neon spectral lamp and a Fourier transform spectrometer, substantially reducing the uncertainty in effective wavelength calculations caused by wavelength errors. Experimental results indicate that the upgraded system achieves an order-of-magnitude improvement in the measurement repeatability of spectral responsivity

within the passband region. The measurable responsivity in the cutoff region advanced from 10^{-6} to 10^{-8} , with the uncertainty in effective wavelength evaluation determined as 0.032 nm.

A new spectral responsivity measurement of a 1.6 μm photoelectric pyrometer across 600 nm–2500 nm, with an in-band peak at 1550 nm and out-of-band rejection exceeding 10^{-7} , has been established at NIM. Wavelength calibration shows repeatability better than 0.05 nm. A segmented calibration strategy is applied to calibrate a long-wavelength enhanced InGaAs detector as a reference. The effective wavelength standard uncertainties at Zn fixed points are below 0.096 nm, with temperature effects under 0.02 °C. Calibration deviations between the effective-wavelength and fixed-point methods are within ± 0.16 °C, verifying measurement reliability. However, the system still lags behind international advanced levels due to relatively large standard detector uncertainty. Nonlinearity of the InGaAs detector at low power and insufficient long-term stability are observed. Future improvements include establishing a traceability chain via national primary standards, developing linearization algorithms, and adopting a wavemeter for real-time wavelength calibration to enhance uncertainty performance for mid- and low-temperature radiometric thermometry.

3. Thermometry for Meteorology and Climate

The second-generation Vacuum Radiance Temperature Standard Facility (VRTSF) at NIM has been developed with a temperature range from 100 K to 500 K. NIM is developing spaceborne infrared radiance primary standard blackbody system for China's Infrared remote sensing benchmark satellite. The combined uncertainty of the blackbody is 0.04K. The miniature fixed points are employed in the blackbody.

4. Thermophysical Properties

Partnership Agreement for bilateral comparison of spectral and bandwidth emissivity under air condition between NIM and LNE was officially assigned. This compares the spectral infrared emittance measurement capabilities of LNE and NIM, utilizing the comparison artefacts as the transfer standard. The preliminary results will be discussed this May 2026 at LNE.

NIM proposed a robotic arm-based continuous scanning method, which effectively decouples angular coupling effects and drastically shortens the measurement time. In conjunction with a measurement scheme utilizing blackbody radiation sources to address the shortage of broadband sources, the proposed methods have overcome the bottlenecks of low spatial resolution and inadequate wavelength coverage, thus enabling high-precision infrared BRDF characterization across a wide temperature and spectral range.

In the field of thermal diffusivity measurement, we have upgraded the measurement capability: the measurable temperature range has been extended down to 173 K, the measurement scope expanded to the in-plane direction of anisotropic thin-film materials, and the overall measurement uncertainty optimized to better than 10%.

Short summary of recent comparison activity:

CCT K11 is to undertake a global key comparison of blackbodies used for calibrating ear and forehead thermometers between 34.0 °C and 43.0 °C. The comparison will ensure that there is a robust metrological framework in place for the calibration of such thermometers. The pilot laboratory is NIM (China). The comparison experiments in EURAMET have all been completed. The comparison experiments in APMP is ongoing. The transfer artefact has been delivered to KRISS. NMC A*STAR has just completed the comparison. The next NMI after KRISS would be NMIA and NMISA. We plan to finish Draft A by the end of 2026.

NIM piloted and finished APMP.T-4.1 (Comparison of local realizations of Silver freezing-point temperatures) between NIM and CMS/ITRI, Chinese Taipei in 2024.

Short summary of other activities:

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Link to bibliography or list of bibliography (last 5 years):

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