Program & Abstracts for the
8th International Temperature Symposium

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11:45	Closing Remarks	Dr. Dean Ripple, Program Chair NIST, Gaithersburg, Maryland, USA
12:00	Closing Plenary Talk	Dr. Terry Quinn, Director BIPM, Sevres, France *Life Before, During and After Key Comparisons*

12:45 Adjourn

Program & Abstracts for the 8th International Temperature Symposium

Monday, October 21, 2002

7:30 Speaker Breakfast – Location: N426c
8:00 Registration

9:00 Opening Plenary

9:00 Opening Remarks Dr. Larry Rubin, General Chairman

9:30 Keynote Talk *Temperature Metrology and Its Impact on Industry*
Dr. Hratch Semerjian, Director, Chemical Science and Technology Laboratory, NIST, Gaithersburg, MD USA

10:30 Break / Exhibits

10:45 Session A-1. Thermodynamic Thermometry

A-1, 10:45 Investigation of the Accuracy of the ITS-90 with Reference to Thermodynamic Temperature in the Range from 400 °C up to 600 °C

D. R. Taubert, J. Hartmann, J. Hollandt, J. Fischer
Physikalisch-Technische Bundesanstalt, Abbestraße 2-12, D-10587 Berlin, Germany

For several years Physikalisch-Technische Bundesanstalt (PTB) has performed thermodynamic temperature measurements at a large area blackbody applying filter radiometers based on silicon photodiodes and interference filters with center wavelengths at 676 nm, 800 nm, 900 nm, and 1000 nm. These filter radiometers were used for the determination of possible systematic deviations of temperatures measured according to the International Temperature Scale of 1990 (ITS-90), T_{90}, and the thermodynamic temperatures T. The measurements revealed a difference of 50 mK of $T-T_{90}$ at temperatures around the freezing point of silver (961.78 °C). The observed difference decreases with decreasing temperatures, indicating that it may be attributed to a systematic deviation in the ITS-90 from T due to the gas thermometric temperature measurement at 457 °C, which has been used as reference temperature for extrapolation of the ITS-90 to higher temperatures. For a further, more detailed investigation it was necessary to measure the difference $T-T_{90}$ down to temperatures of 420 °C, the temperature of freezing Zinc, which serves as one of the temperature fixed points of the ITS-90. However, the spectral responsivity of silicon photodiodes does not allow their application in filter radiometers with center wavelengths beyond 1000 nm, which are needed for precise thermodynamic temperature measurements below 450 °C. Therefore a filter radiometer with center wavelength around 1600 nm based on an Indium-Gallium-Arsenide photodiode has been developed. The design of this radiometer, the assessment of its spectral responsivity and its temperature dependence will be shown. $T-T_{90}$ results are presented for the temperature range from 400 °C to 600 °C obtained with filter radiometers with their center wavelengths at 800 nm, 900 nm, 1000 nm, and 1600 nm.

A-1, 11:05 Determination of the Thermodynamic Temperature of the Freezing Point of Copper by Noise Thermometry

F. Edler[1], E. Tegeler[1], E. Zimmermann[2]
[1]Physikalisch-Technische Bundesanstalt, Berlin, Germany, [2]Forschungszentrum Jülich GmbH, Jülich, Germany

The thermodynamic temperature of the freezing point of copper was measured by noise thermometric methods. A conventional approach was used which combines the noise voltage of the measuring resistor with that of a reference resistor maintained at a known temperature. Besides this comparison method the thermometer is characterized by a two-channel arrangement to eliminate parasitic noise of electronic components by cross correlation. The thermo-dynamic temperature measured at the freezing point of copper amounts to a value of 1084.54 °C ± 0.12 K ($k = 2$). This corresponds to the value of the ITS-90 temperature of this fixed point of 1084.62 °C within its thermodynamic uncertainty of 0.12 K ($k = 2$).

A-1, 11:25 Using Fourier-Transform Blackbody Spectra to Determine Thermodynamic Temperature in the 600 °C to 1000 °C Range

A. L. Reesink , N. L. Rowell, and A. G. Steele
National Research Council of Canada, Ottawa, ON, Canada

Results of experimental determinations of thermodynamic temperatures using Fourier transform spectroscopy of blackbody radiation sources are presented. These results are augmented by and compared with theoretical simulations of blackbody spectra in order to assess the feasibility and accuracy of the method. Much of the information on thermodynamic temperature contained in such spectral sets is redundant, and we present a method (based on the original suggestion by Gebbie and recent work done at NRC) to exploit this redundancy in a straightforward way to obtain thermodynamic temperatures for each of the spectral sources. Here, we briefly describe the experimental apparatus, the analysis of the most recent experimental results and a comparison with our simulations.

A-1, 11:45 Techniques for Primary Acoustic Thermometry to 800 K

D. C. Ripple, D. R. Defibaugh, M. R. Moldover, and G. F. Strouse
National Institute of Standards and Technology, Gaithersburg, MD, USA

The NIST Primary Acoustic Thermometer will measure the difference between the International Temperature Scale of 1990 and the Kelvin Thermodynamic Scale throughout the range 273 K to 800 K with uncertainties of only a few millikelvins. The acoustic thermometer determines the frequencies of the acoustic resonances of pure argon gas contained within a spherical cavity with uncertainties approaching one part in 10^6. To achieve this small uncertainty at these elevated temperatures we developed new acoustic transducers and new techniques for the maintenance of gas purity and for temperature control. Lacking a suitable commercial acoustic transducer, we developed novel electro-acoustic transducers based on the capacitance between a flexible, single-crystal, silicon diaphragm and a rigid, stainless-steel, backing plate. These transducers have been used successfully to 575 K. To preserve the purity of the argon, no polymers were used in any components of the acoustic thermometer that contacted the argon. Without the damping usually provided by polymers, mechanical vibrations caused unstable, spurious acoustic signals. We describe the techniques that we developed to suppress vibrations and obtain stable signals. In contrast with constant-volume gas thermometry, acoustic thermometry allows the thermometric gas to be continuously flushed through the resonator, thereby preventing the build up of outgassed impurities. We describe how the argon pressure is stabilized while flushing and measuring resonance frequencies. The argon exiting from the resonator is sampled directly and analyzed with a customized gas chromatograph. The dominant impurity is hydrogen that evolves from the stainless steel resonator. To determine the thermodynamic temperature within a few millikelvins, the temperature of the resonator must be stable and uniform to within 1 mK during the measurement. Because the acoustic resonator was so large—it has an outer diameter of 20 cm—a sophisticated furnace, based on surrounding the resonator with three concentric aluminum shells, was designed to achieve this goal. We describe the design, modeling, and operational characteristics of the furnace.

A-1, 12:05 Progress in Primary Acoustic Thermometry at NIST: 273 K to 505 K

G. F. Strouse, D. R. Defibaugh, M. R. Moldover, and D. C. Ripple
National Institute of Standards and Technology, Gaithersburg, MD, USA

In the limit of zero pressure, the speed of sound in a monatomic gas is a measure of the thermodynamic temperature of the gas. The NIST Acoustic Thermometer determines the speed of sound in argon, and consequently its thermodynamic temperature, by measuring the frequencies of both the acoustic and the microwave resonances of an argon-filled, spherical cavity. The microwave frequencies determine the thermal expansion of the cavity from 273.16 K to the operating temperatures while the acoustic frequencies determine the changes of speed of sound in the argon with temperature. We report our progress in redetermining the thermodynamic temperature of three fixed points on the International Temperature Scale of 1990: the melting point of gallium (302.9146 K) and the freezing points of indium (429.7485 K) and tin (505.078 K). Preliminary results for the deviation of thermodynamic temperature from the ITS-90 defined temperature are $T-T_{90}$ = (4.8 ± 0.8) mK at the gallium melting point, and $T-T_{90}$ = (11.1 ± 1.6) mK at the indium freezing point, where uncertainties have a coverage factor of k=1. The measured thermal expansion of the resonator between the triple point of water and the melting point of gallium, and the measured deviation of ITS-90 from thermodynamic temperature at the gallium point are both in excellent agreement with the 1992 determination at NIST. In these preliminary data, the dominant uncertainties come from frequency-dependent and time-dependent cross-talk between the electroacoustic transducers. There is hope for reducing these uncertainties.

10:45 Session A-2. Industrial PRTs

A-2, 10:45 Intercomparison of Pt-100 Thermometers of Some Secondary Laboratories of Germany and México (DKD And SNC)

S. Friederici[1], A. Aulich[1], E. Méndez-Lango[2], and R. Ramírez-Bazán[2,3]
[1]PTB, Berlin, Germany, [2]CENAM, Querétaro, México, [3]Universidad Autónoma de Guadalajara, Jalisco, México

On the basis of Mutual Recognition Agreements signed by different organization not only the calibration certificates of the National Metrology Institutes, but also of the accredited calibration laboratories should be accepted worldwide. Therefore international intercomparisons should include also secondary laboratories. Such an intercomparison was organized between 8 secondary laboratories in Germany and México using platinum resistance thermometers in the temperature range between -20 °C and 250 °C. The results are analyzed using different methods, including Youden diagrams for the evaluation of the capabilities of the laboratories.

A-2, 11:05 Efficient Calibration Methods For Platinum Resistance Thermometers

Richard W. Phillips
Sensor Systems, Goodrich Corporation, Eagan, MN, USA

Calibration methods for platinum resistance thermometers are simplified by reducing the number of calibration points. For applications that do not require the low uncertainties of the ITS-90 definitions, several modifications are available to improve calibration efficiency. The proposed schemes utilize the ITS-90 reference functions, simplified deviation equations, and in some cases correlations between resistance ratio values. Calibration ranges of interest include: 20 K to 273 K, 273 K to 933 K and various subranges spanning the ice-point from 77 K to 505 K. Thermometers are tested using two to three calibration temperatures with media convenient for comparison calibration. The methods apply to a broad class of thermometers constructed with high purity platinum. Several examples of fit error are presented for standard platinum resistance thermometers (SPRT) and more rugged aerospace sensor designs. Recommendations to minimize the influence of thermal hysteresis are also discussed. The approximations introduce errors typically between 10 mK and 100 mK depending on thermometer type and temperature range. For many applications, these calibration methods satisfy the tradeoff between cost and uncertainty.

A-2, 11:25 Development of Metal Sheathed Secondary Standard and Precision RTD Thermometer at Temperatures up to 960 °C and 1,100 °C

Chaoying Xing
Advanced Sensing Products

High quality metal sheathed secondary standard and precision RTD thermometers were developed. They were designed for both laboratory and industrial applications. There are two temperature ranges of the RTD: up to 960°C and up to 1,100°C. The PRT with metal sheath can be used at temperature up to 1,100°C without contamination due to special manufacture process to overcome contamination. This article presents test data to show the stability, hysteresis, and thermal cycle at different temperatures up to 1,100°C. Both secondary standard PRTs and precision industrial RTDs were tested.

A-2, 11:45 Investigation of Functions $W(T_{90})$ for Low-α PRTs in the Sub-ranges above 0 °C

N. P. Moiseeva
D.I. Mendeleyev Research Institute of Metrology, St. Petersburg, Russia

The most practical method of interpolation for industrial platinum thermometers is the use of the Callendar-Van Dusen second-order equation. Standard tables R(T) for IPRTs of different purity of the platinum wire were established by number of Standards (IEC, DIN, GOST, JIS). From fitting the coefficients B vs. A of the CVD equations, obtained for 166 thermometers with W(100) ranging from 1.380 to 1.392, the linear function B(A) was generated in this work, which makes it possible to establish the second-order reference function for PRTs of any nominal W(100) value. It is important, that substantial distortion of the interpolating CVD curves was found for the IPRTs with film platinum sensing elements. Although the ITS-90 interpolation method is supposed to be applied only to the PRTs, that have a strain-free sensing element made of platinum wire of a very high purity (W(Ga)> 1.11807), it has become usual practice to use the ITS-90 function for industrial thermometers. As shown in the paper, a systematic difference occurs between temperature values calculated by means of the CVD equation and the ITS-90 interpolation technique, which does not depend on the purity of the platinum wire in a large W(100) range, but highly depends on the temperature sub-range. For individual calibration of an IPRT in the sub-range 0-230 °C, it is possible to use only one calibration point, besides 0 °C.

A-2, 12:05 Maskless Deposition of Platinum for Contact Thermometry

Marcelino Essien[1], Michael J. Renn[1], Pam Seigal[1], Richard W. Phillips[2]
[1]Optomec Inc., Albuquerque, NM, USA, [2]Sensor Systems, Goodrich Corporation, Eagan, MN, USA

Optomec Inc., Albuquerque, NM, has developed a direct write process that may be used to deposit resistive thermometers onto low temperature, planar and non-planar surfaces. The process, Maskless Mesoscale Materials Deposition (M^3D), is an aerosol-based technology that uses an aerodynamically focused stream of droplets or particles to deposit films of electronic materials onto a wide range of substrates, including polyimide, FR4, and alumina. The linewidth of the deposit may be as small as 25 microns, and various geometries are produced using computer-driven motion control. The deposits are processed either thermally, or by using laser sintering and laser chemical decomposition. Optomec has demonstrated thermal and laser chemical decomposition of Pt precursor deposits on polyimide and alumina, with resistivities from 3 –10 times that of bulk Pt. This work investigates the feasibility of using direct write Pt resistors for contact thermometry. A discussion of XRD and SEM results detailing surface morphology and densification of the deposits will be given. Results on Pt adhesion to various substrates, resistance-temperature characteristics, and environmental studies of the thermometers will be discussed.

10:45 Session A-3. Radiation Thermometry-Pyrometers & Detectors

A-3, 10:45 Design and Construction of a New Primary Standard Pyrometer at NPL

D. Lowe, H. C. McEvoy and G. Machin
National Physical Laboratory, Teddington, TW11 0LW, United Kingdom

For many years the temperature scale at NPL has been realized and maintained using the NPL primary pyrometer. This instrument has reached the end of its useful life and a replacement instrument has been built and is currently being validated. This new instrument will give reduced uncertainties in disseminating the temperature scale.

A-3, 11:05 Use of an InGaAs Radiation Thermometer to Verify the Accuracy of the NPL Blackbody Reference Sources from 156 °C to 600 °C

Brian Chu, Helen McEvoy, and Graham Machin
National Physical Laboratory, Teddington, TW11 0LW, UK

A transfer standard radiation thermometer based upon an InGaAs detector was developed at the NPL in 2001. The purpose of this instrument was to provide a compact high-resolution device, which could be used to maintain and disseminate a radiance temperature scale between 156 °C and 962 °C. The thermometer requires calibration at the ITS-90 fixed-points. For this purpose fixed-point blackbody sources have been designed and constructed using high purity metals comprising In, Sn, Zn, Al and Ag. Using the results of the calibration, an interpolating equation based upon the Wien function is calculated which relates the thermometer output to the radiance temperature of the source. This paper describes the development of the InGaAs thermometer with results which illustrate its stability between successive calibrations. The InGaAs thermometer was used to verify the calibration of the NPL variable-temperature water and caesium heat-pipe blackbody sources, whose temperatures are normally derived from ITS-90 calibrated SPRTs inserted into the rear of the sources. This was achieved by comparing the radiance temperature of these sources obtained using the calibrated InGaAs thermometer with the ITS-90 contact thermometry at various test temperatures. Allowing for measurement uncertainties and the emissivity of the reference sources, differences within ±0.1°C have been obtained at a number of test temperatures over the range 156 °C and 600 °C.

A-3, 11:25 The Development and the Characterization of an Absolute Pyrometer Calibrated for Spectral Radiance Responsivity

David W. Allen, Robert D. Saunders, B. Carol Johnson, Charles E. Gibson, and Howard W. Yoon
National Institute of Standards and Technology, Gaithersburg, MD 20899-8441 USA

The International Temperature Scale of 1990 (ITS-90), for temperatures above the freezing temperature of silver, is defined with pyrometers which rely upon spectral radiance ratios to one of the silver, gold or copper freezing temperature blackbodies and the use of the Planck radiance law. However, due to the use of spectral radiance ratios, the temperature uncertainties of ITS-90 increase as the square of the temperature ratios. Such increases in the temperature uncertainties can be reduced by using absolute radiometry with pyrometers traceable to cryogenic radiometers, and the resulting temperature uncertainties can be smaller than those measured using the ITS-90 techniques. We describe the development and the characterization of an absolute pyrometer (AP1) constructed at NIST and calibrated using absolute radiance responsivity. The calibrations were performed with the pyrometer as a single unit and thus separate measurements of the lens transmittance and the spectral responsivities of the filters and detectors were not necessary. The temperature measurement capabilities of the AP1 are shown using the melt and freeze cycle of the gold-point blackbody.

A-3, 11:45 High Accuracy Radiation Thermometer TSP for Radiometric Scale Realization in the Temperature Range from 600 to 2500 °C

V.I.Sapritsky, S.N. Mekhontsev, M.L.Samoylov, and S.A.Ogarev
All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI), 46 Ozernaya St., Moscow, Russia 119361

Designed at VNIIOFI high-accuracy radiation thermometer TSP for radiometric scale realization in the temperature range from 600°C to 2500 °C, has been recently modified and investigated. It has a successful record of functioning at precision measurement facilities at VNIIOFI (Russia), CNR Instituto di Metrologia (Italy), Ulusal Metroloji Enstituzu (Turkey), and has been ordered by Lot-ORIEL Sa (France), National Physical Laboratory (India) and some other metrology labs.

A-3, 12:05 Calibration and Characterization of the Transfer Standard Radiation Thermometer for APMP Intercomparison

Fumihiro Sakuma and Ma Laina
National Metrology Institute of Japan, Tsukuba, Ibaraki, Japan

APMP Key comparison of radiance temperature in 0.65 µm was carried out from 1997 to 2000 among seven institutes NMIJ, KRISS, NIM, CSIRO, NMC, KIM-LIPI and ITRI. Afterward APMP Supplementary comparison of radiance temperature in 0.9 µm started. Both of the comparisons employ transfer standard radiation thermometer as a transfer instrument. This paper describes the calibration and characterization of the 0.65 µm transfer standard radiation thermometers. The 0.65 µm thermometer was calibrated according to ITS-90. The copper-point calibration, spectral responsivity measurement and nonlinearity measurement were carried out. The measured spectral responsivity was multiplied by Planck equation and was integrated over wavelength. The coefficient was determined by the copper-point calibration. The integral scale of the output V at temperature T was approximated by an interpolation equation, $V(T)=C/[\exp\{c2/(AT+B)\}-1]$. Here $c2$ is the second radiation constant and three parameters A, B and C were determined from the calibrated outputs of the integral calculation at the copper- point, 2000 ˚C and 3000 ˚C. The difference between the interpolation and the integral calculation was less than 5 mK from the copper-point to 3000 ˚C. The nonlinearity was measured by the two-aperture method. An integrating sphere, a standard lamp and a halogen lamp were used so that the radiance sources cover from the copper-point to high radiance. The nonlinearity of the 0.65 µm thermometer was better than 0.005% in doubling from 960 ˚C to 2500 ˚C. The characterization included zero offset stability, gain ratio, ambient temperature dependence, long-term stability, stability in transport, size of source effect and distance effect.

10:45 Session A-4. Surface Temperature Measurement

A-4, 10:45 Traceability of Surface Temperature Measurements using Contact Thermometers

H. G. Liedberg
CSIR – National Metrology Laboratory, P O Box 395, 0001 Pretoria, South Africa

Two methods of transferring traceability from contact thermometers calibrated by immersion to thermocouples measuring surface temperature are compared. The temperature of a reference surface is determined (i) by extrapolation from thermometers inserted at different depths, or (ii) by measurement on the surface using a thermally compensated thermocouple. Components of measurement uncertainty are discussed for each technique, and results are compared from 50 °C to 300 °C.

A-4, 11:05 Temperature Measurements on Nonmetallics in Gas Turbine Engines

Raymond H. Niska
Honeywell Engines, Systems & Services, Phoenix, Arizona, USA

The gas turbine engine industry has been developing nonmetallics such as ceramic matrix composites (CMCs) and monolithic silicon nitride for use in hot section hardware. New product development requires characterization of the hardware during component and engine testing. Of primary importance in propulsion engine hot sections such as the combustor and turbines is knowledge of thermal patterns and profiles, identification of hot streaks, and component maximum temperatures. This is especially critical information to estimate hardware life and time-in-service between required maintenance inspections and teardowns. Thin-film thermocouples and flame-sprayed aluminum oxide installation methods have been developed and are being used for temperature measurements on these new materials.

A-4, 11:25 Analysis of Surface Temperature Measurement Errors in Vertical Natural Convection Cooled Channels

D. Zvizdic and L. Grgec Bermanec
LPM-FSB, University of Zagreb, Zagreb, Croatia

This paper describes iterative methodology for calculation of surface temperature measurement errors applied to symmetrically heated, vertical parallel plate channels. Heat transfer calculations within the channel (marching, control volume based, numerical procedure) are first based on initial raw and uncorrected surface temperature measurements. Those data are then utilized for determination of surface measurement errors modeled with emphasis on thermocouple induced local heat sink and convective stray looses. The new, corrected surface temperatures are then input to heat transfer calculations until satisfactory convergence. The scope of the methodology is investigated by it's application to surface measurement error estimation for several groups of channels, each group having different, but fixed height, and variable aspect ratio. The mutual influences of channel geometry and wall temperatures on surface measurement errors at various measurement locations along the channel height are analyzed with results presented in graphical form. It was found that close to the channel entrance errors tend to be significantly augmented due to thermo-siphon induced convective stray looses. As thermal boundary layers approach and meet, errors monotonically decrease and cease to exist in thermally saturated channel sections. It was also found that, because of the non-linearity, the channels with the same aspect ratio but different height, induce different convective stray looses to the sensors.

10:45 Session A-5. Novel Contact Thermometers

A-5, 10:45 Dynamically Self-Validating Contact Temperature Sensors

Daniel A. Barberree
AccuTru International Corporation, USA

Thermocouple and RTD technology is the workhorse of the temperature measurement industry. It has been refined and extended to cover a broad range of temperature measurement needs. However, it is well documented that these measurement devices experience "drift" or de-calibration while in service. For various reasons the sensor output can "drift" away from representing the true temperature. The magnitude of the drift depends on sensor type, construction, installation and process conditions, but it is well established, though not widely advertised, that these sensors are subject to drift. The real problem is that there has been no way to tell when drift begins to occur or to determine its magnitude, or even its direction. Now, Dynamically Self-Validating Sensors have been invented that eliminate unreliable readings and warn in advance of the onset of drift. In this paper, the technology of Self-Validating Sensors is explained and data is provided showing the performance of a Self-Validating sensor.

A-5, 11:05 New Generation of Resistance Thermometers Based on Ge Films on GaAs Substrates

N.S.Boltovets[1], V.K.Dugaev[2], V.V.Kholevchuk[3,4], P.C.McDonald[5], V.F.Mitin[3,4], I.Yu.Nemish[3], F.Pavese[6], P.V.Sorokin[7], E.A.Soloviev[3] and E.F.Venger[3]
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The latest achievements in the development of the resistance thermometers based on germanium films on gallium arsenide are summarized. The preliminary results in the development of a new generation of radiation-resistant thermometers and multifunctional sensors for the range from 0.03 K to 400 K and high magnetic fields, based on thin-film microelectronic and micromachining technologies, which have been produced in an international collaboration recently funded by the EU INTAS are introduced.

A-5, 11:25 A Primary Self-calibrating Thermometer Using Noise of a Tunnel Junction

L. Spietz, K. Lehnert, I. Siddiqi, R. Schoelkopf
Yale University, New Haven, Connecticut, USA

The wide range of thermometers used in cryogenic systems today all suffer from some combination of lack of absolute accuracy, complexity, and sensitivity to magnetic fields. We describe a primary thermometer that is fast, compact, insensitive to magnetic fields, and operates over a range from millikelvin temperatures to room temperature. The thermometer consists of a 50 Ohm tunnel junction whose noise power is measured by standard techniques of microwave radiometry. In such a junction, the quantum shot noise is an elementary function of the applied bias voltage, the electron's charge, the Boltzmann constant, and the temperature. In contrast to Johnson noise thermometry, this method is self-calibrating and depends only on applied DC voltage, temperature, and fundamental constants. Hence this system may have metrological applications. If we assume that the density of states and the tunneling matrix element are both independent of energy near the Fermi energy, it can easily be shown that the total current through the junction is a linear function of the voltage applied and that the current spectral density of the noise is given by 2eI Coth (eV/kT). This turns out to be realizable for aluminum-aluminum oxide-aluminum tunnel junctions with area of several microns. Because this functional form is independent of temperature at high bias, it can be used to perform a self-calibrating measurement of the thermal noise of the junction. This eliminates the need for detailed calibration of the amplifier chain that makes Johnson noise thermometry so difficult. Without being concerned with the frequency dependence of the measurement chain, we can use a much higher bandwidth than is possible in Johnson noise thermometry (of order 10^8 Hz compared to 10^5 or less for Johnson noise thermometry), allowing for much shorter integration times. We demonstrate that our tunnel junctions exhibit the stated functional form over more that 4 orders of magnitude in temperature. Furthermore, we demonstrate its use as a fast, primary thermometer, and speculate as to its implications both for a thermometer for general use in cryogenic labs and for metrology.

A-5, 11:45 Spherical Wireless Temperature Sensor

Yoshinori Shiote, Shigeo Miyagawa, Takeshi Fukiura, and Nobuo Takeda
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The concept of a wireless temperature sensor using spherical semiconductor technology is proposed. Various applications for this sensor are expected in the field where installation of conventional sensors is difficult or impossible. The authors are now developing its first phase prototype. State of development and technical issues are discussed in this paper. This concept can cause a paradigm shift in conventional control systems by the features of wireless, small size and low cost.

A-5, 12:05 Comparison between a Second Sound Thermometer and a Melting Curve Thermometer from 0.8 K down to 20 mK

L. Pitre, Y. Hermier, C. Geneville, A. Vergé, G. Bonnier
BNM-INM, Paris, France

BNM-INM realized the Provisional Low Temperature Scale of 2000 (PLTS-2000) [1]. Aside, for several years, the low temperature team of BNM-INM was studying the possibility to use the properties of dilute mixtures of 3He in 4He in order to develop a local temperature scale. It made the choice to develop a new type of thermometer based on the propagation of sound in diluted solutions of helium-3 in superfluid helium-4, a second sound thermometer. For low temperatures, the properties of low concentrated ^3He in superfluid ^4He are those of a nearly ideal Fermi gas. The experiments of Greywall[1] and Owers-Bradley and al.[2] have shown that the velocity of second sound in ^3He-^4He mixtures is very sensitive to temperature and this, specially below 0,5K. In the second sound thermometer developed by BNM-INM, the speed of the sound is determined from the resonance spectra of an acoustic cavity. The temperature is deduced from the measurement of the resonnane frequencies, by using a physical model describing the relation between the speed of sound, the acoustic length of the cavity and the temperature. This paper will present the experimental results obtained for the temperature determinations using the second sound thermometer and for the comparison between this thermometer and the melting curve thermometer in the temperature range from 0.8 K down to 20 mK. A detailed budget of uncertainty on the temperature comparison will be given. This study corresponds to a contribution of BNM-INM to an European research project, named Ultra Low Temperature dissemination [4].

[1] Pitre and al, "Realization of the Provisional Low Temperature Scale of 2000 at BNM-INM", this symposium.

[2] Greywall D., Physical Review B, 1979, **20**, p 2643-2657

[3] Owers-Bradley J., Main P., Church R., Hampson T., Bowley R. , J.L.T.P, 1989., **77** , p 327-346

[4] R. Rusby et al., " European Dissemination of the Ultra-low Temperature Scale, PLT-2000"

12:30 Lunch
13:30 Exhibits

15:00 Session B-1. Temperature Scales: SPRT Ranges

B-1, 15:00 Investigation of Non-Uniqueness of the ITS-90 in the Range 13.8 K to 273.16 K

M.J. de Groot, A. Peruzzi and O. Ramadhin
NMi van Swinden Laboratorium (NMi), Delft, The Netherlands

In the frame of the European Project “MULTICELLS”, Standard Platinum Resistance Thermometers (SPRTs) of NMi-VSL were used to test different designs of transportable modular cells with multiple sealed cryogenic fixed points (H_2, Ne, O_2 and Ar). During these tests, between four and five SPRTs were simultaneously mounted in the copper comparator block which held the modular fixed point cells, so that the same SPRTs could be calibrated at the cryogenic fixed points of ITS-90 and the new calibrations could be compared to the original ones. Additionally the thermometers were calibrated in mercury triple points used for long-stem thermometers. These calibration results were compared with the earlier calibrations at fixed points and in the gas thermometer to arrive at a full-range ITS-90 calibration. During the cryogenic fixed-point measurements we used the copper comparator block for isothermal measurements on the SPRTs at intermediate temperatures to assess the non-uniqueness of the thermometers. In parallel to this experimental study and for comparison purposes, we recalculated the extensive experimental non-uniqueness study of Compton and Ward on 37 SPRTs for the IPTS-68 to approximate calibration of these SPRTs in terms of ITS-90. We looked at the non-uniqueness of these thermometers in terms of ITS-90 and its sensitivity to our choice of the additional ITS-90 fixed points. From this experimental and mathematical work we could investigate the non-uniqueness of the ITS-90 arising from the intrinsic differences between the individual SPRTs. We compared the non-uniqueness with the uncertainties of these thermometers as progressed from the fixed-point measurements and the estimates involved in these studies.

B-1, 15:20 Study on Non-uniqueness of ITS-90 in the Temperature Range from 83.8058K to 273.16K

Ping Qiu, Helian Wu, and Yuning Feng
National Institute of Metrology,Beijing, P.R.China

This paper presents the investigations on the non-uniqueness and inconsistency of ITS-90 in the temperature range from 83.8058K to 273.16K with several selected capsule type platinum resistance thermometers, whereas the measurements were carried out in the high precise low temperature cryostat. In the measurements, one thermometer was used as reference with the others calibrated. In order to achieve the high measurement accuracy, two current comparator resistance bridges (model 9975) recorded the readings simultaneously. The measurements on the non-uniqueness were made at the steps of 15K between the fixed points. In addition, the inconsistency of two thermometers was also investigated over the temperature ranging from 13.8K to 273.16K.

B-1, 15:40 The Non-Uniqueness of the ITS-90: 13.8033 K to 273.16 K

Kenneth D. Hill and Alan G. Steele
National Research Council of Canada, Ottawa, Canada K1A 0R6

Estimates of the non-uniqueness of the ITS-90 are reported based on comparisons of capsule-style standard platinum resistance thermometers at more than eighty temperatures between 13.8033 K and 273.16 K. Using the measurements reported here, as well as those of Ward and Compton and Head, we conclude that the non-uniqueness takes on its largest value (± 0.4 mK) in the range from 83.8058 K to 234.3156 K. This result may have been anticipated due to the fact that the argon and mercury fixed points are separated in temperature by more than 150 K, with no intermediate calibration points. Discussions concerning the details of the temperature scale that will eventually replace the ITS-90 must consider this fact if the non-uniqueness is to be minimized. At the present time, however, there are no candidate fixed points within this temperature range that are realizable to the required level of accuracy for inclusion into a revised International Temperature Scale.

B-1, 16:00 Realization of the ITS-90 over the Temperature Range 83K to 693 K at the National Institute for Standards NIS-Egypt

M. Gamal, K.Ali, M.R.Moussa
National Institute for Standards (NIS_Egypt)

Thermometry group of the National Institute for Standards (NIS) has realized the International Temperature Scale 19990 (ITS-90), as defined over the temperature range from 83 K to 2200 °C. This work concerning the temperature range from 83 up to 693 K only. A brief review is given of techniques and apparatuses used, source and purity of the fixed points in this range, cell designs and uncertainties of our realization.

B-1, 16:20 Realization of the ITS-90 Fixed Points from the Argon Triple Point Upwards: New Developments at IMGC

P. Marcarino, P.P.M. Steur, R. Dematteis
CNR Istituto di Metrologia "G.Colonnetti", Torino, Italy

The actual status of IMGC facilities for the realization of the ITS-90 fixed points is illustrated, including new apparatus for the realization of the triple point of argon and of the freezing points of gold and copper. For each fixed point very long phase transitions are obtained, and several thermometers can be calibrated on each plateau. The present apparatus is described, with the techniques developed at IMGC to obtain well-constant plateaus. Each fixed point is examined, and information on their realization is presented.

B-1, 16:40 A Quadratic Interpolation Equation for SPRT for Secondary Measurements in the Range 0 °C to 660.323 °C

Kang Zhiru[1] and Lan Jingbo[2]
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In the sub-range from 0 °C to 660.323 °C ,the ITS-90 interpolation equation for SPIT is a three degree polynomial with respect to the resistance ratio W(t), determined by the calibration values at the triple point of water and the fixed points of tin, zinc and aluminum. A quadratic polynomial, determined by the calibration values at the triple point of water and the fixed points of tin and aluminum, or at the triple point of water and the fixed points of zinc and aluminum, is a good approximation to the ITS-90 interpolation equation in the range from 0 °C to 660.323 °C. This paper proves that the error of the quadratic equation is about 5 mk., and the accuracy is sufficient for the second measurement.

15:00 Session B-2. Base Metal Thermocouples

B-2, 15:00 Improved Operating Efficiency Through the Use of Stabilized Thermocouples

Jeff Jablin[1], Michael R. Storar[2], and Phillip L. Gray, P.E[2].
[1]Thermo Electric Company, Inc., USA [2]Watson Cogeneration Company, USA

The development of a "stabilized" temperature sensor has led to significant increases in turbine operating efficiency by maximizing output when compared with present sensor technology. These stabilized type K and E thermocouples are superior to existing standard non-stabilized thermocouples because they are not prone to the typical aging effects in the 400 to 600°C (752 to 1112°F) temperature range that can result in measurement errors. A complete set of 18 stabilized type K thermocouples were installed on the exhaust of several gas turbines used for power generation. These thermocouples were subjected to normal operating conditions for a period of one year. During that year, the increase in turbine output has ranged from 0.5% to almost 2.0%. This increase in output also translates into significant cost savings. In addition, the stabilized thermocouples have given the turbine maintenance technicians more confidence in the accuracy of their temperature measurements and resulted in improved troubleshooting and decision making.

B-2, 15:20 Stability Of A Cable Nicrosil-Nisil Thermocouple Under Thermal Cycling

A.V. Belevtsev, A.V. Karzhavin, A.A. Ulanowsky
Industrial company " TESEY ", Obninsk, Kaluga region, Russia

The experimental data on stability of cable Nicrosil-Nisil thermocouples (type N) under stepped thermal cycling in the range of temperatures 20…1100 °C and also under continuous heating on air at the temperature 1085±10°C are presented. The analysis of thermal cycling influence on thermal EMF drift is carried out. The conclusion that N type thermocouple can be used as the reference thermocouple while graduation of industrial base-metal thermocouples has been made.

B-2, 15:40 Development of new Type N Thermocouple for Harsh Environments

Jim Walker and Gerard Cassidy
ECEFast,26 Business Park Drive Notting Hill Australia 3168

Temperature measurement can represent a significant burden of cost, through replacement parts, installation time and lost production when applied in difficult environments. The Excalibur was developed by combining a number of existing technologies to address the problems of short life in high temperature, and aggressive or abrasive environments.

B-2, 16:00 High Resolution Differential Thermocouple Measurements Using an Improved Noise Cancellation and Magnetic Amplification Technique

K.C. Sloneker, D.N. Polsky, A. Zhagrov, and V. Lutsenko
Electronic Development Laboratories Incorporated, Danville, Virginia, USA

Comparing two absolute temperature measurements using Thermistors, RTDs, or Thermocouples has proven to be the best method of obtaining differential measurements. In spite of their susceptibility to external influences and physical changes during use, thermocouples are well suited for making direct differential measurements over a wide range of temperatures and hostile environments. To improve differential temperature measurements will mean improvements in other parameters such as pressure and flow, as they are fundamentally dependent on temperature. The work described in this paper attempts to overcome the existing technical limitations that prevent differential thermocouple measurements from being used as high precision measurement devices. Under the control of a digital timing circuit, a discrete quantity of energy is magnetically amplified. A null balancing method is used to quantify the signal and develop its relationship to temperature. Since the balancing method utilizes a current flow within the system, the Peltier effect at the junctions of the differential thermocouple is discussed. Extraneous interference and internally produced noise, such as Johnson noise, is effectively cancelled by a physical balancing method that is part of a negative feedback system. Reduction of variances caused by changing magnetic fields is accomplished by using an optically isolated timing system that is synchronized to local power. Thermocouple duality in the negative feedback circuit reduces the effects caused by inhomogeneity in the thermocouple materials. The equations describing the operation of the device are presented in the form of a set of differential equations. Test results and the theoretical equations describing the signal are in nearly perfect agreement. Measurements have been made at zero degrees centigrade to a resolution of 1×10^{-3} °C. The system can resolve to a level of 1×10^{-4} °C, but testing is difficult because of limitations in our laboratory establishing this low differential temperature. With further development, the described method could be applied to improving many types of measurements, for example, Johnson Noise Thermometry, low-level pressure measurements, and possibly high accuracy absolute measurements. The method described follows a different path for its solutions; they are not found by using traditional digital electronics, but return to a more fundamental method of amplification and measurement.

B-2, 16:20 High Stability Type K & Type N Thermocouples for Operation up to 1200°C

Gilles Bailleul and Stephane Fourrez
THERMOCOAX BP 26 – F61438 FLERS CEDEX France

In laboratory experiments, with microgravity furnaces for example, temperature sensors need to be small, flexible and very reliable. Thermocoax manufacture high integrity mineral insulated cables and thermocouples. We have studied the behavior of type K and type N small diameter thermocouples, in air and under vacuum, at 1100°C and 1200°C for up to 4,000 hours. Thermocouple samples were produced from small diameter MI cables (1 to 2 mm, .040" to .080") and different sheath alloys. The thermoelectric conductors are extremely small for use at these high temperatures (0.18 to 0.36 mm, .007" to .014"). We selected four different sheath alloys : two conventional Ni-Cr-Fe alloys and two specific (but commercially available) alloys one with a high Co content and another one with a high Al-Y content. Our study has shown that this last special refractory alloy can very effectively protect the thermoelectric conductors and lead to very small, and predictable, e.m.f. drifts. This study has shown interesting results in terms of sheath and conductor corrosion resistance, grain growth, conductor alloys chemical composition changes with time, but mainly led to the development of very stable type N and type K thermocouples. We have shown that type N thermocouples as small as 2 mm in diameter can drift by less than 10°C after 4000 Hours at 1200°C in air or under vacuum. A very simple relation was established to estimate the drift of such a thermocouple versus its outside diameter.

This work was partly sponsored by CNES (Centre National d'Etubes Spatiales, French National Space Administration).

B-2, 16:40 High Temperature Characteristics of the Ultra Fine Mineral Insulated Type K Thermocouples

Jun Ode[1], Shunichi Douji[2], Miyoshi Ogawa[3]
[1]Tokyo Metropolitan Industrial Technology Research Institute, Japan
[2]Nippon Netsudenki Seisakusho Co., [3]Yokogawa Research Institute Co., Japan

Trial manufacture of the ultra fine diameter and long length type K Mineral insulated thermocouples (outer diameter 0.25mm and 0.3mm, Length 2000mm and 3000mm) is made of laser welding method, And it Evaluated of the high temperature characteristics. The high temperature characteristics is the continuation heating of 2000 hours at the 600 °C, and the stability test which implemented 10 hours heating and repeated 10 times at the 600 °C and shunt error test. The drift of thermal electromotive force in all test was the within permitted limit.

15:00 Session B-3. Radiation Thermometry-Measurement Techniques

B-3, 15:00 The European Project TRIRAT: Part 1. Experimental Arrangements and Procedures for the Comparison of Local Temperature Scales with Transfer Infrared Thermometers between 150 °C And 962 °C

M. Battuello[1], F. Girard[1], T. Ricolfi[1], M. Sadli[2], P. Ridoux[3], O. Enouf[3], J. Pérez[4], V. Chimenti[4], T. Weckström[5], O. Struss[6], E. Filipe[7], N. Machado[7], E. van der Ham[8], G. Machin[9], H. Mc Evoy[9], B. Gutschwager[10], J. Fischer[10], V. Schmidt[11], S. Clausen[12], J. Ivarsson[13], S. Ugur[14], and A. Diril[14]
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[12]RISOE, Roskilde, Denmark, [13]SP, Boras, Sweden, [14]UME, Gezbe-Kocaeli, Turkey

In the course of the EC-funded project TRIRAT ("TRaceability in Infrared Radiation Thermometry") an international comparison of local radiation temperature scales took place among fourteen laboratories in the temperature range from 150 °C to 962 °C. This paper describes the equipment and the transfer standards used for the comparison. The results and the procedures adopted for deriving a "comparison reference value" (CRV) and the degree of equivalence of each laboratory with respect to the CRV are then discussed. The different arrangements adopted for the calibration of the thermometers and additional experimental investigations allowed an analysis on the effect of some influencing parameters, e.g., the SSE, to be performed and indications on the most convenient experimental arrangements to be derived.

B-3, 15:20 A Simple Experimental Technique for Estimation of the Band-pass of Infrared Radiation Thermometers

Mark Ballico
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The infrared radiation thermometer is now becoming a very widely used instrument for industrial temperature measurement and hazardous temperature assessment. Its simple design allows a very low manufacturing cost, and hence its widespread adoption as a convenient non-contact thermometer. The spectral sensitivity of these instruments is usually set by the transmission properties of the windows on the pyrometer, and, although the manufacturer usually makes some statement as to the operating wavelength region, it is difficult to know exactly what is being reported. Calibration laboratories often require knowledge of the band-pass for appropriate calculations of uncertainty, corrections for blackbody emissivity, or, as is commonly becoming required, correction of blackbody radiance temperatures for the calibration of cheaper 'fixed emissivity (eg. 95%)' pyrometers. An explicit measurement of the spectral response of the pyrometer would require a tunable IR source, and special attention to the effects of ambient radiation. This paper presents a very simple experimental technique for the estimation of effective pass-band of an IR radiation thermometer using only a mesh and a blackbody radiator at several temperatures. An analysis of the uncertainty in this determination of the band-pass is also presented.

B-3, 15:40 A Comparison of Two Methods for Measuring the Nonlinearity of Infrared Radiation Thermometers

M. Battuello[1], P. Bloembergen[2], F. Girard1, T. Ricolfi[1]
[1]Istituto di Metrologia G. Colonnetti (IMGC-CNR), Torino, Italy, [2]National Metrology Institute of Japan (NMIJ-AIST), Tsukuba, Japan

The superposition and the dual-aperture methods for measuring the nonlinearity of photodetectors have been compared using three ad hoc devices and testing three radiation thermometers using different detectors. The results of this study have shown that interreflections and interference with the optical beam originating from the nonlinearity device should be considered carefully to avoid large measurement errors particularly with the dual-aperture method. It has also been shown that with some detectors the nonlinearity is mostly generated at the edge of their sensing area.

B-3, 16:00 The Method of Two-Color Pyrometry of True Temperature with Unknown Emissivity

D. Ya. Svet
Institute of High Temperatures, Russian Academy of Sciences, Russia

A new pyrometric method (and an experimental two-color pyrometer to realize this method) is suggested for measuring the spectral emissivity during heating and cooling. The method is based on the utilization of the effect of the temperature dependence of emissivity. The method involves the use of relative laser reflectometry which does not require the validity of Lambert's law. The results of measurements of the emissivity of tungsten, rhenium, and tantalum using the suggested pyrometer are given.

B-3, 16:20 Blackbody Sources within the 100 to 3500K Temperature Range for Precision Measurements in Radiometry and Thermometry

V.I.Sapritsky, S.A.Ogarev, B.B. Khlevnoy, M.L.Samoylov, V.B.Khromchenko
All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI), 46 Ozernaya St., Moscow, 119361, Russia

The paper presents the detailed review of blackbodies that are ranged to Low-, Middle-, and High-temperature sources developed at VNIIOFI during more than 25 years. There is a successful record of delivering advanced precision BBs including high temperature BB3200 and BB3500 to major National standard laboratories: NIST (USA), PTB (Germany), NPL (Great Britain), NPL (India), NIM (China) and large-area low- and medium-temperature BBs in other laboratories.

B-3, 16:40 Low Scatter Optical System for Emittance and Temperature Measurements

Sergey Mekhontsev and Leonard Hanssen
National Institute of Standards and Technology, Gaithersburg, MD 20899-8441 USA

The development and evaluation of an optical system for a new spectral directional emittance facility at NIST is reported. The imaging quality and signal contributions due to out-of-field-of-view scattering, commonly characterized by the “size-of-source effect (SSE)” parameter, have been measured across the spectral range of 0.65 to 4 microns by three independent methods. The SSE measurement results of scatter levels not exceeding 2-3 parts in 10^4 are consistent and exceed the design targets. The potential application of the optical system to construction of a portable instrument with low scatter/emission and an operating spectral range of 0.65 to 20 microns are discussed.

15:00 Session B-4. Fluorescence and Laser Techniques

B-4, 15:00 Phosphor Thermometry at ORNL

S. W. Allison, M. .R Cates, D. L. Beshears, and G. T. Gillies
Oak Ridge National Laboratory, National Transportation Research Center, Knoxville, TN 37932, USA

Phosphor materials are, by design, capable of efficiently converting excitation energy into fluorescence. The temperature-dependent characteristics of this fluorescence provide the basis for noncontact thermometry. In the past decade this approach has been applied to turbine engine diagnostics, liquid temperature measurements for heat pump research, combustion engine intake valve and piston measurements, galvanneal steel processing, transient thermometry of particle beam targets, and microcantilevers used in MEMS devices. The temperatures involved range from ambient to in excess of 1200 C. Some of these applications have involved fiber optics for light delivery and/or fluorescence signal collection. In addition to fielding

these applications, there has been considerable work in the laboratory aimed at exploring further improvements and adding to the data base of temperature-characterized phosphors. The activities involve investigation of short-decay time phosphors for use on imaging surfaces moving at high speeds, measuring and modeling pressure as well as temperature dependence, developing to phosphor adhesion methods, developing phase-based data acquisition approaches. A significant advance is that light emitting diodes can now be used to provide adequate stimulation of fluorescence in some applications. Recently nanophosphors have become available. The spectral properties and, by implication, thermal dependence of these properties change which particle size. This has ramifications which need to be explored. The ways in which such materials can be exploited for micro- and nano-technology are just now being addressed. These applications and developments mentioned above will be surveyed and discussed as well as envisioned future improvements and new uses for this thermometry technique.

B-4, 15:20 Ultra High Precision Phosphor Thermometry near 1100 K

Michael R. Cates, Alvin J. Sanders, Jason Newby
Oak Ridge National Laboratory, TN USA

Using the rare-earth doped phosphor Y_2O_3:Eu, which has a strong temperature dependent emission near 611 nm beginning around 600 C, we studied the precision with which the fluorescent lifetime followed temperature changes near 800 C. The goal was to investigate the utility of such a material as a temperature standard in this relatively high temperature range. We used a thermal mass of alumina that drifted in temperature predictably following Newton's Law of Cooling, along with a nitrogen-laser (337 nm) excitation system. Our results showed precision near 10 mK, with potential for further improvement.

B-4, 15:40 A Calibration System for Fluorescence Thermography

L. Rosso, V.C. Fernicola, A. Tiziani
CNR - Istituto di Metrologia G. Colonnetti, Torino, Italy

A temperature reference system for calibrating fluorescence-based sensors was developed. The system is based on a special thermostatic chamber and on an electro-optic system equipped with a fiber-optic scanner. A thin layer of the sensing material to be calibrated can be coated onto a temperature controlled reference surface, which is housed inside the thermostatic chamber. It was designed in such a way as to operate under different conditions (from vacuum to atmospheric pressure) in order to evaluate the effect of the surrounding fluid on the surface temperature measurements. The reference surface can be heated both radially, by a wire wound heater, and axially, by a thermoelectric cooler. Experimental investigations were carried out in the temperature range –50 °C to about 200 °C. The results showed a temperature stability of better than 0.03 °C and a surface temperature uniformity to within 0.02 °C. The system was used to characterize a sensitive phosphor. The phosphor calibration curve was thus obtained, with a single-point repeatability of better than 0.1 °C. The spatial temperature uniformity of the phosphor-coated surface was also investigated by using the built-in fiber-optic scanner in both environments. The results showed a temperature uniformity to within 0.1 °C.

B-4, 16:00 Fluorescence Thermometry in Microfluidics

L David Ross, Michael Gaitan, and Laurie E. Locascio
National Institute of Standards & Technology, Gaithersburg, MD USA

Two techniques are described for the measurement of fluid temperatures in microfluidic systems based on temperature-dependent fluorescence. In the first technique, a single, strongly temperature-dependent fluorophore, rhodamine B, is used as the basis for fluorescence intensity-based thermometry. For the second technique, two different fluorophores are used with different emission wavelengths, and the ratio of the signals at the two different colors is used to calculate the temperature. Both techniques are easy to implement with a standard fluorescence microscope and CCD camera. In addition, the methods can be used to measure fluid temperatures with micrometer spatial resolution and millisecond time resolution. The methods are demonstrated by measuring temperature distributions within a variety of microfluidic devices resulting from either direct contact heating or Joule heating as fluid is electrokinetically pumped though the systems.

15:00 Session B-5. Cryogenic Thermometry: Devices

B-5, 15:00 Review of Zirconium Oxy-Nitride (Cernox™) Thin Film Resistance Temperature Sensors

S. Scott Courts and Philip. R. Swinehart
Lake Shore Cryotronics, Inc., Westerville, OH 43082 USA

Cernox™ resistance thermometers were commercially introduced in 1993. The Cernox™ temperature-sensing element is fabricated from zirconium reactively sputtered in a nitrogen-oxygen atmosphere. The resulting thin film is comprised of conducting zirconium nitride embedded within a zirconium oxide nonconducting matrix. This material has a negative temperature coefficient of resistance making it useful as a temperature sensor. The ratio of conducting to nonconducting material can be varied to tailor thesensor to a given temperature range. A single device can be fabricated for use from below 0.3 K to 420 K. Cernox™ temperature sensors possess many attributes desirable in a temperature sensor including high sensitivity, excellent short-term and long-term stability, small physical size, fast thermal response and small calibration shifts when exposed to magnetic fields or ionizing radiation. This paper presents a review of Cernox™ temperature sensors with regard to their physical, thermometric and operational properties and environmental effects.

B-5, 15:20 Low-temperature Composite Sapphire -RuO_2 Thermometer And Its Application In Heat Capacity Measurements

Yang-Yuan Chen
Institute of Physics, Academia Sinica, Taipei, Taiwan, Republic of China

A new low-temperature composite sapphire - RuO_2 thermometers have been studied under magnetic field up to 9 T and temperature down to 0.5 K. For a typical 2 ohm thermometer (at room temperature) with a logarithmic temperature coefficient ~ 3.5 at 2 K, its temperature deviations d T / T for H = 9 T are about 0.5 % and 2 % at 4 K and 2 K respectively. Comparing with the existing low temperature thermometers, RuO_2 - and ZrO_2 - based thermometers, the thermometers exhibit more advantages in many aspects. A calorimetric sapphire square for the use of heat capacity measurement demonstrates its potential capability to measure film specimens due to its small thermal mass ~10^{-7} J / K (at 4 K) and fast time response t < 1 ms.

B-5, 15:40 A New Capacitance Thermometer with Novel Design for Use at Low Temperatures and High Magnetic Fields

E. C. Palm, T. P. Murphy, L. Peabody, and S. W. Tozer
National High Magnetic Field Laboratory, 1800 E. Paul Dirac Dr., Tallahassee, FL 32310, USA

A capacitance thermometer made of thin layers of Kapton and copper that is insensitive to high magnetic fields is described. This thermometer can be easily fabricated and the final thermometer is a thin rigid tube that can be easily incorporated into the sample space of most high field cryogenic systems. We have demonstrated that the minimum in capacitance vs. temperature of these thermometers can be moved to progressively lower temperatures even below our base temperature of 20mK by changing the construction parameters of the devices. We present data demonstrating their lack of magnetic field dependence, specific sensitivity, and discuss power dissipation in typical operation.

B-5, 16:00 Open

B-5, 16:20 Long-Term Stability of Germanium Resistance Thermometers

S. Scott Courts and C. Joseph Yeager
Lake Shore Cryotronics, Inc., Westerville, OH 43082 USA

Doped germanium resistance thermometers (GRTs) have been used as cryogenic thermometers for forty years. GRTs exhibit a negative temperature coefficient of resistance and possess a high sensitivity that allows for sub-millikelvin control at lower temperatures. These devices also exhibit excellent short- and long-term stability and were used to maintain national temperature scales below 30 K until the advent of the rhodium-iron thermometer. Lake Shore Cryotronics uses GRTs, model GR-200A-1000, as the transfer thermometer for temperature calibration below 30 K. A typical GRT working standard is thermally cycled from 1.4 K to 330 K once a week on average. Every six months, to ensure stability and traceability, these working standard GRTs are compared against a set of standards-grade germanium, platinum, and rhodium-iron resistance thermometers calibrated by the National Institute of Standards and Technology in the US and/or the National Physical Laboratory in the UK. These comparisons yield a measure of the long-term stability of these GRTs over a period of years.

This paper reports the long-term stability from 1.4 K to 30 K of ten germanium resistance thermometers as a function of time and thermal cycling during their use as working standard thermometers.

B-5, 16:40 New Paramagnetic Susceptibility Thermometers and Bolometers for Fundamental Physics Measurements

Robert Duncan, Dmitri Sergatskov, Peter Day, Beverly Klemme, Raymond Nelson, S.T.P. Boyd, and Alex Babkin
Jet Propulsion Laboratory, Low-Temperature Physics and Engineering Group, USA

New paramagnetic susceptibility thermometers have been developed for use in fundamental physics missions on earth orbit. These devices use a SQUID magnetometer to measure the variation in the dc magnetization of a thermometric element that consists of a dilute concentration of either iron or manganese in a palladium matrix. Near 2.2 K these new MnPd thermometers have demonstrated a temperature resolution of better than 100 pK per root-Hz and a time constant of 48 ms when operated with a 50 K/W thermal resistance to the liquid helium sample. These thermometers have been observed to be remarkably stable, with a drift of less than 3 fK/s. The observed power spectral density of the noise from these thermometers is consistent with separate measurements of the device's time constant and thermal standoff from the bath. These thermometers will be used within the Critical Dynamics in Microgravity Experiment, which will study the dynamical properties of the superfluid transition in ^{4}He with unprecedented precision as part of the first microgravity fundamental physics mission to the International Space Station in the year 2005. Recently these PdMn materials have been made into thin films and microstructures for use in other studies of quantum liquids, and for use in a new class of bolometers and radiometers. The sensitivity of these devices has been measured as a function of the magnetic ion concentration, of the charging magnetic field strength, and of temperature. A new device is currently under construction that should achieve a thermal noise level of less than one pK per root-Hz. This device may prove useful in a new class of ultra-stable space radiometers for background radiation measurements.

Tuesday, October 22, 2002

7:30 Speaker Breakfast – Location: N426c

8:00 Registration

8:30 – 10:30 Morning Sessions C-1 through C-5

10:30 – 10:45 Break

10:45 – 12:30 Mid-Day Sessions D-1 through D-5

12:30 – 15:00 Lunch & Exhibit time

15:00 – 17:00 Afternoon Sessions E-1 through E-5

8:30 Session C-1. Temperature Scales: Below 1K

C-1, 8:30 PTB-96: The Ultra-Low Temperature Scale of PTB

B. Fellmuth, D. Hechtfischer, A. Hoffmann
Physikalisch-Technische Bundesanstalt (PTB), Abbestrasse 2-12, 10587 Berlin, Germany

The temperature scale PTB-96 for the range from 0.9 mK to 1 K is one of the melting-pressure scales, on which the Provisional Low Temperature Scale of 2000, PLTS-2000, is based. The construction and the thermodynamic significance of the PTB-96 are discussed in detail considering the now available comprehensive information including recently obtained experimental data. The thermodynamic significance has been evaluated primarily by means of noise thermometry. The internal consistency has been checked applying platinum NMR (nuclear magnetic resonance) thermometry and CMN (cerous magnesium nitrate) thermometry. Considering the results both of primary noise thermometry and consistency checks, a detailed uncertainty budget is presented.

C-1, 8:50 The Provisional Low-Temperature Scale from 0.9 mK to 1 K, PLTS-2000

R. L. Rusby[1], M. Durieux[2], A. L. Reesink[3], R. P. Hudson[4], G. Schuster[5], M. Kühne[5], W. E. Fogle[6], R. J. Soulen[7], E. D. Adams[8]
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The Provisional Low Temperature Scale from 0.9 mK to 1 K, PLTS-2000, was adopted by the Comité International des Poids et Mesures in October 2000. It is defined using an equation for the melting pressure of ^{3}He over the complete temperature range, and forms an extension of the International Temperature Scale of 1990, ITS-90, below its lower limit of 0.65 K. An internationally-accepted ultra-low temperature scale is needed to provide the basis for reliable thermometry in the temperature range in which commercial dilution refrigerators operate, and at lower temperatures where experiments investigating the thermodynamic properties of ^{3}He and other condensed matter are carried out in many research centres. This paper is a summary of a fuller publication describing the background and derivation of the scale, published in the Journal of Low Temperature Physics, and includes tables of values of melting pressure, p_m / MPa, and temperature T_{2000} / K, and the derivative, $\mathrm{d}p_\mathrm{m} / \mathrm{d}T$ in MPa/K.

C-1, 9:10 Thermodynamic Consistency of the New Ultra-Low Temperature Scale PLTS-2000

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The thermodynamic consistency of the temperature scale PLTS-2000 has been checked with new measurements using a noise thermometer, which is supposed to indicate thermodynamic temperature, and a platinum nuclear magnetic resonance thermometer, which is assumed to follow a Curie law. The different results are interpreted in terms of the properties of these thermometers, and with supporting calculations using the specific heats of solid and liquid ^{3}He. On this basis, it is possible to specify uncertainty limits of the scale with respect to thermodynamic temperature.

C-1, 9:30 European Dissemination Of The Ultra-low Temperature Scale, PLTS-2000

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The first phase of the EU collaborative project on sub-kelvin thermometry, 'ULT Dissemination', is nearing completion, leading to the development of several thermometers and devices, and the instrumentation needed to disseminate the new Provisional Low Temperature Scale, PLTS-2000, to users. Principal among these are a current-sensing noise thermometer (CSNT), a CMN thermometer adapted for industrial use, a Coulomb blockade thermometer, a second-sound acoustic thermometer and a superconductive reference device SRD-1000. Several partners have set up ^{3}He melting-pressure thermometers to realise the PLTS-2000, and will check it using Pt-NMR, CMN and other thermometers. The scale, which was formally adopted by the Comité International des Poids et Mesures in October 2000, covers the range of temperature from 1 K down to 0.9 mK, and is defined by an equation for the melting pressure of ^{3}He. The SRD employs novel fabrication and detection techniques with up to 10 samples, and is expected to meet the requirement for fixed points below 1 K, formerly filled by the NIST SRM 767 and 768. Other devices included in the project are ruthenium oxide sensors and a self-contained ^{3}He melting pressure thermometer. This paper reviews the project progress to date and indicates the potential for research, metrological and industrial application of the devices developed.

C-1, 9:50 The Realization of the Provisional Low Temperature Scale of 2000 at BNM-INM

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The lower limit of the International Temperature Scale of 1990 (EIT-90) is 0,65 K. Below this limit, no internationally-accepted scale existed before 2000 when the CIPM, following the CCT recommendations, adopted the Provisional Low Temperature Scale of 2000 (PLTS-2000). This scale is based on the ^{3}He melting curve and spans the range 0,9 mK to 1 K. BNM-INM realized PLTS-2000 throughout the range from 20 mK to 1 K by using absolute pressure measurements. BNM-INM studied in details the uncertainty in temperature measurements due to the absolute pressure measurements, in particular near the minimum of the melting curve. The paper presents the results and the uncertainty budget related to the practical realisation of T2000 at BNM-INM.

C-1, 10:10 Implementation of PLTS-2000: He-3 Melting Pressure Temperature Scale

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The recently adopted PLTS-2000, which extends the temperature scale to 0.9 mK, is defined by the melting pressure of ^{3}He and various fixed points on the melting curve. Because of the minimum in P(T) at 315 mK, pressures at lower temperatures must be measured with an *in situ* transducer. In this paper, the equipment necessary for producing melting helium and measuring the pressure will be described. This will include the Straty-Adams capacitive pressure transducer, the bridge for measuring capacitance, and the He^3 gas handling system. Procedures for calibrating the pressure transducer and for observing the various fixed points established in PLTS-2000 will be presented.

8:30 Session C-2. SPRTs: Effects & Errors

C-2, 8:30 Evaluation of Linear Prediction as a Quality Check in PRT Calibrations on the Range 0 to 420 °C

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The observed linear correlation between sets of ratio (W) measurements at ITS-90 fixed points among certain platinum resistance thermometers has led to the proposition that sets of measurement results might be evaluated for consistency using linear prediction. Wire quality and probe construction largely effect the quality of the correlation. Data seems to indicate that the technique is inadequate for identifying subtle calibration errors in the general population of PRT’s but may play a role in defending against more extreme anomalies. Certain secondary probes appear to have highly correlated resistance ratio values. A simple technique is given for visual identifying anomalous results from a small set of data.

C-2, 8:50 Experimental Study of Different Filling Gases on the Stability of Metal-Sheathed Standard Platinum Resistance Thermometers

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There is a trade-off between the oxidation effect and element contamination in metal-sheathed standard platinum resistance thermometers (MSPRTs). Excessively high O_2 partial pressure causes the platinum sensor to oxidize, and excessively low O_2 leads to sensor contamination. The oxygen content in a thermometer may become unknown after a period of operation due to slow oxidation of the metal sheath and consequent loss of oxygen in the MSPRT. This can significantly affect the thermometer’s performance. Our recent research has shown that a thermometer may eventually become contaminated due to a deficiency of oxygen surrounding its element. In order to research this phenomenon and improve the stability of MSPRTs, ten MSPRTs were specially manufactured for testing. In this paper, the construction of these MSPRTs is described. A series of experiments and their results are presented. Based on the experiment results, a feasible solution (having the element sealed separately from its sheath) is put forward. This solution can resolve the conflict between the oxidation effect and element contamination and improve the long-term stability of MSPRTs. The R_{tp} and W(Al) stabilities of the MSPRTs with this new design can be as good as 1 mK and 2 mK respectively after operation at high temperature over 1000 hours.

C-2, 09:10 On the Criteria of Uniformity of the Temperature Field at Realization of the Fixed Points of the ITS-90

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The basic document on realization of the fixed points of the ITS-90 contains the requirements to uniformity of a temperature field in cell. One of them is a uniformity of a temperature field in cell. It should be ≤10 mK over the entire length of the sample, as measured in the cell held at a temperature a few Kelvin’s below, or above, the phase-transition temperature. And another requirement - the temperature field during freezing plateau should correspond to hydrostatic dependence of the phase-transition temperature on height of metal. If the second requirement about a hydrostatics is understandable, it is confirmation of thermal balance between the thermometer and liquid-solid phases interfaces, first is not proved at all. The researches of temperature fields in cells of different designs and in different furnaces on different thermal modes (lower than temperature melting, in melting metal, on a freezing plateau) have shown groundless of the first criterion.

C-2, 9:30 Influence of SPRT Self-Heat on Measurement Uncertainty in Fixed Point Calibration and Calibration by Comparison

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The following paper describes the influence of the self-heat of standard platinum resistance thermometers (SPRTs) on the uncertainty in fixed point calibration and calibration by comparison. The self-heat is a well-known phenomenon, which occurs, when the SPRT resistance is measured with a measurement current that dissipates power and therefore additionally heats up the SPRT sensor. A value of the self-heat at the measurement current of 1 mA is typically in the range from 0,2 mK to 5 mK, depending on the SPRT design, temperature and the surrounding medium. A series of measurements was performed in order to understand the behavior of the self-heat with different SPRT designs and measurement conditions. Procedures to reduce the uncertainty of self-heat correction are discussed and conclusions regarding uncertainty estimation are presented.

C-2, 9:50 Oxidation of Platinum Resistance Thermometers

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PRTs were soaked at different temperatures and the resulting changes caused by oxidation and the subsequent dissociation of the formed oxide were observed. The resistance of the unoxidized PRTs remained stable for a few days during soaking at the Zn point. Soaking near 350°C initiated oxidation, in some PRTs, and then the resistance of the PRTs steadily increased with increasing temperatures up to about 520°C. Soaking near 520°C, the resistance of the PRT remained stable , suggesting that the thermal energy "KT" equals the energy that binds oxygen to platinum, at the existing oxygen pressure. At temperatures higher than 520°C the formed oxide dissociated. The higher the temperature the higher the thermal energy and thus the higher the rate of dissociation. One hour of soaking near the Al point dissociated the oxide that took hundreds of hours to accumulate. Three out of seven PRTs tested however would not oxidize.

8:30 Session C-3. Radiation Thermometry: Modeling

C-3, 8:30 Modeling of Emissivities of Metals and their Behaviors during the Growth of the Oxide Film

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The variation of emissivity is a serious problem to cause large temperature errors in radiation thermometry, thus it is critical to get hold of the emissivity for an accurate measurement of temperature. This paper describes the modeling of the behaviors of directional and polarized emissivities of metals during the growth of oxide film and compares with experiments. Quite new and strange phenomena on the emissivities were found by the simulations, which corresponded well with experimental results. The simulations due to the emissivity modeling provide a clue for a new emissivity compensated pyrometry.

C-3, 8:50 Effects of Wafer Emissivity on Rapid Thermal Processing Temperature Measurement

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Lightpipe radiation thermometers (LPRTs) are widely used to measure wafer temperatures in rapid thermal processing (RTP) tools. Using blackbody-calibrated LPRTs to infer the wafer temperature, it is necessary to build a model to predict the effective emissivity accounting for the wafer and chamber radiative properties as well as geometrical features of the chamber. The uncertainty associated with model-corrected temperatures can be investigated using test wafers instrumented with thin-film thermocouples (TFTCs) on which the LPRT target spot has been coated with films of different emissivity. A model of the wafer-chamber arrangement was used to investigate the effects of Pt (ε_s = 0.25) and Au (ε_s = 0.05) spots on the temperature distribution of the test wafers with the emissivity of 0.65 and 0.84. The effects of the shield reflectivity and the cool lightpipe (LP) tip on the wafer temperature were evaluated. A radiance analysis method was developed and a comparison of model-based predictions with experimental observations was made on a 200-mm wafer in the NIST RTP test bed. The temperature rises caused by the low-emissivity spot were predicted and the cooling effect of the LP tip was

determined. The results of the study are important for developing the model-corrected temperature measurement and uncertainty estimates using LPRT in semiconductor thermal processes.

C-3, 9:10 Reciprocity Principle and Choice of the Reflectance Model for Physically Correct Modeling of Effective Emissivity

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In the last two decades considerable progress has been made in numerical modeling of isothermal and non-isothermal cavities by the Monte Carlo method, in particular, by the use of the uniform specular-diffuse reflection model and backward ray tracing techniques. However, this technique has no essential theoretical foundation. The choice of physically correct reflectance model for the cavity walls plays the leading role in the justification of computational algorithms as well as in the validity of the results. In present paper the comparative numerical analysis of forward and backward ray tracing algorithms for reflectance models that do and do not, respectively, obey the reciprocity principle is performed.

C-3, 9:30 Evaluating the Effective Spectral Emissivity of Blackbody Radiators without Measuring Temperature Distribution

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A new procedure for evaluating the effective spectral emissivity of a blackbody radiator has been developed at NIM. This new procedure is of the advantage independent of temperature distribution can be conveniently used in conducting the evaluation of blackbody radiators in situ. Estimates for several cases in this paper have demonstrated that the proposed procedure can provide a precise evaluation on practical blackbody radiators. An experiment setup built to test the procedure included a temperature controlled blackbody radiator, a radiation thermometer with four wavelengths and a calibration system. The experiments verified the validity of the procedure for evaluating the effective spectral emissivity.

8:30 Session C-4. Calibration Quality Assurance

C-4, 8:30 Diagnostics in Temperature Measurement: a Tool for Measurement Validation

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Measurement accuracy and stability has been the main focus subject for the process industry for quite a long time. As a result, some instruments today offer accuracy and stability performances that can hardly be verified by the normally available tools. Accuracy and stability are important characteristics of measuring instruments, but measurement health is fundamental for plant performance and safety. During normal operation, several external factors may impact measurement health and reliability. Environment temperature changes, Electromagnetic Interference, Sensor and Wiring degradation, Moisture and Contamination are some of the factors that cause measurement drift or failure. Modern electronics allow sophisticated measurement validation through advanced diagnostics. Digital communications enable more accurate measurement reading as well as real time measurement health information. Detailed diagnostics inform maintenance people about failure causes. Some types of sensor failure can be predicted with good accuracy, allowing sensor replacement before a catastrophic failure. This paper discusses several sensor and transmitter degradation modes, their respective diagnostics and their impact on plant reliability, performance and validation.

C-4, 8:50 Usage of Reference Datasets in Testing and Validation of Thermometry Software Modules

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The objective of the following paper is to discuss preparation and usage of adequate input parameters (called reference data sets) for efficient testing of temperature measurement software modules, applying the white-box software testing strategy. Furthermore, the extension of suggested approach is presented in area of intercomparison of temperature measurement software modules. With this new approach better equivalence of the results of the software modules will be possible.

C-4, 9:10 Checking the Reliability of the Calibration of Large Batches of Industrial Thermometers for LHC by Automatic Data Processing

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The complete procedure to calibrate thermometers is a complex process, especially when several thousands of semiconductor-type thermometers are used and must individually be calibrated, as in the case of the instrumentation of the new LHC machine at CERN. Indeed, the similarity of the characteristics of semiconducting thermometers is more limited than that of wire-wound thermometers. The span of the characteristics spread can result to be a homogeneous set, or can show clusters (groups) of characteristics. In the latter case, one of the reasons for clustering may be the fabrication process by batches of numerous devices on the same chip. Consequently, the detection of the groups can be useful, from the supplier point of view, to give information relevant to improving the fabrication uniformity. From the user point of view, it is useful for making a guess of the possible thermometer stability with time, when this is a must, as in the LHC case. In fact, thermometers showing characteristics outlying or in small clusters should be considered to be potentially anomalous, also from the point of view of their stability with time and thermal cycling, with respect to the bulk of the batch. In addition, the identification of anomalous groups allows the detection of artifacts due to the experimental process For a large number of thermometers, this analysis requires the use of automatic procedures and, consequently, automated decisions that avoids false effects. The paper describes the mathematical methodology adopted for the identification of the clusters, based on the mixed-effect modeling of the thermometer characteristics.

C-4, 9:30 About the Uncertainties Achievable with Closed Indium Freezing Point Cells

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Part of the metrological basis for thermometry at the Swiss Federal Office of Metrology and Accreditation (METAS) is formed by eight sets of three sealed fixed point cells covering the range from -38 °C to 961 °C according to ITS-90. This basis is metrologically supervised by means of international comparisons with other National Metrology Institutes (NMIs). Between such comparisons, the stability of a given fixed point is verified by comparing the corresponding METAS' cells two by two in three measurement series of paired simultaneous fixed point realizations. Our measurements show that the differences between the cells are, although not zero, quite small. Repeating these internal comparisons for the three Indium cells after about two and four years, the variations in the mutual temperature differences between these cells show up to be small and to remain far within the estimated overall uncertainty of that fixed point. The uncertainty values considered are mainly determined by the contributions attributed to a certain shortcoming of information on chemical impurities and on the cell gas pressure when using commercially available sealed cells. It is demonstrated for our Indium fixed point, that the overall estimated uncertainty can be lowered from 1.74 mK to 1.10 mK (k=2) due to a reduction of the chemical impurity contribution to the uncertainty. In the hole the described concept to check the sealed fixed point cells by comparisons turned out to provide a high level of confidence in the thus supervised part of the temperature basis.

8:30 Session C-5. Dynamic and Transient Thermometry

C-5, 8:30 A Fast Fiber-optic Two-color Pyrometer for Temperature Measurements of Metallic Surfaces with Varying Emissivities

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A two-color pyrometer has been developed to measure the temperature of metallic surfaces with unknown or varying emissivities in manufacturing processes, e. g. the chip temperature during turning. The absolute temperature accuracy has been analyzed for metallic surfaces with various surface properties for the pyrometer wavelengths 1.7 and 2.0 µm. The influences of the digitization and the noise on the temperature resolution have been determined. Fast amplifiers and data acquisition allow a maximum time resolution of 2 µs. To enhance the pyrometer sensitivity a low-loss optical system, variable gain low noise amplifiers, and Peltier-element cooled InGaAs-photodiodes have been used. The pyrometer is capable of measuring temperatures of metallic surfaces with emissivities as low as 0.2 down to ~300 °C. Quartz-fibers with small

diameters enable locally resolved measurements at positions with limited optical access and small sizes. Test measurements at different metallic surfaces have been performed to verify the temperature accuracy.

C-5, 8:50 Microsecond Time-Resolved Pyrometry During Rapid Resistive Heating of Samples in a Kolsky Bar Apparatus

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Analysis of machining processes is important in the understanding and improving of manufacturing methods. The modeling of machining processes relies on high-strain rate, high-temperature material properties. A split-Hopkinson pressure bar (or Kolsky bar) is being installed in a NIST high current pulse heating facility. By heating the material sample rapidly with a controlled current pulse immediately before the mechanical impact in the bar, structural changes in the sample are inhibited, thus better simulating conditions during machining. A stress-strain relationship can be determined at various temperatures for test materials. We describe the design and the development of a millisecond-resolution split-Hopkinson apparatus, where the sample is resistively heated by the passage of a sub-second-duration electric current pulse. The impact bar is constructed out of maraging steel and the sample is a cylinder of AISI 1045 steel. The current is transmitted through the oiled-bronze sleeve bushing of the impact bar. The temperature measurements are performed using a near-infrared micro-pyrometer (NIMPY). The NIMPY consists of a refractive 5x microscope objective with a numerical aperture of 0.14 attached to a traditional microscope body. The thermal measurement is performed with an InGaAs detector with ~ 1 μs response time. The procedure used to calibrate the pyrometer with a variable temperature blackbody is described. A brief description of a model of the pulse heating process is given and the predicted sample temperature history is compared with measured temperature data.

C-5, 9:10 A High-Speed Four-Channel Infrared Pyrometer

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A high-speed, four-wavelength pyrometer has been developed for dynamic temperature measurements on samples that are heated by shock compression. The pyrometer uses a pair of off-axis parabolic mirrors to collect radiance emitted from a target of 1 mm in diameter. A single optical fiber delivers the collected radiant flux to the detector housing. Three dichroic beam splitters are used to spectrally split the light into four beams that are then focused onto an equal number of LN_2-cooled InSb photodetectors. Broad bandwidth interference filters that are nominally centered at 1.8, 2.4, 3.4, and 5.0 μm define the wavelength ranges of the four channels. The blackbody-temperature threshold of the pyrometer is at about 400 K. The signals are recorded at intervals as short as 20 ns using a four-channel digital oscilloscope. Procedures for calibration and temperature measurements are described.

C-5, 9:30 Normal Spectral Emissivity of Liquid Copper and Liquid Silver at 684.5 nm

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Up to now temperature measurements on pulse heated liquid metal samples reported by different authors have always been performed under the assumption of a constant emissivity in the whole liquid phase because of the lack of data for the liquid metals. The emissivity for most metals is known at the melting point and it is also known that large changes in specific volume occur between melting point and maximum experimental temperatures. Since electronic structures, optical properties, and emissivities have a large dependence on the electron density of a material, it follows that the emissivity of the liquid cannot be assumed to be constant and equal to the value at the melting point a priori. The key innovation which removes ambiguity present in all previous measurements is that uncertainty in temperatures is eliminated by the direct measurement of material optical properties and emissivities for the first time during the experiments. Normal spectral emissivity measurements at 684.5 nm have been successfully established by linking a laser polarimetry technique to our high speed measurements of thermophysical properties on liquid metal samples during microsecond pulse-heating experiments. This work presents results of these measurements on copper (Cu) and silver (Ag) from melting up into the liquid phase and compares them with literature data. These two materials are of special interest, because their freezing point temperatures are used in ITS-90 as fix-points for the temperature measurements in the range where Planck's radiation law is applicable.

C-5, 9:50 High-Resolution Pyrometers for Thermophysical Scientific Experiments

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An accurate temperature measuring is of a great importance in most modern researches on thermophysical properties of materials. Two high-resolution automatic pyrometers for real-time monitoring of surface temperature in thermophysical experiments, such as ''laser-flash'' method or during single-crystal growth from a melt are described. The developed pyrometers measures temperature in wide dynamic temperature range 400-2900 °C at typical resolution value 0.02 °C, and response time up to 100 µs. The main details of the pyrometers design, calibration and performance are presented.

C-5, 10:10 The Normal Spectral Emissivity at a Wavelength of 684.5 nm and Thermophysical Properties of Liquid Zirconium up to the End of the Stable Liquid Phase

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It is very difficult to determine normal spectral emissivity under pulse-heating conditions in the liquid state. Nevertheless normal spectral emissivity is an important quantity for temperature determination when measuring thermophysical properties. In the 80's Azzam [1] developed a laser polarimeter for the determination of optical parameters without any moving parts. Recently such a polarimeter was adapted for pulse-heating experiments, which are performed in a sub-microsecond time-scale, and integrated into the existing measurement setup. The behavior of normal spectral emissivity for liquid metals at 684.5 nm can be illustrated by three groups: a) increasing, b) decreasing, or c) constant emissivity values as a function of temperature in the liquid phase. Thermophysical properties of the liquid phase obtained by using the actual measured value, can change drastically in comparison to those obtained with the assumption of a constant emissivity in the whole liquid phase (which always was assumed to have the same value as at the end of melting). To achieve reliable thermophysical properties of liquid metals involves the measurement of normal spectral emissivity in conjunction with the radiometric temperature. Within this paper recent results of normal spectral emissivity at 684.5 nm as well as thermophysical properties for zirconium at melting and for the liquid phase are reported.

10:45 Session D-1. Bilateral SPRT Comparisons

D-1, 10:45 Comparison Of Fixed Point Realizations between Inmetro and PTB

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Between the National Institute of Quality, Normalisation and Industrial Quality (Inmetro), Brasil, and the Physikalisch Technische Bundesanstalt (PTB), Germany, an interlaboratory comparison in the temperature range between -190 °C and 420 °C was organized. The comparison followed the same protocol as the EUROMET K3 comparison and took place during the year 2001. A standard platinum resistance thermometer (SPRT) of 25 Ω was calibrated at the temperature fixed points of Ar, Hg, WTP, Ga, In, Sn and Zn, with at least 3 realisations of each fixed point in both institutes. A detailed uncertainty evaluation is given and any difference in the calibration procedures or in the measuring instruments used is described. The agreement between both institutes was not in all cases within the combined uncertainties. Results of other comparisons are presented, which give additional information on the equivalence of the realised temperature scales.

D-1, 11:05 Bilateral Comparison of SPRT in the Range of 0 °C to 420 °C between SIRIM and KRISS

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SIRIM and KRISS have recently conducted a bilateral comparison of SPRT in the range of 0 °C to 420 °C. Two pieces of SPRTs from two different manufacturer were used and calibrated at five fixed-points i.e. water triple point, the freezing points of Zn, Sn, In and the melting point of Ga. A total of six sets of measurement were made through out the comparison i.e. one set for each SPRT calibrated at SIRIM, KRISS and SIRIM facilities respectively. Each set of measurement consists of two numbers of realisations of melt/freeze at each of the metal fixed-points. Two different type of bridges i.e. DCC (Guildline 6675) and AC bridges (ASL F18 and F900) were used in the measurement. The immersion depth profiles for each of the fixed-point were conducted and the different of results in measurement between the F18 and F900 will be reported. The preliminary results have shown that the temperature difference at water triple point, Zn and Sn between SIRIM and KRISS were 2.0 mK, 2.0 mK and 3.0 mK respectively. Both standard laboratories were also agreed to adopt the same method of evaluation for the standard uncertainty in the overall measurement.

D-1, 11:25 Intercomparison of the Realization of the ITS-90 in the Temperature Range -40 °C to 420 °C between CENAM and PTB

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A comparison of the realization of the temperature scale ITS-90 was organized between PTB and CENAM in the range from -40 °C to 420 °C which includes the Hg, H_2O, Ga, In, Sn, and Zn fixed points. Measurements were carried out with two platinum resistance thermometers in different schemes. The results obtained with both thermometers coincide well within 0.5 mK for all fixed points except for the Zn freezing point, where the deviation between PTB and CENAM was 1.6 mK with one PRT and 0.1 mK with the other PRT. The difference observed between the two Zn measurements resemble results previously obtained during past international comparisons. Some discussion is presented about this subject.

D-1, 11:45 Bilateral Intercomparison of the ITS-90 Realisations in the Range from –189,3442 °C (Triple Point Of Argon) to 961,78 °C (Freezing Point Of Silver) between the MIRS/FE-LMK (Slovenia) and the PTB (Germany)

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The paper describes the results of a bilateral intercomparison of the ITS-90, as realized and maintained at MIRS/FE-LMK and PTB, respectively, in the range between the triple point of argon (-189,3442 °C) and the freezing point of silver (961,78 °C). Both laboratories base their scale on fixed points and long stem standard platinum resistance thermometers as interpolating instruments in this range, as prescribed in the ITS-90. The results of the intercomparison show that a transition from a secondary temperature laboratory to a primary temperature laboratory was successfully reached by MIRS/FE-LMK.

D-1, 12:05 A Bilateral Comparison between UME and PTB

Murat Kalemci[1], Aliye Kartal Doğan[1], Sevilay Uğur[1]
Ute Noatsch[2], Erich Tegeler[2], Bettina Thiele-Krivoj[2]
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A standard platinum resistance thermometer (SPRT) has been calibrated at the ITS-90 fixed points of UME and PTB in the range between the triple point of argon (83.8058 K) and the freezing point of zinc (692.677 K). This bilateral comparison was mostly carried out according to the protocol of EUROMET Project 552 based on the protocol of CCT-K3. It was observed that in all fixed-point measurements, the agreement between UME and PTB is better than 0.50 mK. All differences found are significantly smaller than their expanded combined uncertainties (coverage factor $k = 2$). The detailed analysis of the results and the uncertainty budget related to the measurements are presented.

10:45 Session D-2. Thermocouple Inhomogeneity Studies

D-2, 10:45 A Study of the Temperature Dependence of Inhomogeneity in Platinum Based Thermocouples

Ferdouse Jahan and Mark Ballico
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It is well known that contamination of platinum based thermocouples due to use at high temperatures causes the local Seebeck coefficient of the wire to change from its 'initial' state. As this exposure and contamination is usually not uniform along the length of the thermocouple, the Seebeck coefficient also becomes a function of position along the thermocouple, leading an exposure dependent thermoelectric signature or inhomogeneity. At NML (CSIRO) we have, for many years, included explicit measurement of the thermocouple inhomogeneity in all calibrations of 'used' thermocouples, using a special uniform temperature 'scan furnace' having an entrance region with a steep gradient. The thermocouple inhomogeneity value is used in the calculation of the calibration uncertainty: indeed it is usually the dominant component, as the uncertainty in the reference

standard SPRTs and fixed points is usually negligible by comparison. The inhomogeneity measurements at NML are usually done at 450°C, low enough to limit defect annealing drift, but high enough to generate a reasonable thermoelectric voltage. The inhomogeneity measured at 450°C, expressed as a percentage of the total EMF, has been assumed to be representative of the inhomogeneity at other temperatures. To date, this assumption has not been thoroughly validated. In this paper, the thermoelectric signatures of several thermocouples with inhomogeneities caused by years of 'real world' use are examined at temperatures 250, 450, 650, 850 and 1000°C, and compared with our traditional 450°C homogeneity assessments. The results allow us to assess the validity of the assumption that inhomogeneity may be expressed as a percentage of the total thermo-voltage.

D-2, 11:05 Performance, Thermoelectric Homogeneity and Stability of Au/Pt and Pt-10%Rh/Pt Thermocouples

M. Halawa, F. Megahed, Y. A. Abd El-Aziz and M. M. Ammar
National Institute for Standards (NIS), Egypt

The performance, thermoelectric homogeneity and stability of Au/Pt and Pt-10%Rh/Pt thermocouples had been studied and compared at the freezing point temperatures of Zn, Al and Ag. The emf-temperature relationship was presented for both thermocouples. To assess the thermoelectric homogeneity of thermocouples, their insertion-withdrawal characteristics in the freezing point cells were studied. The results show that the Au/Pt thermocouple is capable of temperature measurement with repeatability ±4mK in the range from 0 to 900 °C. The homogeneity and sensitivity of Au/Pt thermocouple was found to be better than that of Pt-10%Rh/Pt thermocouple.

D-2, 11:25 Thermoelectric Scanning Study of Pt/Pd and Au/Pt Thermocouples up to 960°C with a Pressure Controlled Sodium Heat-Pipe

Masahiko Gotoh
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The performance of the Gold/Platinum(Au/Pt) thermocouple and the Platinum/Palladium(Pt/Pd) thermocouple received considerable study and it is found that stability of these thermocouples approaches those of Standard Platinum Resistance thermometers. However there is still some question on the uncertainties due to the different temperature profiles of the furnaces. In this paper results of the measurements on the irregular thermal emf by means of the thermoelectric scanning are reported. Scanning is carried out in the pressure controlled heat pipe at 960°C over 50cm along the thermocouples. An Au/Pt thermocouple and two Pt/Pd thermocouples were tested. One of the Pt/Pd thermocouples was subjected to 500 hours exposure to 1300 °C air environment. The other Pt/Pd thermocouple is newly fabricated one and act as the reference. There found no significant difference in the spurious Emf between the two Pt/Pd thermocouples. Discrepancy due to the different immersion was 55mK for Pt/Pd at most.

D-2, 11:45 The Effect of Interrogating Temperature Profile in the Seebeck Inhomogeneity Method of Test (SIMOT)

R. P. Reed
Proteun Services, Albuquerque, NM, USA 87109-3962

Seebeck inhomogeneity commonly occurs in thermoelectric thermometry. It is noticed in thermometry only in special circumstances, rarely in calibration, even when the error is large. It is easily measured by a range of authentic Seebeck Inhomogeneity Methods of Test. Such tests range from high resolution spatial profiling of Seebeck coefficient to lower resolution quality screening tests. The significance of a SIMOT depends on imposed test conditions. Swept interrogating patterns of temperatures must be documented to allow meaningful interpretation.

10:45 Session D-3. Radiation Thermometry: ITS-90 & Uncertainties

D-3, 10:45 Uncertainty Budgets for Realization of ITS-90 by Radiation Thermometry

Joachim Fischer[1], Mauro Battuello[2], Mohamed Sadli[3], Mark Ballico[4], Seung Nam Park[5], Peter Saunders[6], Yuan Zundong[7], B. Carol Johnson[8], Eric van der Ham[9], Fumihiro Sakuma[10], Graham Machin[11], Nigel Fox[11], Wang Li[12], Sevilay Ugur[13], Mikhail Matveyev[14]
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Recent international comparisons [1,2] and key comparisons have shown that the realization of the ITS-90 above the freezing point of silver and its dissemination may be less straightforward than expected. In many cases, the deviations of the local scale realizations resulted in higher values than the combined estimated uncertainties could reasonably justify. On the other hand, it must be considered that the realization of the ITS-90 by radiation thermometry is a complex exercise involving a large number of operations with many influencing parameters. Furthermore, the key comparisons need a unified approach to the treatment of uncertainties. Consequently, a rigorous standard approach for the calculation of uncertainties is necessary. In this paper three different operational schemes have been identified for realizing the ITS-90 by radiation thermometry. For all three schemes an analysis is presented of the base-line parameters underlying the scale realization above the freezing point of silver with respect to their contribution to the uncertainty budget. The paper is a joint effort of the CCT working group on radiation thermometry summarizing the knowledge and experience of all experts in this field.

D-3, 11:05 Uncertainty Arising from the Use of the Mean Effective Wavelength in Realizing ITS-90

Peter Saunders
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An analysis is made of the uncertainties arising from the approximations inherent in the use of the mean effective wavelength in the calculation of temperature on ITS-90 by radiation thermometry above the silver point. The uncertainties are evaluated for Gaussian shaped and interference-filter shaped spectral responsivities with typically used center wavelengths and bandwidths. This approach to determining ITS-90 is contrasted with the exact numerical solution of the integral equation for temperature, and an algorithm is presented for determining temperature with a small number of integrations.

D-3, 11:25 Experimental Investigation of the Temperature Drop Across the Wall of a Copper-freezing-point Blackbody

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National Research Council of Canada, Ottawa K1A 0R6, Canada

In the precise realization of the freezing point of copper, it is necessary to account for the temperature drop across the wall of the cavity of the copper-freezing-point blackbody. This temperature drop (~ 1 mK) is exceedingly difficult to measure and is often estimated by theoretical calculations. We envision that it may be measurable after accentuation in a suitably devised experiment. This paper is an account of our endeavor to measure the temperature drop. In our first experiment we constructed a number of cylindrical cavities, each having a circular base of non-uniform thickness. During freezing or melting we anticipated the temperature distribution of the base to reflect the varying temperature drop due to the varying thickness. Results shows that the effect of the non-uniform surface condition dominates over that of the varying thickness, making the latter undetectable. In our second experiment we constructed four atypical copper-freezing-point blackbodies which are practically identical to one another except that the wall thickness is uniform but different from one another. We compare the melting points of these blackbodies with the melting point of a reference blackbody. Results generally show the increase of the temperature drop with increasing wall thickness. We apply the results to a more typical copper-freezing-point blackbody and estimate the temperature drop at the centre of base to be 1.1 mK. A previously calculated value for a similar cavity is 1.7 mK.

D-3, 11:45 Spectral Radiance Comparisons of Two High-Temperature Blackbodies with Temperatures Determined using Absolute Detectors and ITS-90 Techniques

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For calibrations of spectral irradiance standards, a high-temperature blackbody (HTBB) is used as a source of spectral radiance or irradiance as derived from Planck's radiance law. The temperature of such a blackbody can be determined using radiance ratios to the gold freezing-temperature blackbody based on the technique described in the International Temperature Scale of 1990 (ITS-90), or by using a primary thermometer, which is an absolute detector referenced to a cryogenic radiometer. One of the primary motivations of using the detector-based method is that the uncertainties in the temperature determination of a HTBB can be lower than those assigned using ITS-90. Previous comparisons of temperatures measured using the two techniques have been at few selected wavelengths due to the limited measurement wavelengths of the comparison pyrometer. In this study, the spectral radiances of a HTBB from 250 nm to 2400 nm are assigned using a spectroradiometer from the known spectral radiances of a variable-temperature blackbody (VTBB) with a 0.999 emissivity, whose temperature is found using ITS-90 techniques. The spectral radiances of the HTBB are also assigned using a primary thermometer. These measurements are performed on four separate occasions over a period of one month. The uncertainties in the detector-based radiance temperature measurements are propagated directly from the spectral responsivity determinations, and taking the correlations into account reduces the detector-based temperature uncertainty to 0.21 K (k=2) at 3000 K, which is more than a of 6 lower than determined using radiance ratios to the gold-point blackbody. The agreement in radiance temperatures between the two methods is within the total combined expanded uncertainty of the temperature determination of the HTBB at 3000 K of 1.2 K (k=2).

10:45 Session D-4. Instrumentation: Signal Processing

D-4, 10:45 A High Accuracy, Universal Ethernet Thermocouple Scanner

Charles A. Matthews
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The growing use of Ethernet interfaces in Aerospace and Industrial Process applications created a need for an Intelligent Thermocouple Scanner to complement Intelligent Pressure Scanners and operate on an Ethernet network.. The scanner must be able to withstand the harsh environments required for flight test, turbine tests, and other turbo machinery development testing. It must be reliable enough to prevent process plant shutdowns and have a long calibration cycle. The scanner must able to accept microvolt inputs from different types of thermocouples, convert the signals to engineering units using NIST thermocouple conversion tables and output the data over a TCP/IP Ethernet link. This paper describes the calibration and communication of this instrument.

D-4, 11:05 The Use of Matrix Addressed Current Output Semiconductor Temperature Devices in TZ Cables for Long-Term Buoy Deployments: Technology Discussion and Case Studies

Christopher J. Owen and Viktor Slobodyan
Apprise Technologies Inc., Duluth, MN 55807, USA

Monitoring of temperature from buoy platforms over long linear distances has long been the desire of oceanographers and meteorologists alike. Design requirements for such a systems include multiple temperature measurements along a single cable over long distances (at the same time maintaining accuracy) while reducing the number of wires needed, thereby sinking the mass of the cable. Recently Apprise Technologies has released a commercial version of its Matrix Based Linear Temperature Array called TempLine to address these design criteria. The system is based on a patented current output bipolar semiconductor transistors, coupled with a matrix addressing system. This design allows for the reduction or elimination of cable voltage "noise" effects, cable temperature gradient and connector effects on the accuracy of temperature measurement. The matrix addressing system allows for a significant reduction in the number of wires, or leads, required for multi-point measurements (i.e. 100 points requires only 20 wires or leads). In addition, the semiconductor temperature devices are easy to calibrate to an accuracy of 0.01°C, with the calibration coefficients restricted to a memory chip in the connector, allowing for the calibration to "travel" with the cable. The output signal from the TempLine TZ cable is processed using an embedded microcontroller and is transferred via RS-232 communication protocol. The technology exhibits a large range of temperature response (-200 to +125°C), a swift response time of less than 20 seconds, is linear in its response, does not require a cold reference junction, and has excellent long-term stability. Apprise has cooperated with the Jet Propulsion Laboratory of NASA to successfully deploy this technology for long-term monitoring of temperature at four buoy locations on Lake Tahoe as part

of its groundtruthing effort for the Terra Satellite program. Examples of this data will be presented. In addition, applications in drifter buoy applications will also be discussed utilizing buoy platforms produced by MetOcean of Halifax Nova Scotia.

D-4, 11:25 Installation Techniques to Minimize the Influence of EMI on Temperature Measurements

Marc Bumgarner
Emerson Process Management, Rosemount Inc., Chanhassen, MN – 55317, USA

The effects of electromagnetic fields and surge voltages on temperature measurement devices can be made more severe by uncoupling temperature transmitters from the RTD's and thermocouples in the process. The physical separation of the sensor and the transmitter can add a significant length of conductive material, making the measurement susceptible to unwanted interference. This, coupled with the fact that temperature measurements are made using very small currents and voltages only adds to the potential degradation of the measurement. Since it is very common for temperature measurements to be made in this manner, many of these installations may not be optimized to provide the accuracy and stability that is desired. Some of the advanced diagnostic features found in today's temperature transmitters can be rendered ineffective due to the presence of unwanted interference. In many instances, these measurements can be made more reliably if some commonly overlooked installation practices are followed. The use of shielded cables and the proper termination of these shields, as well as the proper location of ground connections in the sensor wiring and on the 4 to 20 mA loop can dramatically reduce or eliminate the effects of interference. This paper will provide recommendations on proper installation techniques to minimize the effects of interference based on published standards and practical experience.

D-4, 11:45 Temperature Transmitter or Wire Direct to the I/O card: Cost, Performance and Reliability Analysis

Marcos Peluso
Emerson Process Management, Rosemount Inc., Chanhassen, MN – 55317, USA

Wiring a temperature sensor directly to the I/O card in the host system is a common practice in the industry. Cost and reliability are the main reasons behind this choice. Modern Temperature Transmitters offer superior performance and advanced diagnostics, making them an attractive alternative to Wire Direct. Sensor diagnostics validate measurement and reduce Mean Time to Repair, enhancing measurement quality and plant availability. Predictive diagnostics allows sensor repair even before sensor failure, increasing reliability. Electromagnetic Interference (EMI) represents a serious problem for temperature measurement, worsened by long wire runs. The effects of EMI on measurement uncertainty and consequent impact on operation costs are very high. Appropriate installation practices and hardware and software filtering can minimize EMI effects and its harmful consequences. This paper describes the new trends on temperature measurement diagnostics and EMI reduction and its effects on plant operation cost, performance and reliability.

10:45 Session D-5. Semiconductor Processing-I

D-5, 10:45 Accurate Measurements of Temperatures in the DUV Post Exposure Bake Process

Barney Cohen, Mei Sun, Ph.D., Wayne Renken and Paul Miller
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A system for monitoring the dynamic temperature profile during the deep UV (DUV) post exposure bake (PEB) is described. Platinum resistor temperature detectors (RTDs) are embedded into silicon wafers. Hardware and software convert the resistances to temperatures. The RTD calibration is National Institute of Standards and Technology (NIST) traceable. The wafers are tested on both a thermally uniform and stable hot plate and a production PEB hot plate. The temperature profiles for the PEB are fitted to a heat transfer model allowing heating and cooling time constants to be determined. High accuracy and precision are demonstrated. Reliability through 2000 thermal cycles is shown.

D-5, 11:05 Calibration of Radiation Thermometers in Rapid Thermal Processing Tools Using Si Wafers with Thin-film Thermocouples

K.G. Kreider, W. A. Kimes, C. W. Meyer, D. C. Ripple, B.K. Tsai, D. H. Chen, and D.P. DeWitt
National Institute of Standards and Technology, Gaithersburg, Maryland, USA

Rapid thermal processing (RTP) tools are currently monitored and controlled with lightpipe radiation thermometers (LPRTs) which have been calibrated with thermocouple instrumented wafers. We have developed a thin-film thermocouple wafer that

enables more accurate calibration of the LPRTs. The NIST thin-film thermocouple calibration wafer uses Pt/Pd wire thermocouples welded to thin-film Rh/Pt thermocouples to reduce the uncertainty of the wafer temperature measurement in situ. We present the results of testing these thin-film thermocouple calibration wafers in the NIST RTP test bed at temperatures ranging from 650 °C to 830 °C with a discussion of the materials limitations and capabilities. The difference between the thermocouple junction temperatures and the radiance temperatures indicated by the blackbody-calibrated LPRT can be attributed to the effective emissivity of the wafer, the parameter that accounts for the geometry and radiative properties of the wafer-chamber configuration. An analysis of the uncertainty, u = 1.3 K (k=1), of the wafer surface temperature measurements in the NIST RTP test bed although confirmation of this value was hampered by thermal gradients in the chamber and some problems with the weld pads at high temperature. In addition, we discuss the determination of the Seebeck coefficient of the thin-film thermocouples used on the wafers.

D-5, 11:25 In-Situ Optical Wafer Temperature Measurement

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The need for increasingly tighter process control is eminently apparent as semiconductor device dimensions become smaller and wafers larger. Today “Thermal Budgets” are shrinking and ramp rates increasing throughout wafer processing. Wafer temperature is perhaps the most universally critical process variable in front-end integrated circuits (IC) manufacturing. The use of pyrometry and optical lightpipes continues to gain widespread acceptance as the standard temperature control method in many processes. Lightpipes are used for controlling temperature in chemical vapor deposition (CVD), rapid thermal processing (RTP), epitaxial film growth (EPI) and physical vapor deposition (PVD). Optical thermometry offers numerous advantages over other forms of wafer temperature measurement. This paper presents the current strengths and limitations in optical wafer temperature measurement. Many factors continue to drive the measurement technology. As IC junctions become shallower, thermal budget concerns drive process temperatures down. Processing time and ramp rates continue to shorten in particular for implant anneals. Increasingly, process control requires complete thermal histories of wafers throughout IC manufacturing. These factors and new materials (copper and low-κ dielectrics) push tool manufactures and pyrometer vendors toward lower temperatures while still requiring high sensitivity, and accuracy. The accuracy of most in-situ optical temperature measurement continues to be dominated by uncertainty in wafer emissivity. Factors that limit accuracy, e.g., from wafer to wafer and from tool to tool, and advances in the technology are discussed.

15:00 Session E-1. Metal Carbon Eutectics

E-1, 15:00 On the Effect of Impurities on the Melting Curve of the Eutectic System Fe-C

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A study on the effect of impurities on the eutectic transition of Fe-C is presented in this paper. Experimentally obtained melting curves are compared with the curves calculated on the basis of a thermodynamic model, which includes the impurities in question as components. Melting curves have been measured for three ingots of eutectic Fe-C with nominal total purity levels of 3N, 4N and 5N. The calculations of the melting curves are based upon: (1) the Equilibrium solidification model and (2) the Scheil-Gulliver solidification model, which handle the effects of the impurities, assumed to be distributed between the γ-Fe and the liquid phase, on the transition process in such a way that they may be assumed to set lower and upper boundaries to the associated transition ranges.

E-1, 15:20 Construction and Implementation of a Set of Metal-Carbon Eutectic Fixed Points

Mohamed Sadli, Marcel Fanjeaux, Georges Bonnier
BNM-Institut National de Métrologie/Cnam (BNM-INM/Cnam), 75141 Paris, France

Recent work on the implementation of metal-carbon eutectic points in the field of radiation thermometry initiated in NMIJ [1] and continued presently among several European [2] and international laboratories, incites to an optimistic evaluation of the potential applications of such phase transitions as temperature references in the highest part of the temperature range, above the highest ITS-90 fixed point available, the copper point (1084.62 °C). Here are presented the up-to-date realizations of BNM-INM in the field. The filling of three cells was carried out and the results of these operations are described. The first

plateaux obtained with the Fe-C cell are presented. The difficulties encountered in these first steps are emphasized in order to point out the particular points that have to be taken into account during the design of the cavity cells, choice of metals, filling methods, etc.

E-1, 15:40 Design and Investigation of High Temperature Fixed-Points Based on Metal-Carbon Eutectics for Ultra-Precise Measurements in Radiometry and Spectral Radiation Thermometry

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All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI), Moscow, 119361 Russia.

The fixed-points of ITS-90 are the freezing temperatures of In, Sn, Zn, Al, Ag, Au, Cu, and the melting of Ga. More high-temperature fixed-points (Ag, Au, Cu) are widely used in reference radiometry, and also have utilization as reference sources at the temperature scale reproducibility. Last several years the steadfast attention of metrologists, working in the field of reference radiometry, was attracted by recently offered method of realization of fixed-points based on the usage of metal-carbon eutectics (alloys) instead of ordinary pure metals as a change-of-phase materials. The Re-C metal-carbon eutectics are being investigated for use as high-temperature fixed-point blackbodies as radiance and irradiance sources for precise measurements in radiometry, photometry and radiation thermometry above the conventionally assigned values of temperatures of ITS-90 scale. Re-C metal-carbon eutectic were designed and manufactured at VNIIOFI, Russia using the high-purity materials. The cells containing cavities with diameter varied from 4 to 10 mm emit Planckian radiation that could allow using them not only for radiance applications, but also irradiance. The reproducibility of melting/freezing temperatures of the measured crucibles was investigated carefully. The radiance reproducibility of the Re-C fixed point was found to be from 0.01% to 0.03% in visible in depend on cell. All measured cells agreed at the freezing point within 0.02% in terms of radiance.

E-1, 16:00 Investigation of Fixed Points Exceeding 2500 °C Using Metal Carbide-Carbon Eutectics

N. Sasajima, Y. Yamada, F. Sakuma,
National Metrology Institute of Japan, AIST, Tsukuba, Japan

The melting and freezing plateaus of four metal carbide-carbon (MC-C) eutectics, B_4C-C, δ(Mo carbide)-C, TiC-C and ZrC-C eutectics were investigated by radiation thermometry for the first time. The observed melting temperatures were 2386 °C, 2583 °C, 2761 °C and 2882 °C, respectively. The plateau shapes of δ(Mo carbide)-C, TiC-C and ZrC-C eutectics are relatively flat compared to quite rounded plateau shape of B_4C-C eutectic. The results indicate that MC-C eutectics can establish a new series of high-temperature fixed points above 2500 °C.

E-1, 16:20 HIMERT: A Pan-European Project for the Development of Metal-Carbon Eutectics as Temperature Standards

G. Machin[1], G. Beynon[2], F. Edler[3], S. Fourrez[4], J. Hartmann[3], D. Lowe1, R. Morice[5], M. Sadli[6], M. Villamanan[7]
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Metal-carbon eutectic mixtures show much promise for high temperature standards applications. A research project, Novel, High temperature, Metal-carbon Eutectic fixed points for Radiation Thermometry, Radiometry and Thermocouples (HIMERT) was accepted by the European Union (submitted under the Framework 5 Growth Programme) with a view to developing a unified European approach to these standards. The objectives of the project are to develop fixed-point cells both for radiation thermometry/radiometry and contact thermometry calibration applications. In total three sets of cells will be developed, two for radiation thermometry (by BNM-INM and NPL) and one for contact sensors (by BNM-LNE) and comparisons performed of the differing crucible designs. The cells developed for radiation thermometry will be calibrated according to the ITS-90 and measured radiometrically by a third participant (PTB). A set of cells will be transported to a laboratory external to the EU (the National Metrology Institute of Japan, NMIJ) for comparison with the cells developed there. In parallel with the experimental work a theoretical investigation of the eutectic process will be elaborated by the Universidad de Valladolid. Involvement of manufacturers of both contact sensors (Thermocoax) and IR thermometers (LAND Instruments) will ensure that the project works towards the provision of better high temperature standards for the wider measurement community. In addition, at the end of the project a discussion workshop will be held where the research team

will present their findings to the high temperature user community in European industry with the aim of improving metrological standards through stimulating the uptake of metal-carbon eutectic technology on a broad front. A description of the project is given and first results are presented.

E-1, 16:40 A Scenario for Realizing the High-Temperature Part of a Future ITS-20XX with the Aid of Eutectic Metal-Carbon Fixed Points

P. Bloembergen[1], Y. Yamada[1], N. Yamamoto[1], J. Hartmann[2]
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In the proposed scenario temperatures are defined by interpolation and extrapolation with respect to two reference fixed points (n=2), with assigned temperatures. The definition includes one full-range and two subranges in temperature. The scenario in question will be compared with two alternatives referred to (1) as n=1, using one reference point only, as in the ITS-90, and (2) as n=0, involving direct measurement of the thermodynamic temperature by means of absolute radiometry.

15:00 Session E-2. Thermocouple Test and Calibration Methods

E-2, 15:00 Improving Industrial Thermocouple Temperature Measurement

William Schuh and Nathan Frost
Watlow Electric Manufacturing Company, Richmond, Illinois, USA

Traditional industrial temperature measurement at high temperature entails the use of letter designated thermocouples coupled to digital instruments. A known problem with the standard letter designated thermoelements is material related. Manufacturing resources are consumed to minimize the uncertainty and instability of thermocouples in high temperature applications. These measurements can be vastly improved by a twofold approach that uses electronics to improve the available material properties of the thermometers. One half of the approach is to incorporate smart technology into the sensor and instrument system. By converting to smart technology the material constraints can be relaxed and more robust thermocouples can be produced. The paper will describe limits put on the MI cable manufacturing process by the material constraints and describe a system and present the results of testing to show the degree of improvement that is available.

E-2, 15:20 The Quality Testing Method For A Cable Thermocouple Hot Junction

A.V. Karzhavin, A.V. Belewtsev, A.A. Ulanowsky
Industrial company "TESEY", Obninsk, Russia

A method for revealing hot junction technological defects for outlet quality control during the cable thermocouple production is proposed. The disadvantages of existing (traditional) methods are considered.

E-2, 15:40 Possibilities and Limitations of Self-Validation of Thermoelectric Thermometry

R. P. Reed
Proteun Services, Albuquerque, NM, USA, 87109-3962

Increasing interest in so-called "Self-Validating" Sensors has taken advantage of the dramatic reduction in size and cost and the increased power of computer hardware and software. This technology has been applied to thermocouples, the sensor most used for process high-temperature measurement. Unique fault characteristics of thermoelectric circuits demand the use of complementary diagnostic measurands yet also require that inherent diagnostic limitations be understood. Thermocouples allow determination of *invalidity* but can not prove, *in situ,* continued traceably calibrated uncertainty.

E-2, 16:00 Fabrication Of A Small Copper Sealed-Cell For The Thermocouple Calibration

Yong-Gyoo Kim, Kee Sool Gam and Kee Hoon Kang
Temperature-Humidity Group, KRISS, P.O.Box 102, Yuseong, Daejeon, Korea

Small, sealed Cu freezing cells (100 mm high and 27.5 mm diameter) were fabricated for use in calibrating thermocouples in industry. The cell volume was about 15.8 cm^3 and contained about 125 g of Cu. These cells can be used to calibrate a thermocouple of 5.5-mm diameter. The cells were sealed in an argon atmosphere so as to be at a pressure of 1 atmosphere at the freezing temperature. The cells were tested with a Pt/Pd-thermocouple as a reference thermometer, and compared with a large, standard Cu freezing cell. The small cells showed a slightly lower temperature than the standard cell. The uncertainty of the cell temperature was calculated to be 0.1 °C within a confidence range of 95%.

E-2, 16:20 The 'Mini-Coil' Method for Calibration of Thermocouples at the Palladium Point

Ferdouse Jahan and Mark Ballico
National Measurement Laboratory, CSIRO, Lindfield, NSW 2070, Australia

The melting point of palladium (1554.8°C on the ITS-90) has widespread use as a reference point for the calibration of thermocouples to 1550°C. The 'wire bridge' method is widely used to realize this reference temperature. At NML (CSIRO) a more convenient technique, the 'mini-coil' method, in which a small coil of Pd wire is squeezed over the thermocouple junction has been developed and used for some years. In the study presented here the 'mini-coil' method is assessed for any possible systematic errors, such as arising from the Argon gas purge, or the heating rate and is compared with the 'wire bridge' method. The two methods are found to give equivalent results, however the larger mass of the Pd used in the mini-coil method gives longer, better defined and more reproducible melting plateaus (reproducibility is 0.5 µV). Analysis of possible Pt-Pd inter-diffusion is examined by comparing melting plateaus obtained after heating the thermocouple and Pd sample for various periods just below the Pd melting point. Energy Dispersive X-ray analysis was used to analyze both the thermoelements and the Pd sample.

E-2, 16:40 Estimation of Uncertainties in Comparison Calibration of Thermocouples

D. Zvizdic*, D. Serfezi*, L. Grgec Bermanec*, G. Bonnier*, E. Renaot*
**LPM-FSB, University of Zagreb, Zagreb, Croatia, **BNM-INM / CNAM, Paris, France*

The objective of this paper is to present the methodology for estimation of measurement uncertainties in comparison calibration of thermocouples used in Croatia at Laboratory for Process Measurements (LPM) and in France at Bureau National de Métrologie (BNM). The methodology is applied for comparison calibration of rare-metal and industrial base-metal thermocouples within temperature range from –20°C to 660°C with standard/working standard platinum resistance thermometers and from 600°C to 1050°C with standard/working standard thermocouples.

15:00 Session E-3. Radiation Thermometry: Applications in Metal Processing

E-3, 15:00 Spectral Emissivities of Heat Treated Steel Surfaces

W. Bauer*, W. Gräfen+, M. Rink*
**Institute of Applied Materials Technology, Gerhard-Mercator-University, Duisburg, Germany*
+Ipsen International GmbH, Kleve, Germany

The spectral emissivities of steels before and after heat treatment were investigated in relationship to different heat treatment processes (hardening, carburizing etc), temperatures, and atmospheres. Typical standard steel grades were selected from different steel-groups (case hardening steel, cold and hot working tool steel, nitriding steel etc.). Selected results are presented in the paper and show emissivity dependence of heat treatment.

E-3, 15:20 Recent Innovations and Improvements in Infrared Thermometry within the Aluminum Extrusion Industry

Paul Wright & Stuart F. Metcalfe
Land Instruments International, Dronfield, UK

The three main locations for non-contact, infrared thermometers (IRT's) within the aluminum extrusion process are; on the incoming heated billets, at the die exit and following a quench. Each of these locations poses its' own set of problems and requirements which have, until recently, limited the deployment and usefulness of IRT's within this industry. The previous generation of instruments were based upon dual wavelength heads, operating in straightforward ratio, or so called "2 + 1" modes. These required frequent recalibrations against thermocouple spot readings to maintain any sort of accuracy. Recent advances in measurement techniques however have made high accuracy routine and reduced operator input to a minimum. The deployment of these new instruments has been rapid. They have the potential to allow for improved product quality, press utilization and, therefore, material throughput.

E-3, 15:40 Ratio Radiation Thermometers in Hot Rolling and Galvannealing of Steel Strip

G. Raymond Peacock
Temperatures.com, Inc., Brecksville, Ohio, USA

In steel processing, the applications in which ratio thermometers perform as well as, if not better than, single waveband devices occur when near gray body conditions prevail, such as found in the Hot Rolling process. One exception is when steel is coated with zinc that is transforming from one emissivity condition to another, such as the Galvanneal process. A performance parameter for ratio devices, the "equivalent" wavelength approximation, is used to estimate errors with different waveband pairs for the two processes. Estimates of the expected temperature variations due to emissivity ratio uncertainty are compared with plant results from Hot Rolling of oxidized, low carbon steel strip. The required insensitivity to emissivity ratio variations in Galvannealing guided the selection of wavelength pairs, hence changed a standard instrument design to obtain satisfactory performance. The results were subsequently validated in on-line process measurements and used for many years in production.

E-3, 16:00 Simultaneous Measuring System of Emissivity and Temperature for Glossy Metals at Near Room Temperatures

Tohru Iuchi and Shigenobu Wada
Toyo University, Department of Mechanical Engineering 2100 Kujirai, Kawagoe, Saitama 350-8585, Japan

The emissivity change of a target and the extraneous radiation noise from surroundings are essential problems in radiation thermometry. Moreover, when the target is a glossy metal near room temperature, the weak radiance from the object and the temperature drift inside the radiometer increase the difficulty of the measurement. The signal processing using the p-polarized radiances at a direction of more than 80 °C was discovered to sort out the problems described above, enabling a method for simultaneous measurement of emissivity and temperature at room temperatures. In this paper, the basic principle of the measurement and successive experiments are described and an apparatus for the practical use is proposed.

E-3, 16:20 Development of an Industrial IR Sensor to Continuously Measure Total Absorptivity of Steel Sheet on Line: Application to the Optimization of the Thermal Treatment within Annealing Furnaces

Pierre-Jean Krauth
IRSID, Research centre of Usinor, F - 57283 Maizières-lès-Metz Cedex, France

We developed a sensor to measure on line and continuously the radiation properties of polluted Steel sheet. The surface pollution resulting from rolling operations is a mixture of oils and thin particles of iron and is similar to a semitransparent medium. This residual film modifies the infrared absorption of the iron sheet and its heating kinetics during its thermal treatment within the continuous annealing furnace. This sensor uses infrared reflection to measure the total absorptivity of the Steel sheet at the entry of the continuous annealing furnace. The different tests of laboratory, have allowed us to define and realise the prototype of the on-line measurement of the total absorptivity. The oil and thin particles of iron on Steel sheet before the annealing furnace disturbs the reheating of the products. The principal mode of heat transfer in these ovens is mostly radiation. The total absorptivity is the best parameter to control the heating of the products. We have thus defined and realised a system able to measure continuously the total absorptivity. This report presents the prototype we have realised.

E-3, 16:40 New Optical Pyrometry System for Measuring Accurately the Temperature of Aluminum Alloys and Other Highly Reflective, Variable Emissivity Surfaces

Francois Reizine
American Sensors Corporation, Pittsburgh, PA, USA

Improvement in the effectiveness and quality in the modern technological processes employed in the manufacture of aluminum and its alloys cannot be achieved unless the temperature can be measured to an accuracy of ± 0.5 – 1%. In dynamic processes, such as casting, rolling, extrusion, etc., accurate continuous temperature control is possible using non-contact, in particular optical methods. The advanced characteristics of the instruments used in this type of pyrometry (such as high speed, sensitivity, etc.), make it possible to measure relatively low temperatures. The use of optical pyrometry methods in the aluminum industry is, however, associated with a number of fundamental difficulties such as: a) the variable emissivity and transmission of intermediate media intervening between the pyrometer and the measured object in the course of measurements, b) the influence of the light reflected from external radiation sources, and c) the fluctuation of objects within the field of view of the optical pyrometer allowing only partial object sighting. All the above make single and dual wavelength pyrometers often inaccurate and even non-repeatable. The four-wavelength pyrometer system has been proven successfully in the field over the past few years. Its operation is based on the idea that the energy radiation spectra of the object being measured is characteristic to the properties (temperature, material, surface, etc.) of the object and the circumstances (smoke,

light, etc.) of the measurement. If there is a limited number of varieties of the operating conditions and some simple function describing the radiation spectra exists, then it is possible to identify the conditions, and the device can be adjusted to those conditions. The 'function' describing uniquely the radiation spectra, is generated from the brightness temperature values measured at the four different wavelengths. The algorithm according to which it is being done, is the merit of the measurement.

15:00 Session E-4. Fiber Optic and Interferometric Techniques

E-4, 15:00 Fiber Optic Temperature Sensors – A New Temperature Measurement Toolbox

Trevor Rice, Steve Poland, Brooks Childers, Matt Palmer, Jen Elster, Bob Fielder, Dave Maleski, and Mike Gunther
Luna Innovations Incorporated, Blacksburg, VA 24060 USA

This paper provides an overview of fiber optic-based temperature sensor technologies, including a variety of Fabry-Perot and other interferometric techniques (EFPI, IFPI), fiber Bragg gratings (FBG), long period gratings (LPG), Raman backscattering, optical frequency domain reflectometry (OFDR), Brillouin backscattering and other types of fiber optic temperature sensor types. Also included will be a discussion of specific industrial, commercial and aerospace applications in which fiber optic sensors have been, and are being used today.

E-4, 15:20 Double Tubing Encapsulated Fiber Optic Temperature Sensor

Juncheng Xu, Gary Pickrell, Zhengyu Huang, Bing Qi, Po Zhang, Yuhong Duan, Anbo Wang
Center for Photonics Technology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA

Increasing the efficiency of oil production operations requires improved sensors to supply critical information such as mixed phase fluid flow, pressure and temperature measurements within the down-hole oil environment. In order to provide robust and reliable fiber optic temperature sensors capable of operating in the harsh down-hole oil environment, where temperatures might exceed 250°C and pressures might reach 20,000 psi, a novel type of fiber optic temperature sensor has been developed. This temperature sensor functions as an EFPI (extrinsic Fabry-Perot interferometric) sensor. The glass tubing used is a borosilicate glass with a relatively high CTE, allowing a much higher sensitivity to be achieved. The sensor structure utilizes a dual tubing design (tubing within a tubing) to allow pressure isolation. An LED light beam is used as the signal interrogation source to remotely interrogate the sensor which may be located tens of thousands of feet away, connected by an optical fiber. A white-light interferometer measurement system is utilized to process the returned interference signal and to precisely determine the length of the Fabry-Perot interferometric cavity. The sensor has been packaged with a specially developed hermetic protection process to prevent water penetration and to improve the mechanical integrity of the sensor. This protection process has allowed the successful hydraulic deployment of fiber optic sensors through 3mm ID stainless steel tubing into a functioning oil well. Data on the resolution, repeatability and accuracy of the sensor as well as field testing experience will be presented.

E-4, 15:40 Single-crystal Sapphire High Temperature Measurement Instrument for Coal Gasification

Yibing Zhang, Gary Pickrell, Bing Qi, Russell G. May, Anbo Wang
Center for Photonics Technology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA

Increasing the efficiency of oil production operations requires improved sensors to supply critical information such as mixed phase fluid flow, pressure and temperature measurements within the down-hole oil environment. In order to provide robust and reliable fiber optic temperature sensors capable of operating in the harsh down-hole oil environment, where temperatures might exceed 250°C and pressures might reach 20,000 psi, a novel type of fiber optic temperature sensor has been developed. This temperature sensor functions as an EFPI (extrinsic Fabry-Perot interferometric) sensor. The glass tubing used is a borosilicate glass with a relatively high CTE, allowing a much higher sensitivity to be achieved. The sensor structure utilizes a dual tubing design (tubing within a tubing) to allow pressure isolation. An LED light beam is used as the signal interrogation source to remotely interrogate the sensor which may be located tens of thousands of feet away, connected by an optical fiber. A white-light interferometer measurement system is utilized to process the returned interference signal and to precisely determine the length of the Fabry-Perot interferometric cavity. The sensor has been packaged with a specially developed hermetic protection process to prevent water penetration and to improve the mechanical integrity of the sensor. This protection process has allowed the successful hydraulic deployment of fiber optic sensors through 3mm ID stainless steel tubing into a functioning oil well. Data on the resolution, repeatability and accuracy of the sensor as well as field testing experience will be presented.

15:00 Session E-5. Cryogenic Measurements: Techniques & Systems

E-5, 15:00 New Ultra-stable Measurement Platform for Thermal Transport Measurements Near the Superfluid Transition in ^{4}He on Earth Orbit

Robert Duncan, Peter Day, Dmitri Sergatskov, T.D. McCarson, David Elliott, S.T.P. Boyd, Steven McCready, and Alex Babkin
University of New Mexico, Albuquerque, NM and CalTech, Pasadena, CA, USA

A new technique for measuring the thermal conductivity of liquid ^{4}He near its superfluid transition has been developed for use of the first microgravity fundamental physics mission to the International Space Station in the year 2005. This apparatus will permit the cooling power to the helium thermal conductivity cell to be adjusted in increments of a picowatt, while maintaining overall heat stability at the thermal conductivity cell of 0.3 pW/minute in the presence of charged particle heating, which varies with the orbiter's position around the Earth. This platform will support a new method of thermometry with a noise level of less than 100 pK in a one-Hertz bandwidth, near the operating temperature of 2.2 K. The thermal performance and sidewall heat corrections in the thermal conductivity cell have been carefully optimized to assure that the science objectives of the Critical Dynamics in Microgravity experiment may be met during the mission. Extensive thermal performance data will be presented on this new thermal conductivity apparatus.

E-5, 15:20 Simulating Martian Temperatures

Randy K. Buchanan
University of Southern Mississippi, Hattiesburg, MS 39402, USA

The Mars Electrostatic Chamber (MEC) was designed to provide for research and testing relative to future missions to Mars. Environmental characteristics of Mars were emulated, including temperature, pressure, and atmospheric composition. Existing and newly acquired hardware were integrated with a centralized controller to bring about successful near-autonomous operation. The MEC is principally comprised of control systems existent for the purpose of controlling atmospheric pressure, atmospheric content, and chamber temperature. The temperature control system is used to replicate temperatures within actual minimum and maximum values as would be experienced on Mars. Cryogenic liquid/gaseous nitrogen supplies as well as various heating techniques were used to obtain this temperature range. Fundamental to the stabilization of temperature within the chamber was the instrumentation of multiple temperature measurements and optimal control of extremely cold nitrogen. Through testing and characterization, cooling design modifications, and controller instrumentation revisions, the cryogenic supply was successfully throttled by a programmable controller system with appropriate programming. Stable temperature control was ultimately achieved and automated diurnal cycling provided.

E-5, 15:40 Simplifying the Realization of PLTS-2000 with the Tungsten Superconductive Transition

D. Hechtfischer and G. Schuster
Physikalisch-Technische Bundesanstalt, Abbestraße 2-12, 10587 Berlin, Germany

The construction and use of superconductive fixed point devices using tungsten single crystals is described that allow temperature control of a dilution refrigerator near 15.5 mK with a resolution of the order ±2 μK if a few precautions are observed. As this uncertainty corresponds to ±8 Pa in melting pressure, its precision as a pressure calibration point is comparable to that of the ^{3}He phase transitions. Therefore it can be used for pressure calibration of a ^{3}He melting curve thermometer in the case of a dilution refrigerator without nuclear demagnetisation stage.

E-5, 16:00 First Prototypes of the Superconductive Reference Device SRD1000

W.A.Bosch[1], J.Flokstra[2], G.E. de Groot[4], M.J. de Groot[3], R.Jochemsen[4], F.Mathu[1], A.Peruzzi[3], D.Veldhuis[2]
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[4]*Leids Instituut voor Onderzoek in de Natuurkunde, Leiden, The Netherlands*

In the frame of the European Project "Ultra-Low Temperature Dissemination (ULT)", a superconductive reference device (SRD1000) and dedicated external measurement electronics were developed to provide direct traceability to the new Provisional Low Temperature Scale (PLTS-2000). The SRD1000 includes 10 reference points in the temperature range 15 mK - 1 K: W (T_C = 15 mK), Be (T_C = 23 mK), $Ir_{80}Rh_{20}$ ($T_C \approx 35$ mK), $Ir_{92}Rh_{08}$ ($T_C \approx 60$ mK), Ir (T_C = 100 mK), $AuIn_2$ (T_C

= 160 mK), $AuAl_2$ (T_C = 208 mK), Cd (T_C = 520 mK), Zn (T_C = 850 mK) and Al (T_C = 1180 mK). After an extensive research and development in the preparation and in the ultra-low temperature characterization of superconductive reference materials during the past years, eventually a final selection on the materials to be included in the first SRD1000 prototype sensors was made. In this paper, the superconducting transitions observed for the selected materials and the samples preparation are presented, the SRD1000 sensor and external electronics technology is exposed with some details and the ULT facility set up to calibrate the prototype sensors and the future commercial devices is described.

E-5, 16:20 A Cryogen-Free System for Realizing Low Temperature Fixed Points

Hirohisa Sakurai
National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

A cryogen-free system is developed to realize low temperature fixed points including the defining fixed points of the International Temperature Scale of 1990. The system is basically an adiabatic calorimeter using an open cell or a sealed cell. The low temperature gaseous fixed points and the heat capacities at temperatures near the phase transition points such as the heat capacity anomalies of hydrogen are measured by this system. The validity of the relation between the melting temperature and the inverse of the fraction of melt is demonstrated. The relation between the melting ranges and the deuterium content in hydrogen is shortly discussed.

E-5, 16:40 A New Cryostat for Measuring the Triple Point of e-H2 in a Sealed Cell at KRISS

Kee Hoon Kang, Yong-Gyoo Kim and Kee Sool Gam
Korea Research Institute of Standard and Science (KRISS), Temperature-Humidity Group
Daejon, Korea

A new form of cryostat that can realize the triple points defined in the International Temperature Scale of 1990 (ITS-90) at less cost and within a short period of time was designed and manufactured. This cryostat combined a He gas closed-cycle refrigerator, which has less costs for low-temperature maintenance and a lower gas-cooled refrigerator, which has the capacity to transfer low temperature quickly by using a small amount of liquid helium. After examining the cooling speed using the manufactured cryostat, the results showed that it reached 9 K within 9 hours. After realizing the e-H_2 triple point (13.8033 K) by using a new cryostat, the results of achieving the triple point was easy and fast. Moreover, the repeatability of the measurement of the triple point is 0.07mK. In addition, over 15 e- H_2 triple point measurement tests were possible in about three weeks time with 100 L of liquid helium. These results show that the triple point test, especially a new cryostat that can realize the e-H_2 triple point efficiently was manufactured.

Wednesday, October 23, 2002

7:30 Speaker Breakfast – Location: N426c

8:00 Registration

8:30 – 10:30 Morning Sessions F-1 through F-5

10:30 – 10:45 Break

10:45 – 12:30 Mid-Day Sessions G-1 through G-5

12:30 – 15:00 Lunch & Exhibit time

15:00 – 17:00 Afternoon Sessions H-1 through H-5

8:30 Session F-1. The ITS-90 Below 83.8 K

F-1, 8:30 ^{3}He Vapour-Pressure Measurements At PTB

J. Engert, B. Fellmuth
Physikalisch-Technische Bundesanstalt (PTB), Abbestrasse 2-12, 10587 Berlin, Germany

The paper reports on extensive ^{3}He vapour-pressure measurements carried out at PTB. To investigate in detail the main error sources, three different types of vapour-pressure cells and three different arrangements of pressure-sensing tubes were used. In the temperature range from 0.65 K to 1.2 K, the repeatability of the realisation of ^{3}He vapour-pressure temperatures T_{90} according to the International Temperature Scale of 1990, ITS-90, over eight runs was of order of 0.12 mK, whereas the repeatability over four runs using one and the same, optimised cryogenic set-up was of order of 0.03 mK. Below 1 K, the T_{90} realisation is compared to data available in literature via wire scales.

F-1, 8:50 Realization of the ^{3}He Vapour-Pressure Temperature Scale at NMIJ/AIST

Takeshi Shimazaki and Osamu Tamura
National Metrology Institute of Japan, AIST, Tsukuba, Ibaraki, Japan

An apparatus for realizing the ^{3}He vapour-pressure temperature scale has been constructed at NMIJ/AIST. The apparatus is designed to be operated for a long period of time by adopting a continuously operating ^{3}He cryostat. The cryostat has an experimental access port, which is top loading type. The diameter of the access port is 50 mm. An insert for ^{3}He vapour-pressure measurement is placed in the access port. The preliminary measurement results confirm that the cryostat system stabilizes the temperature of a ^{3}He vapour-pressure cell better than 50 μK for several hours. The ^{3}He vapour pressure is measured with a diaphragm differential pressure gauge, which has a silicon-resonant sensor. The differential pressure gauge is used in an absolute pressure mode. The resistance of the rhodium-iron resistance thermometers is measured with a DC bridge.

F-1, 9:10 The IMGC Interpolating Constant Volume Gas Thermometer – New Data

P.P.M. Steur, F. Pavese, I. Peroni, D. Ferri, A. Pugliese
Consiglio Nazionale delle Ricerche – Istituto di Metrologia "G.Colonnetti"
Strada delle Cacce 35, I-10135 TORINO – Italy

The Interpolating Constant Volume Gas Thermometer (ICVGT), designed with a cryogenic sapphire pressure transducer and running, has now a RUSKA pressure balance for the measurement of absolute pressure. The non-linearity of this transducer and the variation of its capacitance at zero differential pressure with temperature and line-pressure have been investigated, at low temperature. Measurements with the ICVGT are presented for the transducer in the differential mode, i.e. as a nulling device.

F-1, 9:30 Interpolating Gas Thermometer For Realizing the ITS-90 At NMIJ/AIST

Osamu Tamura, Yutaka Murakami and Hirohisa Sakurai
National Metrology Institute of Japan, AIST, Tsukuba, Ibaraki, Japan

A new interpolating constant volume gas thermometer (ICVGT) of ^{3}He is constructed for the realization of the International Temperature Scale of 1990 (ITS-90) below 14 K at NMIJ/AIST. The bulb is made of oxygen-free high-conductivity copper and has a spherical inside volume of about 1 L. The pressure of working gas is measured using a pressure gauge set at room temperatures through a pressure sensing tube made of stainless steel with an inner diameter of 2.2 mm. The ICVGT is calibrated against the ^{4}He vapor pressure scale and the triple points of equilibrium hydrogen and neon realized at NMIJ. 3 K or 4.2 K is chosen as the helium vapor pressure point for the calibration of the ICVGT and the ITS-90 is realized in the range from 3 K to 14 K. In this temperature range the temperature values obtained from the ICVGT calibrated at 3 K and at 4.2 K agree within 0.1 mK. The temperatures obtained from the ICVGT calibrated at 3 K agree with that obtained from the ^{4}He vapor pressure scale within 0.15 mK in the range from 3 K to 4.2 K. The temperature distribution along the pressure sensing tube is measured using eight thin film rhodium-iron resistance thermometers to estimate the corrections for the dead space and the aerostatic pressure head due to the sensing tube although these corrections are not basically required for ICVGT's in the Supplementary Information for the ITS-90. When these corrections are included in the interpolating equation, the obtained temperature value deviates about 0.1 mK at most from that obtained ignoring the corrections. A capsule rhodium-iron resistance thermometer is calibrated against the ITS-90 realized by the ICVGT. A 5-th order polynomial is fitted to 12 data points from 3 K to 14 K. The standard deviation of the fitting residuals is 0.06 mK.

F-1, 9:50 The NIST Low Temperature ITS-90 Realization and Calibration Facilities

C.W. Meyer and W. L. Tew
National Institute of Standards and Technology, Gaithersburg, Maryland, USA

Two facilities have been constructed at NIST for realizing and maintaining the ITS-90 below 84 K. The first facility is an integrated low temperature realization system that realizes the ITS-90 below 84 K in its entirety and which we refer to as the NIST Low Temperature ITS-90 Realization Facility (LTRF). The second facility, known as the Low Temperature Calibration Facility (LTCF) is a multi-purpose low temperature facility for dissemination and scale maintenance purposes. The LTRF calibrates reference resistance thermometers exclusively for NIST, while the LTCF maintains the NIST ITS-90 below 84 K and performs comparison calibrations of customer thermometers. Both facilities are used realize triple points; the LTRF is used to realize them in open cells while the LTCF is used to realize them in sealed cells. Below 84 K the ITS-90 has four different overlapping definitions. The first three definitions are ^{3}He vapor pressure thermometry (0.65 K to 3.2 K), ^{4}He vapor pressure thermometry (1.25 K to 5 K), and interpolating constant volume gas thermometry (3 K to 24.5561 K). The fourth definition is standard platinum resistance thermometry with subranges 13.8033 K to 273.16 K, 24.5561 K to 273.16 K, and 54.35 K to 273.16 K. Calibration of standard platinum resistance thermometers over these subranges requires the realization of four triple points below 84 K (argon, oxygen, neon and equilibrium hydrogen) and two e-H_2 vapor-pressure fixed points. The centerpiece of the LTRF is a copper block that contains an interpolating constant volume gas thermometer, three vapor-pressure cells and four open triple-point cells for realization using isothermal calorimetry. The LTCF cryogenic system is configurable as either an adiabatic calorimeter for use with sealed triple point cells or as an isothermal comparator for comparison of capsule thermometers. This system operates with similar resistance-measurement, refrigeration, and control systems to those used in the LTRF, but has no pressure metrology capability. We present here a description of the refrigeration, temperature-control, and resistance-measurement systems of the NIST LTRF and LTCF. For the LTRF, we also describe the copper block, the gas control system, and the pressure measurement system. Measurement procedures and data acquisition of both facilities are described, and an uncertainty analysis is provided.

F-1, 10:10 Recent Results of NIST Realizations of the ITS-90 Below 84 K

W. L. Tew and C.W. Meyer
National Institute of Standards and Technology, Gaithersburg, Maryland, USA

The results at NIST of realizations and comparisons of the ITS-90 below 84 K are presented. The ^{3}He and ^{4}He vapor pressure scales (0.65 K to 5.0 K), and the interpolating constant volume gas thermometer (ICVGT) scale (5.0 K to 24.556 K) as realized from 1994 to 1996 are carried on a series of five reference rhodium-iron resistance thermometers (RIRTs) which are periodically compared. The triple points of *e*-H_2, Ne, O_2, and Ar have been realized using a variety of cells and gas sources over the last 6 years. The resistance ratios of seven reference capsule-type Standard Platinum Resistance Thermometers (SPRTs) at these triple points have been recorded. Resistance ratios of four of the SPRTs at the *e*-H_2 vapor pressure points realized between 1994 and 1998 have been likewise recorded. These reference SPRTs are periodically compared with each other and with the reference RIRTs. Comparisons of the NIST realizations as recorded on these RIRTs and SPRTs are presented. Comparison results complied since 1997 are presented relative to those RIRT resistances and SPRT resistance ratios as submitted by NIST for the Consultative Committee on Thermometry (CCT) Key Comparisons (KC-1 and KC-2). Data from all NIST fixed-point realizations are compared to those which were submitted by NIST to the EuroMet 377 Star Comparison and which were performed using sealed triple-point cells. Further linkage to historical scales as maintained at NIST/NBS is presented through comparison of SPRTs, RIRTs, and GeRTs.

8:30 Session F-2. SPRT Quality Assurance & Uncertainties

F-2, 8:30 Internal Measurement Assurance for the NIST Realization of the ITS-90 from 83.8 K to 1234.93 K

G. F. Strouse
National Institute of Standards and Technology, Gaithersburg, Maryland 20899 USA

The National Institute of Standards and Technology (NIST) is responsible for realizing, maintaining, and disseminating the International Temperature Scale of 1990 (ITS-90) to the United States of America. The ITS-90 fixed-point cells necessary to calibrate standard platinum resistance thermometers (SPRTs) require an extensive internal measurement assurance program to insure that the assigned fixed-point cell uncertainties are achieved. There are six interactive elements for the realization of an ITS-90 fixed-point cell that contribute to the uncertainty of an SPRT calibration. These six elements are the fixed-point cells, furnace/maintenance systems, SPRT, measurement system, realization techniques, and measurement assurance. Within these six elements, there are twenty-eight parameters that are used to quantify and maintain the NIST-assigned fixed-point cell and SPRT calibration uncertainties.

F-2, 8:50 Contribution of Uncertainties in Resistance Measurements to Uncertainty in ITS-90

D. R. White
Measurement Standards Laboratory, PO Box 31310, Lower Hutt, New Zealand

The various effects giving rise to uncertainty in the ac and dc resistance measurements typical of those made in platinum thermometry are reviewed. Included is a brief statement of the origin of the effect, and where appropriate, a model of the effects and references to more detailed studies. Terms covered include noise due to thermal, detector, 1/*f*, quantisation and magnetic effects, various impedance and heating effects leading to large-scale non-linearities, and differential non-linearity effects arising from non-ideal voltage and current dividers. Techniques used to assess the accuracy of resistance bridges include simple linearity and complement checks, combinatorial methods, and direct comparison against reference voltage or current ratio sets. The advantages, disadvantages and limitations of the various techniques are summarized. The final section considers how the effects contribute to uncertainties in the measurements of temperature. Numerical examples based on the bridges commonly used in NMIs, are given. When only one bridge is used for both calibration and use of an SPRT, the various effects in the resistance bridge contribute uncertainties of about 0.1 mK to the uncertainty in temperature measurements. Also in this case the SPRT interpolation formulae correct for large-scale non-linearity errors in the bridge. When different bridges are used, such as when calibrating SPRTs

F-2, 9:10 Practical Uncertainty Limits in Calibration of Standard Platinum Resistance Thermometers by Comparison

T. Tasić[1], J. Bojkovski[2], V. Batagelj[2], D. Hudoklin[2]
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The following paper describes the practical uncertainty limits in calibration of standard platinum resistance thermometers (SPRT) by comparison. Usually, SPRT are calibrated at fixed points, but due to the high cost of a primary realization of physical quantities it is also reasonable to calibrate them by comparison at the highest level. The calibration by comparison is a technique most widely used to calibrate measuring instruments, not only in industry but also in many secondary calibration laboratories. Calibration procedures of a typical secondary laboratory are based on the use of transfer standards. These are reference standards of a secondary laboratory, which are usually calibrated in a primary laboratory, thus providing traceability through a process of dissemination of a unit to (inter)national standards. The aim of the work is to show that temperature calibrations by comparison, in the range from –95 °C up to 300 °C, can result in the calibration uncertainty being close to the calibration uncertainty of the thermometer calibrated at fixed points in certain subranges.

F-2, 9:30 Performance Assessment of Resistance Ratio Bridges used for the Calibration of SPRTs

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Automatic balancing dc and ac resistance ratio bridges are the primary measurement devices used by National Measurement Institutes for the calibration of standard platinum resistance thermometers (SPRTs) on the International Temperature Scale of 1990 (ITS-90). Performance assessment of these resistance ratio bridges is critical to the determination of both the uncertainties of the measurements and for identifying if a resistance bridge is exhibiting non-compliant behavior. NIST and NRC investigated the performance of 18 resistance ratio bridges consisting of 14 ASL F18s, 2 ASL F900s, and 2 MI 6010Bs. The assessment techniques included the use of an AEONZ resistance bridge calibrator, an ASL ratio test unit, and complements checks. Additionally, the possible effects from using different ac frequencies were investigated. This paper presents the methods of assessment employed, indicates the performance results obtained for the 18 resistance ratio bridges, describes the determination of measurement uncertainties, and assesses the contribution to the calibration uncertainty of SPRT measurements at ITS-90 fixed points.

F-2, 9:50 The Development of a Primary Laboratory for the Calibration of Standard Platinum Resistance Thermometers

Steven Armstrong
Henry Troemner LLC, USA

Henry Troemner LLC has assembled a temperature calibration laboratory for the calibration of standard platinum thermometers (SPRT's). Calibrations are performed using thermometric fixed-points to realize the International Temperature Scale of 1990 over the range 83.8058 K to 933.473 K. These realizations offer the chance to discuss realization techniques necessary to maintain reproducibility and stability of the fixed-points

8:30 Session F-3. Radiation Thermometry: Industrial Applications

F-3, 8:30 Direct Measurement of Gas Temperatures by Radiation Thermometry Near 4.3 Microns

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Land Instruments International, Dronfield, UK

An infra-red thermometer can measure gas temperature if its operating waveband is coincident with an absorption band in the target gas. Of particular interest are thermometers operating at wavelengths on the long-wavelength edge of the strong 4.3um carbon dioxide absorption band. These are used to monitor gas temperatures in industrial boilers and incinerators and have potential for use in a variety of combustion plant. If the gas path is *optically thick* (ie the thermometer does not "see through" to a back wall) and is of uniform temperature, then the thermometer will read the gas temperature directly. Presence of an optically thick condition depends on absorption strength, path length, gas concentration, temperature and pressure. So-called *band models* can be used to analyze the situation. They can estimate the "penetration" of the thermometer into the gas. They can also estimate the thermometer reading if the gas temperature is non-uniform and/or if the optically thick condition is not well met. This paper develops such a model based on data published by NASA and verified by laboratory measurements in a tube furnace. The model is then extended to allow at least some estimation of the effect of particulates. Calculations presented are for a particular thermometer spectral response but data is referenced to allow extension to other CO_2 band instruments. The model aims to allow straightforward assessment of the applicability of these instruments in industrial situations.

F-3, 8:50 Absorption and Emission Effects on Radiation Thermometry Measurements in Reformer Furnaces

Peter Saunders
Measurement Standards Laboratory of New Zealand, Lower Hutt, New Zealand

A simple model of the effects of atmospheric absorption and emission on radiation thermometer readings is described, and methods of correcting for these effects are given. These methods are applied to measurements made in a large reformer furnace using a commercially available radiation thermometer whose spectral responsivity partially overlaps some of the water vapor absorption bands. An effective absorption coefficient for the thermometer and the flue gas temperature are calculated and used to correct the thermometer readings. For relatively long measurement path lengths the corrections are almost as significant as reflection errors, and the uncertainties in the corrections increase very rapidly with path length.

F-3, 9:10 Measuring Systems For Temperature Monitoring Of Thermal Spraying And Combustion Processes In Industry

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Pyrolab ltd., Moscow, Russia

Conventional optical pyrometry methods do not always yield satisfactory results in case of temperature monitoring in complicated industrial processes. For example, measuring the temperature of heated particles in thermal plasma spraying jets requires recognizing the object being measured by solving a mathematical problem. In addition to perform temperature diagnostic of heated gas flows based on its self-radiation it is necessary to utilize an irradiation physical model of IR active molecules. The paper briefly describes two diagnostic systems and methods for the above-mentioned industrial application. The main details of the systems design, calibration and performance are presented.

F-3, 9:30 Automatic Emissivity Measurement Setup For Industrial Radiation Thermometry

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[2]now with Berliner Glas KGaA., Berlin, Germany
[3]Raytek Corp., Santa Cruz, USA

Recent progress in the technology of radiation thermometers has improved their accuracy significantly. The best Transfer Radiation Thermometers achieve accuracies of 0.1K or 0.1%. Based on this improvement in the primary calibration accuracies, also industrial radiation thermometers increased their accuracy in respect to blackbody radiation sources. But typical measuring objects for industrial radiation thermometers are often showing a non-gray spectral and non-lambertian angular emissivity characteristic. Typical emissivity uncertainties in industrial measurements are 3% to 10%. Especially for long-wavelength radiation thermometers the resulting measuring accuracy is in such cases dominated by the emissivity uncertainty. To improve this situation, the authors started a project to develop an emissivity measurement station that meets the needs of industrial radiation thermometry. The station is able to measure the spectral emissivity of samples in respect to their temperature, the emission angle and the polarization. For the industrial use, it was most important to design the setup as a fully automatic station.

F-3, 9:50 Thermal Imaging of High Temperature and Low Emissive Objects

Bruno Albano
J.M. Canty Inc., Lockport, NY USA

A vision based approach for non-contact 2 dimensional thermal imagining in hazardous and weatherproof industrial environments. This vision based system operates mainly in the visual range from .6 to .9 microns. Thus, changes in emissivity are insignificant and do not affect the results like with most traditional non-contact temperature measurement systems. A CCD camera suitable for the industrial environment provides a live video image, which is digitized by an image processor. Unique imaging software then combines temperature, level and position information to give repeatable temperature values at exact locations. Operators have a live view of the process that is a visual verification. The paper will describe detailed specifications along with calibration, accuracy and repeatability. Real time results can range from a simple display or be outputted to a control system with signals similar to 4-20mA closed loop to enable process control as well as a file archive for a historical record.

F-3, 10:10 Blackbody Models for High Temperature Measurements (1800 - 10000 K) of Metals, Hard Steels and Carbon in Liquid States under Fast Heating

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Temperature measurements were made with a two-strip wedge-shaped blackbody model up to 4100 K (for zirconium), up to 5600 K (for tungsten). Specific heat capacities were obtained for both metals in liquid state. We developed a blackbody model that would exist not only in solid state but also in the liquid state. The model was constructed specially for metals, hard steels and carbon investigations. The improved data on thermophysical properties of liquid carbon (up to 12000 K) are presented.

8:30 Session F-4. Secondary Fixed Points

F-4, 8:30 Thermodynamic Temperature Amplification by Means of Two Coupled Gas-Controlled Heat-Pipes

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Two gas-controlled heat-pipes, one working with mercury and the other with sodium, have been connected to a same helium pressure line. At any given pressure, the high temperature of the sodium heat-pipe is thermodynamically related with the low temperature of the mercury heat-pipe. Pressure control well within 1 ppm is obtained in both devices by using a 25-Ω SPRT inserted in the thermometer well of the mercury heat-pipe. A computer controls the helium pressure by operating input/output electrovalves and a variable volume. With such a system, helium pressures between 8 kPa and 200 kPa are controlled with a sensitivity well beyond the resolution of currently available pressure gauges, thus reaching a temperature stability in the mercury heat-pipe at a level of about 0,2 mK. The very high reproducibility of the 25- Ω SPRT used in the mercury heat-pipe between 240 °C and 400 °C, within $2 \cdot 10^{-7}$, is transferred with this amplification system to higher temperatures, thus obtaining in the sodium heat-pipe between 660°C and 961°C a reproducibility better than can be obtained with the high temperature standard platinum resistance thermometers. An accurate measurement of the thermodynamic relationship between the ITS-90 temperatures of the two substances during their liquid-vapour transitions at identical pressure values has been done and the results are hereby presented. The reproducibility of this " temperature amplifier" is then compared with measurements at the fixed points.

F-4, 8:50 Mercury and Sodium Liquid-Vapor Transitions and Thermal Analysis of Sodium Purity

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The liquid-vapor transitions have been studied of pure mercury between 240 °C and 400 °C and of pure sodium between 660 °C and 960 °C. The phase transitions are realized at IMGC by means of gas controlled heat-pipes, all connected to the same, very accurate, pressure control system. This control uses a SPRT as sensor and allows the study of the phase transitions at the level of a few tenths of a millikelvin. For the mercury phase transition, a perfect agreement could be reached between the temperature immersion profiles and the Clausius-Clapeyron curve. These temperature profiles have been obtained with the pressure control compensating the small pressure changes due to the ratio change in vapor and liquid amounts during movement of the thermometer in the thermometer well. In co-operation between IMGC and BNM-INM/CNAM, a study has been carried out on the sodium phase transition, as obtained in two different heat-pipes, one of IMGC and the other of INM. The temperature values in the two heat-pipes connected to the same pressure line are compared, as well as their temperature profiles. The effect of the purity of sodium on these measurements has been studied by substituting the sodium in the INM heat-pipe with new 3N5 pure sodium.

F-4, 9:10 Application of Binary Alloys in Miniature Fixed-point Cells as Secondary Fixed Points in the Temperature Range from 500 °C to 660 °C

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In this paper, some special features found during phase transformations of binary alloys which can influence their potential utilization as reproducible temperature fixed points are described. Furthermore, some experiences gained when applying alloys as phase transformation materials in miniature fixed-point cells are presented. For a number of selected binary alloys, some investigations for determining their melting and solidification temperatures as well as their reproducibility under laboratory conditions have been carried out. In addition, substantial investigation results concerning the influence of the mixing ratio on the phase transformation plateaus which can be measured using miniature fixed-point cells are presented. So far, miniature fixed-point thermocouples with binary alloys as fixed-point material have been successfully applied, even under industrial conditions, for realizing an automatic single-point recalibration of the temperature measurement sequence, with even a multiple-point recalibration being possible when special alloys are used.

F-4, 9:30 The Investigation of the First-Order Phase Transition of the High-Temperature-Materials by the Thin Plate Method

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The Infinitely Thin Plate (ITP) method has been used to determine the parameters of first type phase transition. Experiments and main estimates were performed in a one-dimensional approximation. The method was validated for high-temperature materials with known melting parameters, namely, Zr, Ti, Ta, W for $P \sim 10^5$ Pa. Furthermore, W fusion temperature for $P \sim 10^7$ Pa and carbon sublimation temperature for $P = 5 \cdot 10^4$ Pa were also measured. Experiments proved the ITP method to be useful for investigating the random component of the "time-temperature" curve.

F-4, 09:50 About the Reproducibility of High temperature Eutectic Melting Points

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It is shown that using static adiabatic experimental methods the equilibrium melting curves of high temperature eutectic substances can be determined just as reproducibly as equilibrium melting curves of pure metals. As illustration s melting curves of Al; AlSb eutectic (1.7°C below the Al point) and Al:Cd monotectic samples were repeatedly realized. The melting range of the eutectic sample was about 6 mK, within 20 % and 80% liquid range. The realized melting curves lay within 1 mK band of scatter. For the monotectic sample the scatter was a little larger and the melting range was about 10 mK within 20% and 60% liquid range. Using the concept of eutectic unit cell it becomes obvious why the eutectic melting temperatures are independent of concentration. Solid-liquid phase transformation could already be detected at as low as 1/10th of the eutectic concentration. It is only the heat of fusion that is concentration dependent.

8:30 Session F-5. Special Sensing Applications and Installation Techniques

F-5, 8:30 Reducing Thermowell Conduction Errors in Gas Pipeline Temperature Measurement

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It is well known that conventional thermowells will thermally "couple" with the vessel in which they are mounted resulting in an error in the temperature measurement. Conduction error, commonly called immersion error, is present whenever a temperature gradient exist between the vessel or pipe the thermowell is installed into, and the substance being measured. Sources of conduction error in gas temperature measurement and methods of reducing it, specifically the use of finned thermowells, are discussed.

F-5, 8:50 Measuring Process Temperature in Small Diameter Pipes

John Zwak, Greg Thorp
Burns Engineering

In today's high-performance process systems, measuring the process temperature in small diameter pipes or tubes down to 1/8-inch diameter must be understood. The most common applications have processes running in the temperature range of –50°C to +200°C. Measurement uncertainties can easily reach several degrees Celsius over this temperature range due to thermodynamics that can induce stem conduction effects of the sensor. Other real-world factors, such as the required time response of the temperature measurement, the ability to replace sensors during process operation, and the ability to clean-in-place all contribute to the difficulty of this measurement. This paper looks at several methods that can be used for making these measurements including direct immersion (without a thermowell), indirect immersion (with a thermowell), and non-intrusive methods. The temperature sensor assembly can range from simple clamp-on surface sensors to sensors with elaborately designed thermowells. This paper will focus on measuring the process using a platinum resistance thermometer (PRT), due to the performance required for most applications. It will also discuss the advantages and disadvantages of each temperature measurement method along with uncertainty estimates based on some common conditions.

F-5, 9:10 Web Technologies and Foundation™ Fieldbus in Temperature Monitoring

Loren Engelstad and Eric Rotvold
Emerson Process Management
Rosemount Measurement Division

In high-density temperature installations, the use of simple transmitters is sometimes not economical; therefore users would turn to wire-direct installations or use temperature multiplexers. Wire-direct may be cost effective when the distance from the measurement to the control room is short, where longer distances produce expensive wiring costs and performance degradation. The other solution, temperature multiplexers, is done with older, under supported equipment using wire direct installation techniques. With the emergence of new smart transmitters and digital communication technology, these points are now more cost effective to install, reliable, information rich and provide added diagnostic capabilities.

Foundation™ Fieldbus enables the use of multiple sensor inputs in a single transmitter with measurement status reporting being an integral element of this technology. Since Foundation™ Fieldbus is a digital communication protocol, system performance is enhanced compared to wire direct and other analog measurement solutions. Multisensor fieldbus transmitters also offer temperature measurement diagnostic capabilities that are not found in wire direct and multiplexer installations. The architecture of this technology using multiple sensor inputs connected through one pair of wires will greatly reduce the installation wiring cost. As Foundation™ Fieldbus is relatively new, many existing systems cannot benefit from all the features enabled by the technology. A new generation of devices can interface Foundation™ Fieldbus devices to legacy systems that offer MODBUS and/or Ethernet inputs. These devices can also contain an OPC (OLE for Process Control) server as well as a Web server and other open protocols. The Web connectivity allows the use of web browsers to monitor and configure each one of the measurement points. Through this configuration, it is possible to access a large number of points at a very low installation cost. On top of the savings the solution presented in this paper offers better performance, higher reliability and all the benefits of truly open connectivity.

10:45 Session G-1. International Fixed-Point Comparisons and Projects

G-1, 10:45 An International Star Intercomparison Of Low-Temperature Fixed Points Using Sealed Triple-Point Cells

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An overview of the main results of an international star intercomparison of low-temperature fixed points is given. Between 1997 and 2002, 51 sealed triple-point cells (STPCs) of the thirteen laboratories represented by the authors have been investigated at PTB. The STPCs are used to realise the triple points of hydrogen, neon, oxygen, and argon, respectively, as defining fixed points of the International Temperature Scale of 1990, ITS-90. The melting curves of all STPCs have been measured on the same experimental equipment, adhering strictly to a single measurement program. This protocol enables separation of the effects influencing the melting curves and direct comparison of the thermal behaviour of the STPCs, which are quite different with respect to design, age, gas source, and filling technology. In the paper, emphasis is given to the typical properties of the four fixed-point substances and to the spread of the STPC parameters. Connections between the star intercomparison and completed and on-going international activities, including the CIPM Key Comparisons, are also discussed.

G-1, 11:05 An European Interlaboratory Comparison of Indium Freezing Point

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This interlaboratory comparison has been performed within EUROMET frame as one of the projects carried out by the TC-THERM group. The main objective with this exercise was to establish the agreement between the realization of the indium freezing point from different participating laboratories, to identify and eliminate possible discrepancies and to develop an improved procedure for realization and determination of the freezing point of indium. The equipment has been made available by BNM-INM. Justervesenet coordinated this project.

G-1, 11:25 A Key Comparison of Water Triple Point Cells

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Under the Mutual Recognition Arrangement (MRA), the metrological equivalence of national measurement standards is determined from a set of key comparisons chosen and organized by the Consultative Committees of the International Committee for Weights and Measures (CIPM). At its last meeting, in September 2001, the Consultative Committee for Thermometry (CCT) decided to carry out a key comparison of water triple point cells, to be designated as CCT-K7 in the framework of the MRA.

G-1, 11:45 Main Results of the European Project "MULTICELLS" on Cryogenic Temperature Fixed Points in Sealed Cells

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[7]DG Technology, Parma, Italy

In January 2000 a European Project called "MULTICELLS" started, in the field of the realisation of temperature standards – fixed points in the range (2,18–216,6) K, ending in April 2003. Two lines of cell design were developed for both, modular multi-component cells (IMGC and INM down to 13,8 K) and ^{4}He lambda-point cells (IMGC and PTB) tested mainly by INTiBS, NMi, NPL, and PTB. Studies were also performed on the thermal design and to improve the knowledge on the underlying physical chemistry, with the goal of reducing the overall uncertainty budget within 0,1 mK. This involved also the comparison of the new modular multi-compartment cells, which are made of several elements –each realising one different fixed point, e.g., e-H_2, Ne, O_2, Ar, but also D_2, N_2 and CO_2– mounted on a common frame where the thermometers are fitted, with the previous-generation cells. The new cells represent a substantial improvement in the state-of-the-art of the realisation of these fixed points and of their use for the realisation of the ITS-90 and for thermometric checkpoints. A self-contained cryogenic-free computer-run cryostat is under development as the final stage of the Project for measuring the modular cells and for thermometer intercomparison.

G-1, 12:05 Realization of an Open Copper Fixed Point for Thermocouple Calibration

Mohammed Megharfi , Eric Devin, Anne Royer, Ronan Morice
BNM-LNE Paris, France

BNM-LNE had been studied Pt-Pd thermocouple behavior with the aim to adopt this type of sensor as an approximation of ITS-90 above 660 °C. In order to complete fixed points cells which are available for the calibration of Pt-Pd thermocouple and other Pt based thermocouples, BNM-LNE has recently developed an opened copper fixed point cell. This cell was developed as a test cell in order to improve the realization method, to estimate uncertainty contributions and also the freezing temperature traceable to ITS-90. The cell was checked using a copper fixed point mini cell. This paper describes all the steps of the construction needed for cell realization and its characterization. The choice to manufacture an open cell at this point is justified in the paper. Metal impurities, metal filling conditions in the cell and atmospheric pressure effects are studied. The freezing temperature of ITS-90 was preliminarily estimated by contact thermometry awaiting his comparison with radiation thermometry realization. The consistency of this estimated uncertainty will be confirmed by a comparison with other NMI facilities organized in Europe (Euromet project 624). This comparison is under process.

10:45 Session G-2. High-Temperature SPRTs

G-2, 10:45 Platinum-Sheathed High-Temperature Platinum Resistance Thermometers for Use up to 1200 °C

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A new type of HTPRT with a platinum sheath was developed. The stability of the resistance at temperatures above 1100 °C up to 1170 °C was studied. The HTPRTs have shown the resistance changes of 1.0 mK/h at 1100 °C, 0.7 mK/h at 1150 °C and 0.2 mK/h at 1170 °C, respectively. The values of W(29.7646 °C) after the exposure at 1170 °C were found to be larger than 1.118 07. This fact may imply that the HTPRTs developed can be used as a standard thermometer in the ITS-90. Measurements of this type of HTPRTs applied for furnace control are also give

G-2, 11:05 Measurement of the Insulation Resistance for the Development of High Temperature Platinum Resistance Thermometers with a Guard Electrode

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In the present study, the insulation resistance of insulators within standard platinum resistance thermometers (SPRT) is measured to evaluate the bias in temperature measurements caused by the leakage current flowing through the insulator, and a prototype SPRT to overcome the problems was built. First, a model representing four sources of such leakage has been proposed, and the significance of each source has been estimated quantitatively based on the measurements of the insulating resistance. It has also been found that two of the sources can effectively be eliminated by introducing a guard electrode within the SPRT. Based on this result, a prototype of new design SPRT equipped with alumina insulators and a guard electrode has been developed. Further measurements showed that the value of the bias agrees well with the model based upon preliminary insulating resistance measurements, and the guard electrode could successfully eliminate a bias as large as 37mK caused by the leakage effect.

G-2, 11:25 Approximation of ITS-90 with High Temperature Thermometers up to 1085 °C

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The upper limit of the ITS-90 in the contact thermometry part of the scale is the silver freezing point 961.78 °C. This limit is justified by the decrease of the stability and reliability of the high-temperature platinum resistance thermometers above the silver point. It was shown in several papers before, that some HTPRTs were able to work up to the gold and copper points with accuracy better than that for thermocouples or pyrometers. So, HTPRTs can be successfully used in some applications in the high-temperature range, such as calibrations of standard thermocouples or pyrometers by comparison with a high-temperature thermometer. To calculate the temperature measured with an HTPRT above the silver point, it is necessary to develop an interpolation function. Some methods for the interpolation have already been suggested in several papers. In the work on developing the new reference functions for noble metal thermocouples (Burns et al. 1992) one interpolation model was applied to a Russian-made HTPRT. In this paper we are investigating 8 interpolation equations, for which 3 to 5 calibration points are used. The functions were applied to 13 Russian HTPRTs calibrated up to 1064.18 °C and 7 HTPRTs calibrated up to 1084.62 °C. The uncertainty of the approximation was found to vary from 3 mK to 25 mK depending on the thermometer and interpolation model.

G-2, 11:45 Properties of a High-Temperature Platinum Resistance Thermometer up to 1350 °C

Masaru Arai[1], Akiyoshi Kawata[2]
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[2]*Japan Science and Technology Corporation, Tokyo, Japan*

Properties of high-temperature platinum resistance thermometers developed at NMIJ are studied in the range from 1100 °C to 1350 °C. The HTPRTs have shown drift rate of 0.1 mK/h at 1100 °C and 0.5 mK/h at 1170 °C. The W(29.7646 °C) values of the HTPRTs increased after the exposure at 1100 °C, while they slightly decreased at 1150 °C and 1170 °C. After exposed at 1170 °C for 500 hours, three of six HTPRTs showed W(29.7646 °C) values larger than 1.118 07. It was also found that the decrease in resistance continued above 1200 °C up to 1350 °C.

10:45 Session G-3. Radiation Thermometry: Calibration Facilities

G-3, 10:45 Low-Temperature Infrared Radiation Thermometry at NMIJ

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The NMIJ has established a facility for infrared radiation thermometry near ambient temperatures. It essentially consists of reference blackbody sources and infrared radiation thermometers. The temperature range from -20 °C to 160 °C is covered by two stirred fluid-bath blackbodies. The estimated uncertainties (k = 2) of the radiance temperature of the blackbody sources are better than 60 mK. A compact infrared radiation thermometer has been developed as a transfer instrument. The thermometer consists of an InSb detector operated in the dc-mode and simple lens optics. The short-term stability and resolution of the thermometer are much better than 10 mK. The facility allows us to calibrate the industrial standard blackbodies with uncertainty less than 100 mK.

G-3, 11:05 Temperature and Flux Scales for Heat-Flux Sensor Calibration

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Methodologies for calibrating heat-flux sensors designed for direct measurement of heat-transfer at a surface are presented. These sensors, extensively used in fire-test methods and aerospace applications, vary in range from a few kW/m^2 to in excess of 500 kW/m^2. Traceable source- and detector-based techniques using blackbody radiation are described to cover the wide range of calibration. Calibration results on typical sensors from three blackbody facilities: 25 mm and 51 mm diameter heated graphite tubes and a 23 cm diameter spherical cavity, are presented. These results demonstrate the equivalence between the source- and detector-based techniques in the range from 50 kW/m^2 to 200 kW/m^2, and also the superiority of detector-based calibration when reflected radiation effects are important. The problems associated with extending the calibration techniques to high heat-flux levels by inserting the sensor inside a blackbody cavity are also discussed.

G-3, 11:25 UME Radiation Thermometer Calibration Facilities Below The Freezing Point Of Silver (961.78 °C)

Ahmet Diril, Humbat Nasibov, Sevilay Uğur
Ulusal Metroloji Enstitüsü, Kocaeli, Turkey

Facilities at UME for the calibration of radiation thermometers at the range (below 961.78 °C) are described. Traceability in the range 200 C to 960 C is obtained over fixed-point blackbody radiators, while traceability in -30 °C to 200 °C is obtained through a homemade variable temperature blackbody with calibrated Pt100 temperature sensors. The overall best uncertainty for the first range is 0.3 °C, for the second range is 0.6 °C (k=2).

G-3, 11:45 The NRC Blackbody-Based Radiation Thermometer Calibration Facility

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The utilization of radiation thermometers by industry is increasing at a significant rate. At the same time, the need to establish the traceability of the resulting measurements to national standards has never been more important. NRC has responded to this demand by establishing a calibration facility comprising both variable-temperature and fixed-point blackbody cavities spanning the range from -40 °C to 2500 °C.

10:45 Session G-4. Temperature Control/Automation

G-4, 10:45 "Milli-Kelvin-Stabilized Cell" for the Precise Study of Phase Transitions

Akira Kojima[1], Yukio Yoshimura[2], Hiroshi Iwasaki[2] and Ken-ichi Tozaki[3]
[1]*Department of Materials Science, The University of Shiga Prefecture, Hikone, Shiga 522-8533, Japan*
[2]*Faculty of Science and Engineering, Ritsumeikan University, Kusatsu, Shiga 525-8577, Japan*
[3]*Department of Physics, Faculty of Education, Chiba University, Inage, Chiba 263-8522, Japan*

Simple and versatile "milli-Kelvin-stabilized cell" having fine temperature stability better than 1 mK has been developed to study precisely phase transitions in solids, passing through the transition point very slowly on both heating and cooling. It has multi-shells strongly related to the fine innermost temperature stability. The temperature is regulated by pseudo-predictive control using a personal computer. The "cell" enables us to make not only heat flow measurement but also X-ray diffraction with heat anomaly sensing, dielectric constant and spontaneous polarization measurements simultaneously with endothermic or exothermic heat measurements. Results of application to the perovskite-type compounds are shown.

G-4, 11:05 Oil Bath for Precision Calibration of Thermometers in the Range 90 °C to 200 °C

Jan Ivarsson and Roland Falk
SP Swedish National Testing and Research Institute, SE-501 15 BORÅS, SWEDEN

Calibration of thermometers requires a stable environment. In the range 90 °C to 200 °C normally comparison calibrations are performed in liquid baths with silicon oil as the fluid medium. This range is difficult to cover with good enough stability using commercially available baths. Therefore a calibration bath was constructed in our laboratory and presented at the 21st Nordic conference on Measurements and Calibration in 1999. The experience from this has led to this further improved version. The principle of the bath is based on a closed end aluminium tube, with an inner open concentric tube placed near the bottom and allowing free circulation of the oil around it. The circulation is achieved by a stirring propeller in the lower end, inside the inner tube which is the calibration compartment. The heating power is supplied by two different heaters, one main heater wrapped on the outside of the outer tube and one placed in the space between the cylinders. The main heater acts as a guard heater and is supplied with constant power to give the outer wall a stable temperature, just below the set point. The second smaller heater is performing the regulation with the aid of a commercial controller. The bath is housed in a floor cabinet with a working space of diameter 100 mm and a depth of 500 mm. Temperature stability and uniformity achieved in the bath is around ±1 mK in the whole range up to 200 °C and this is without the use of any kind of equalising block. This is an improvement from the earlier version in the upper temperature range. For example temperature instability and nonuniformity has decreased from ±3 mK to ±1 mK at 200 °C. The performance is now comparable with the best water baths used at lower temperatures. Data and diagrams are presented in the paper.

G-4, 11:25 Kalman-Predictive-Proportional-Integral-Derivative (KPPID) Temperature Control

Andrei Fluerasu, Mark Sutton
Centre for the Physics of Materials, Physics Department, McGill University, Montreal, Quebec, Canada H3A 2T8

With 3rd generation synchrotron X-ray sources, it is possible to acquire detailed structural information about the system under study with ms time resolution, orders of magnitude faster than was possible a few years ago. These advances have generated many new challenges for changing and controlling the state of the system on very short time scales, in an uniform and controlled manner. For our particular X-ray experiments [1] on crystallization or order-disorder phase transitions in metallic alloys, we need to change the sample temperature by hundreds of degrees in milliseconds and to avoid over/under shooting. To achieve this purpose, we designed and implemented a computer-controlled temperature tracking system which combines standard Proportional-Integral-Derivative (PID) feedback, thermal modeling and finite difference thermal calculations (feed-forward) and Kalman filtering of the temperature readings in order to reduce the noise. The resulted Kalman-Predictive-Proportional-Integral-Derivative (KPPID) algorithm allowed us to obtain an accurate control, to minimize the response time and to avoid over/under shooting, even in systems with inherent noisy temperature readings and time delays. The KPPID temperature controller was successfully implemented at the Advanced Photon Source at Argonne National laboratories and was used to perform the coherent and time-resolved X-ray diffraction experiments.

G-4, 11:45 Fast Methods for Slow Loops: Tune Your Temperature Controls in 15 Minutes!

Michel Ruel

Top Control USA, Inc., USA

Traditional methods for PID tuning of slow loops require several hours and sometimes days to complete because they rely on steady-state process response or on continued oscillation. Furthermore, making such a bump can be a major upset to the process, resulting in scrap product and wasted energy. This paper presents methods to tune long, slow control loops quickly: in minutes, not hours.

10:45 Session G-5. Semiconductor Processing-II

G-5, 10:45 Application of Emissivity Compensated Pyrometry for Temperature Measurement and Control during Compound Semiconductors Manufacturing

Alex Gurary, Mikhail Belousov, Jeff Bodycomb, Vadim Boguslavskiy, Jeff Ramer, and Richard Hoffman

EMCORE Corporation, Somerset, NJ 08873 USA

Deposition processes for many Compound Semiconductors devices (such as InGaAsP/InP infrared laser diodes or InGaP/GaAs heterojunction bipolar transistors) are extremely temperature sensitive with temperature windows as small as 2-3°C. Requirements for process temperature repeatability can be less than +/- 0.25°C at temperatures in the range ~ 650 – 750 °C which significantly exceed typical requirements for the silicon industry. While temperature control is a vital requirement for growing reproducible structures, wafer temperatures can deviate significantly from those measured by conventional techniques such as close proximity thermocouples or optical pyrometers. Elements (such as susceptor, wafer carrier and gaps filled by low pressure gas) located between the thermocouple and the wafer lead to measurement errors, particularly when the environment of the chamber changes such as during gas switching. Optical pyrometer measurements may have an error up to 100°C due to emissivity oscillations during deposition of the thin epitaxial layers. To overcome these problems, Emcore recently developed an Emissivity Compensated Pyrometer (ECP) known as RealTemp® for use in multi-wafer Rotating Disk Reactors (RDR) which provides real-time accurate measurement of the wafer surface temperature during growth. RealTemp® is a device that combines a reflectometer (for accurate, real-time emissivity calculations) and a pyrometer (utilizes measured emissivity for accurate temperature measurements). We also use this more accurate temperature data for real-time wafer surface temperature control. In our presentation we will report on basic metrological parameters of the developed RealTemp® pyrometer including effect of the target emissivity on the accuracy of the temperature measurements. We will describe a high-speed algorithm that separates temperature measurements on the semiconductor wafers from measurements on the carrier used to hold wafers during deposition processes. Also we will describe experiments performed to verify the accuracy of the temperature measurements using emissivity compensated pyrometry.

G-5, 11:05 Characterization and Calibration of Lightpipe Radiation Thermometers for use in Rapid Thermal Processing

B.K. Tsai and D.P. DeWitt

Optical Technology Division, National Institute of Standards, Gaithersburg, MD, USA

Lightpipe radiation thermometers (LPRTs) are the sensor of choice for temperature measurements in Rapid Thermal Processing (RTP) applications. At the National Institute of Standards and Technology (NIST), we have developed protocols for calibrating and characterizing LPRTs for use in RTP and other applications. In this paper, the LPRTs and the sodium heat pipe blackbody (Na-HPBB) used in the calibration process at NIST will be introduced. The calibration and characterization methods (spatial response, spectral response, temporal response, and optical inspection) of the LPRTs will be described also. Finally, a discussion of the application of LPRTs in an environment outside of the calibration laboratory, along with a list of recommendations for proper use of LPRTs, will be presented.

G-5, 11:25 Comparison of Silicon Wafer Temperature Measurements Using Thin Film Thermocouples and Lightpipe Radiation Thermometers in a Thermometry Test Bed

Kenneth S. Ball, Kerry S. Huston, and Gerald Y. Tan
The University of Texas at Austin, Austin, Texas, USA

This paper reports on the results of a research study to compare the temperature measurements obtained using NIST (National Institute of Standards and Technology) thin-film thermocouple calibration wafers [1] and other commercial calibration wafers to those of lightpipe radiation thermometers (LPRTs) from at least two commercial manufacturers. These comparisons have been performed in the UT (The University of Texas at Austin) RTP Thermometry Test Bed, which has been previously described [2]. The LPRT-to-thermocouple comparison measurements have been made at temperatures ranging from 700 °C to 900 °C in the UT Test Bed. The Thermometry Test Bed is a joint project by UT, NIST, SA (SensArray Corporation) and ISMT (International SEMATECH) under Sponsored Research Agreement No. 38060302. The Test Bed facility is evolving into a temperature standard, traceable to ITS-90, for commercial sensors (OEM pyrometers) targeting applications in RTP and (MO)CVD. The Test Bed facility can accommodate a wide variety of commercial sensors. The performance of the Test Bed is indicated by the following wafer temperature characteristics: run-to-run repeatability better than ± 1.0 ºC at 1000 ºC, and overall temperature uniformity better than ± 1.5 ºC across the wafer (better than ± 1.0 ºC at any given radial location). Results using standard TC (thermocouple) instrumented wafers from SA are presented to characterize the performance of the Test Bed, as well as results from the NIST thin-film thermocouple calibration wafers. Several commercial sensor suppliers have initiated tests of their pyrometers. The pyrometers tested in this study are the CI Systems NTM500, and the Mikron Instrument Company's M680S IR Fiberoptic Temperature Measuring System.

15:00 Session H-1. Cryogenic Sealed Cells

H-1, 15:00 Century-Stable Accurate Cryogenic Temperature Fixed Points: Problems Solved and Problems to be Solved

F. Pavese
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It is now more than a of a quarter century since the first cryogenic triple-point cell was sealed, a cell still existing at IMGC and reproducing the same temperature value of the triple point of argon within about ± 0,15 mK. Most of the other cells of a half a dozen different designs, subsequently sealed with several substances at IMGC– and now amounting to more than 150 in total,– are still existing and retain the initial value of their triple point realisations. Some are not, for problems that were studied: most of these problems have been solved, some have been understood but not solved yet, a few others are still not understood well enough. The cell thermal design was found to be of little influence for realisations aimed at an uncertainty level of 0,2–0,5 mK, but its optimisation was found essential when the aim is, as presently it is now, to lower the total uncertainty down to a ≈30 µK level. Major contributions to the total uncertainty may arise from the purity of the sealed substance and, only in a few cases, from its stability with time and from the accurate and reliable knowledge of the main impurities. The paper discusses the main problems solved since the '70s, the problems still caused by the cell design or by the enclosed substance, and the problem of a definition of the transition temperature that could remove the ambiguities present in the ITS-90 current definition, when the experimental uncertainty is lowered by one order of magnitude with respect to the time when the Scale was promulgated.

H-1, 15:20 Cryogenic Temperature Sealed Fixed Points: IMGC New-Generation of Modular Cells

F. Pavese[1], D. Ferri1, I. Peroni[1], A. Pugliese[1], P.P.M. Steur[1], B. Fellmuth[2], D. Head[3], L. Lipinski[5], A. Peruzzi[4], A. Szmyrka Grzebyk[5], L. Wolber[2]
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Mainly in the frame of the European Project MULTICELLS, IMGC developed a new generation of sealed temperature fixed-point cells, based on the principle of modular elements, each containing one substance, several of which can be mounted in a copper frame of reduced dimensions where thermometers are fitted. The device being modular, the user can select the fixed points, up to six, to be mounted each time in the device. The paper describes the design of the devices and reports on three years of testing on e-H_2, Ne, O_2 and Ar elements and of investigations not only at IMGC but also at INTiBS, NMi, NPL and

PTB. The results obtained with the new devices are better than those obtained with the previous single-substance IMGC cells. These studies mainly concerned the effect of the geometry of the elements, which are now much smaller in size than the previous IMGC cells, on the thermal behaviour, in order to optimise the thermal response time and minimise the thermal resistance between the solid-liquid interface of the substance and the thermometers. For *e*-H_2, the new elements also allowed to investigate the effect of the isotopic composition on the triple-point temperature.

H-1, 15:40 A New Generation of Multicells for Cryogenic Fixed Points at BNM/INM

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In January 2000 a European Project called “MULTICELLS” started, in the field of the realisation of low-temperature standards [1]. In the range from 14 K to 234 K, two competing designs of modular multi-compartment cells (multicells) for the realisation of low-temperature fixed points of the ITS-90 were developed and fabricated by two different partners: BNM-INM and IMGC [2]. The multicells device allows the calibration, in the same run, of up to three thermometers at all the ITS-90 triple points in the low-temperature range, including the mercury point. Several secondary reference points could be optionally added to the system. The limitation of the number of elements is mainly due to the thermal effects (thermal homogeneity and response time) and to the dimension of the experimental space of the calorimeter used for measuring the melting curves. In order to reduce the response time, the phase-transition interface of each element of the multicell containing the substance must be in close thermal contact with the thermometers to be calibrated, although the different elements must be easily separated. BNM-INM developed and improved the device in co-operation with the testing partners from other institutes represented by the authors. The technical choices leading to the BNM-INM design are presented and justified. Experimental results on the thermal behaviour of the multicells are given. The tests were performed in accordance with a detailed protocol in order to enable a direct comparison of different designs of the multicells.

H-1, 16:00 New Sealed Cells for the Realization of Cryogenic Fixed Points at NMIJ/AIST

Tohru Nakano, Osamu Tamura, Hirohisa Sakurai
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New sealed cells are developed at National Metrology Institute of Japan (NMIJ), which are used for realization of the cryogenic fixed points of the International Temperature Scale of 1990. A metal O-ring made of stainless steel is introduced as a sealing device for the sealed cells. The triple point of equilibrium hydrogen has been realized using the new sealed cells containing hydrogen and ferric hydroxide as a catalyst for the orth-para equilibration. Double anomalous peaks on the heat capacity curves are observed at temperatures just below the triple point, but they are suppressed by reducing the amount of the catalyst. The triple point temperature of equilibrium hydrogen obtained by the new sealed cells is in good agreement with those reported previously in measurements of open cells by assuming that the dependence of the triple point temperature on the deuterium content is 5.4 μK per ppm of deuterium in the hydrogen. A similar anomalous peak on the heat capacity curves of equilibrium deuterium is also discovered at temperatures just below the triple point using a sealed cell fabricated at Instituto di Metrologia G. Colonnetti

H-1, 16:20 Realization of the Lambda Transition Temperature of 4He Using Sealed Cells

Lin Peng[1], Mao Yuzhu[1], Hong Chaosheng[1], Franco Pavese[2], Ilaria Peroni[2], David Head[3], Richard Rusby[3]
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This paper presents lambda-point measurements obtained at CL, IMGC, and NPL in the past two years using sealed cells made at CL. The cells consist of two chambers containing liquid helium, separated by a stainless steel capillary. When the HeI/HeII interface is located in the capillary, the large thermal conductivity of HeII ensures that the lambda temperature is established in the top chamber. Heat flows change the position of the interface, but have only a small effect on the temperature of the top chamber. Because of the self-adjusting effect of the HeI column within the capillary, the lambda transition temperature plateau was recorded in the top chamber for many hours with a fluctuation of 3.2 μK. The temperature of the lambda transition at zero heat flow is determined by measuring the temperature at several heat flows and extrapolating to zero.

The best realizations of the T_λ were made at NPL with a standard deviation of 5.8 μK, and the effect of the finite conductivity of HeII was observed for the first time in this cell.

H-1, 16:40 An Argon Triple Point Device to Calibrate Long Stem Thermometers in Quasi Adiabatic Conditions

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An argon triple point apparatus has been fabricated to calibrate long stem SPRT's (Standard Platinum Resistance thermometer) in quasi-adiabatic conditions. The detailed description of this apparatus is given below. The results obtained and a comparison with a system realizing the argon triple point using a continuous heat flux method [1] are presented.

15:00 Session H-2. ITS-90 Fixed Points: Ar, Hg, and Ga

H-2, 15:00 Argon Triple Point Apparatus for SPRT Calibration

Stanley Pond
Pond Engineering, Berthoud, CO, USA

The argon triple point is a required reference point for calibration of standard platinum resistance thermometers (SPRT's) on the International Temperature Scale of 1990 (ITS-90) for use in all four subranges extending below the triple point of mercury. Availability of affordable commercially produced apparatus to realize the triple point of argon has been very limited. An apparatus to realize the argon triple point comprising an integrated system including a microprocessor controlled, liquid nitrogen cooled maintenance system and sealed argon cell containing approximately 1.8 moles of high purity argon is described. Operating procedures for use of the apparatus have been developed with input from personnel at the National Institute for Standards and Technology (NIST) and are presented. Following these procedures, measurements of multiple plateaus realized by the apparatus (made using the NIST argon reference SPRT) show agreement with the NIST apparatus realization within ± 0.1 mK.

H-2, 15:20 Open

H-2, 15:40 NIM Realization of the Gallium Triple Point

Yan Xiaoke, Qiu Ping, Duan Yuning, Qu Yongmei
National Institute of Metrology, Beijing 100013, China

In the last three years (1999~2001), the gallium triple point cell has been successfully developed and many corresponding researches have been carried out at the National Institute of Metrology (NIM), China. The paper presents the cell design, apparatus and procedure for realizing the gallium triple point, and study on the different freezing methods. The reproducibility is 0.03mK and the expanded uncertainty of the realization of the gallium triple point is evaluated to be 0.17 mK (p=0.99, k=2.9).

H-2, 16:00 A New Stainless Steel-Cased Gallium Cell and Its Automatic Maintenance Apparatus

X. Li, D. Davis, A. Sjogren, D. Farley, M. Zhao, and D. Chen
Hart Scientific, American Fork, Utah 84003, USA

A new stainless steel-cased gallium cell has been developed. The new cell design, including an open cell version, is described in detail. A new cell was compared against a NIST-certified gallium cell, and the difference between them was well within 0.1 mK. Multiple cells of the new design were intercompared with each other, with differences well within 0.1 mK. A new automatic maintenance apparatus has been developed for simplifying the operation. A melting plateau as long as seven days is easy to obtain using the new apparatus. The expanded uncertainty (k=2) was estimated to be within 0.1 mK for the whole system.

H-2, 16:20 **Calorimetric Realization of the Triple Point of Mercury**

Hirohisa Sakurai
National Institute of Advanced Industrial Science and Technology, Tsukuba 305-8563, Japan

The triple point of mercury is realized by a calorimetric method using two small Pyrex glass tube cells with 10 mm in outer diameter and 5 cm in length. About 0.1 mol of pure mercury are filled and sealed off. It is proposed to use the cell in the horizontal position to reduce the uncertainty of the hydrostatic correction and its advantage is confirmed from the experimental results. The heat capacity of mercury is measured in the range 230 K to 236 K within the accuracy of 0.2 % and the reproducibility of the melting curves is better than 0.1 mK.

H-2, 16:40 **Mercury Triple Point Cell 99,99% Pure**

S. G. Petkovic[1], J. F. N. Santiago[1], R. R. Filho[2], R. N. Teixeira[1] and P. R. F. Santos[1]
[1]*Inmetro, Duque de Caxias, Brazil*
[2]*Visomes, São Paulo, Brazil*

Fixed points cells are primary standards in ITS-90. They contain reference material with purity of 99,999% or more. The gallium melting point cell purity, for example, already reached a purity of 99,99999%. This level of purity is not easy to obtain. However, substances like water and mercury can be purified by means of distillation and chemical procedures. This paper presents the results of mercury triple point cells made in Brazil with a purity of 99,99% at least. It was directly compared to a mercury triple point cell 99,999% pure. This reference cell made by Isotech (England) was previously compared to cells from CENAM (Mexico) and NRC (Canada) and the maximum deviation found was approximately 0.4 mK. The temperature of the tested mercury triple point cell was few milikelvins different from the reference cell, considering results taken between the melting and freezing curves. The purification stage started with a sample of mercury 99.3% pure, and using repeatedly both mechanical and chemical processes, led to a purification grade of 99.99%, which was considered good enough for the calibration of standard platinum resistance thermometers. The purification procedures, the method of construction of the cell, the laboratory facilities, the comparison results and the budget of uncertainties are described in this paper.

15:00 Session H-3. Radiation Thermometry: Calibration Methods

H-3, 15:00 **To Substitute Tungsten Strip Lamps or Not?**

M.S.Matveyev, A.I.Pokhodoun and Yu.A.Sild
D. I. Mendeleyev Institute for Metrology, St. Petersburg, Russia

The tungsten strip lamps are most often used means in the temperature range higher 800 ºC for reproduction and precision transfer of a temperature scale by not contact methods. The lamps have a set of dignities. They have very high reproducibility, stability and durability; the lamp can be use tens years at careful fulfillment of the instructions; a relative simplicity of operation, storage and transportation. The unequivocal correlation of temperature and current through a strip allows to use advantages of electrical measurements. At the same time lamps have also set of negative parameters. The small deviations from fulfilment of procedural requests can reduce to unpredictable modifications of performance of a lamp and, even, to irreversible modifications of its parameters. The relevant figure of a transfer quality of the temperature scale is the proximity of transmitted temperature to thermodynamic. Only this factor guarantees an exactitude and unity of measurements of temperature by instruments of a miscellaneous principle of operation and constructions. But the lamps have no just this quality. Its main defect - selectivity of radiation stipulated by spectral dependence of emissivity. It urges to demand their mandatory replacement on blackbodies, which one allow completely use the foundation fixed in definition ITS-90. Some years back in our institute started researches on creation of special measuring instrument, for which one sensor was arranged around miniature model of a blackbody. The aperture it blackbody could be as the standard emitter, whose temperature was precisely determined by a resistance of the thermometer. Applying also standard pyrometer, we have updated reference function of platinum resistor in a range between fixed points of Ag and Cu. To expand temperature range up to 1450 ºC - 1500 ºC the instrument as a miniature model of a blackbody manufactured from Pd and connected with three platinum wires, forming Pt-Pd thermocouples was built. Then we have produced the similar device from Pt-Rh alloy. It gives possibility to reach the temperatures up to 1600 - 1700 ºC. Having maximal diameter 8 mm, about 35 mm length and a radiating aperture diameter 1,8 mm, the device has emissivity about 0.9994, it suitable to use for transfer of the temperature scale, without using conditional temperatures. Small dimensions allow applying it as well as a temperature measurements instrument with using the well known developed contact methods. In the report is discussed, whether such instrument equipped with the simple heater will compete to lamps.

H-3, 15:20 A Transfer Radiation Thermometer Covering The Temperature Range From -50 °C To 1000 °C

Ortwin Struß
HEITRONICS Infrarot Messtechnik GmbH, Wiesbaden, Germany

The EC-project TRIRAT (TRaceability in Infrared RAdiation Thermometry) was launched to improve the accuracy in infrared radiation thermometry, on an international basis, at industrial level, in the range from -50 °C to 800 °C. The temperature range has been divided in the LT-range from -50 °C to 300 °C and the MT-range from 150 °C to 800 °C. Within this project a Transfer Radiation Thermometer has been developed which covers both, the LT- and the MT-range from -50 °C to 800 °C. Within the project the MT-range has been extended from 300 °C to 980 °C to meet the silver point. It can be used for the transfer of radiation temperatures in scheme II. The Transfer Radiation Thermometer will be calibrated against fixed-point black body radiators and it is capable to transfer radiation temperatures between BBR's. The instrument has two built-in spectral bands, which are related to the temperature ranges. The construction of the thermometer and the tests characterizing performances are described. General specifications, spectral responses, temperature resolution, influence of ambient temperature and humidity as well as size of source effects are investigated and presented in this paper.

H-3, 15:40 Precision Photoelectric Pyrometer and Its Calibration

Yuan Zundong, Wang Tiejun, Duan Yuning, Wu Jiyu, Zhao Qi
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This paper presents the design and construction of a new type of precise photoelectric pyrometer, a transfer standard in the range of 800 °C to 3200 °C. The modified calibration methods have been applied at NIM to improve the dissemination of the ITS-90 with the new pyrometers. A resolution at copper point of approximate 1mK and an estimated standard uncertainty of 0.22°C ~0.8°C from 800°C ~2200°C were obtained. The comparison measurements performed between the pyrometers and the primary standard lamps from 800°C up to 1700°C shown the agreements within 0.3°C.

H-3, 16:00 A New Method for Calibrating Infrared Thermometers in Terms of True Target Temperature

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A new method for calibrating infrared thermometers is proposed in the paper. Using the method, we make a calibration of the thermometer directly against the target source instead of a blackbody. Moreover, it also avoids both the measurement of the spectral emissivity and the knowledge of the spectral responsivity of the thermometer.

H-3, 16:20 ILART; An Answer to On-Site Calibration of Radiation Thermometers in Industry

E.W.M van der Ham, R. Bosma and P.R. Dekker
NMi-Van Swinden Laboratorium B.V., Delft, The Netherlands

Coordinating the improvement of regional scale realization within Europe in the TRIRAT program, it was confirmed that blackbody radiator facilities for initial calibration of radiation thermometers, like the one at NMi-VSL, satisfies industrial needs. However when the calibrated instrument is used in practice, traceability of the temperature measurement is affected by application-related external factors. That is, the emissivity of the object under study influences the required accuracy negatively. It is this intrinsic problem to radiation thermometry that will be addressed in this paper. Laser absorption radiation thermometry (LART), first introduced by DeWitt and Kunz in 1971, is an answer to on-site calibration as this technique is independent of surface emissivity and discriminates against reflected radiation. The LART-technique involves active modulation of the surface temperature by modulating incident high-power laser beams. Consequently, the detected thermal radiation is modulated from which one can derive the emissivity and surface temperature independently. In a collaborative EC project (SMT4-CT95-2003) this technique was successfully demonstrated with an uncertainty smaller than 4°C in the laboratory within the temperature range from 750°C to 1050°C. On the basis of the obtained results and expertise NMi-VSL has recently started a project to realize a portable and robust instrument for on-site calibration of pyrometers in industrial environments based on this technique; the industrial laser absorption radiation thermometry (ILART) facility. In its on-site application the facility will provide a temperature reading as determined independent of the surface profile, surface emissivity, inline-of-sight absorbing gases and background radiation. The reading will be used to make the initial calibrated industrial radiation thermometer traceable in its application and improve the associated uncertainty. In this paper we report on the first phase in realizing the ILART-facility. The facility is designed to operate in the temperature range from 400°C to 1200°C employing two 1.5W fiber-coupled diode lasers operating at 990 nm and 1945 nm. Consisting of three modules, the laser-, the

detection- and the optical head-module, the ILART-facility will be described in terms of layout and individual characterization.

15:00 Session H-4. Instrumentation: Furnace & Comparator Design

H-4, 15:00 Thermal Characteristics of a Dodecane Heat-pipe over the Range from 190 °C to 260 °C and Related Impurity Effects

E. Renaot[1], J.O. Favreau[2], M. Elgourdou[1], G. Bonnier[1]
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[2]engineer student (scientific instrumentation)

To improve the calibration-comparison capability from 600 °C to 962 °C, BNM-INM is studying the possibility to connecting several heat-pipes filled with different working fluids to the same pressure control system, in order to set-up a “temperature divider». One of these heat-pipes is intended to receive the standard PRT; thus, it must have an operating temperature range which can ensure the SPRT stability. BNM-INM decided to test a heat-pipe filled with Dodecane. The impurity effect on the thermal characteristics of a Dodecane heat-pipe has been studied using two purity samples (99 % and 99, 8%). A significant improvement of these characteristics has been observed using the purest Dodecane. The curve of Dodecane vapour pressure has been determined between 190 °C and 260 °C with an expanded uncertainty of about 16 mK

H-4, 15:20 A Four-Zone Furnace For Realization Of Silver And Gold Freezing Points

D. C. Ripple, K. M. Garrity, and C. W. Meyer
National Institute of Standards and Technology, Gaithersburg, MD, USA

For the past eight years, the Thermocouple Calibration Laboratory at the National Institute of Standards and Technology has used sodium heat-pipe furnaces for the realization of ITS-90 freezing points of aluminum, silver, and gold. When using a fixed-point cell mounted in a long silica-glass tube that extends to ambient temperature at the top of the furnace, we have observed significant thermal gradients along the well of the fixed-point cell, with the top of the well up to 0.1 K colder than the bottom. The lifetime is limited when used at the gold point (1064.18 °C) for more than a few hundred hours. To address these problems, we have designed and built a four-zone furnace based on a temperature-controlled, graphite isothermal block, suspended inside a three-zone tube furnace. The three-zone furnace is of a commercial design. The graphite block is enclosed in an Inconel 600 can, allowing the graphite to be maintained in an argon atmosphere. The argon pressure is maintained at one atmosphere at all temperatures, thereby greatly reducing the stress on the Inconel can. Heaters in intimate contact with the can allow temperature control of the fourth inner zone to high accuracy. In this paper, the measured thermal stability and uniformity achieved with this furnace are described and compared with the predictions of design calculations. We also present the results of test freezes of a silver freezing point cell.

H-4, 15:40 High-Temperature Furnace Systems For Realizing Metal-Carbon Eutectic Fixed Points

Y. Yamada[1], N. Sasajima[1], H. Gomi[2], T. Sugai[2]
[1]National Metrology Institute of Japan (NMIJ), AIST, Tsukuba, Japan
[2]Nagano Ltd., Tokyo, Japan

Two high-temperature furnaces for realizing melting and freezing plateaus of Metal-Carbon eutectic fixed points are described. These are a three–zone furnace and a compact single-zone furnace, in which carbon-fiber-reinforced-carbon-composite heater elements are used. The furnaces have components all made of graphite, can operate without a window at the view port, and have maximum operating temperatures of 2500 °C and 2800 °C, respectively. These furnaces are expected to play a key role in the future investigation of high-temperature fixed points by enabling investigation of the fixed-point performance in optimum conditions, and in acting as transfer standards to compare the effect of different furnace conditions.

H-4, 16:00 Stem Conduction and Light Piping in ITS-90 Fixed Point Cell Assemblies at a UKAS Laboratory

J. P. Tavener & A. Blundell
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Standard Platinum Resistance Thermometers (SPRTs) with length-below-handle of only 480mm are regularly submitted for calibration at ITS-90 Fixed Points from –200°C to +660°C. The length of the thermometer limits the maximum size of fixed point cell that can be used to calibrate the thermometers. Stem conduction effects have been measured at Zinc and Aluminium

temperatures in Resealable Cells. These have been quantified and eliminated by adopting a cell design with a very small connection between cell and gas supply.

H-4, 16:20 A High Temperature Furnace Allowing Comparisons between a Radiation Thermometer and Contact Thermometers

M.J. de Groot, R. Bosma, J. Nielsen
NMi Van Swinden Laboratorium, Delft, the Netherlands

A high temperature furnace has been designed and built for high temperature comparison up to 1700 °C. A five-zone furnace is built around an alumina tube with gas-tight fittings at each end allowing the tube to be purged with non-reactive gas. The power supplies are DC low EMI to allow for comparison of a radiation thermometer with a noise thermometer. The alumina tube contains a graphite blackbody, which can fit four contact thermometers (resistance thermometers or thermocouples). The paper describes the furnace, the blackbody comparator and the evaluation measurements with the uncertainty budget.

H-4, 16:40 Pressure-Controlled Water Heat Pipe for Investigation of the Non-Uniqueness of the ITS-90 in the Range from 65 °C to 157 °C

Jun Tamba, Isao Kishimoto, Masaru Arai
National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology (NMIJ / AIST), Tsukuba, Ibaraki, Japan

A comparison measurement system based on a pressure-controlled water heat pipe was developed to investigate the non-uniqueness of the International Temperature Scale of 1990(ITS-90) in the range from 65°C to 157°C. Its characteristics, such as the temperature stability and temperature uniformity, were measured and the uncertainty of each source was estimated. The combined standard uncertainty on comparison measurements was determined within 0.052mK. Preliminary measurements of the non-uniqueness were performed using six standard platinum resistance thermometers which are the same model. The temperatures indicated by these thermometers showed scattering in the width of ±0.108mK. These results represent that the developed system has sufficient comparison resolution to investigate the non-uniqueness of the ITS-90.

15:00 Session H-5. Harsh Environments

H-5, 15:00 Verifying the Performance of RTDs in Nuclear Power Plants

H.M. Hashemian
Analysis and Measurement Services Corporation, Knoxville, TN 37923 USA

RTDs are used in many nuclear power plants for a number of critical temperature measurements. For example, in Pressurized Water Reactors (PWRs), the temperature of the reactor coolant is measured with a number of redundant RTDs that are installed in the inlet and outlet of the reactor. These RTDs must be both accurate and fast to ensure efficient and safe operation of the plant. Also, RTDs are used in the secondary systems of nuclear power plants in such critical applications as measurement of feedwater temperature. In this application, the RTD accuracy is crucial because it enters into the calculation of the reactor power. Any inaccuracy in RTD indication can result in loss of megawatt output of the plant which is an economical issue of great interest to utilities. On the other hand, any significant inaccuracy in measurement of feedwater temperature can result in plant operating at higher than expected power which could be a safety issue. This paper describes a number of techniques that have been developed for nuclear power plants to verify the steady state and transient performance of RTDs. This includes the Loop Current Step Response (LCSR) method for RTD response time measurements, cross calibration technique to verify the calibration of nuclear plant RTDs, and Time Domain Reflectometry (TDR) test that is used to determine the integrity of RTD cables. These techniques will be reviewed in this paper and test data from nuclear power plants including examples of response time measurements, cross calibration, and cable testing will be presented.

H-5, 15:20 Thermometry for the LHC Accelerator

C.Balle, J.Casas and N. Vauthier
CERN, Geneva, Switzerland

The Large Hadron Collider (LHC) is the next accelerator being built by CERN. The LHC total cold length exceeds 25 km and will use over 1500 long superconducting magnets immersed in pressurized liquid helium II at 1.8 K. The temperature of the superconducting coils and hydraulic pipes will be monitored by about 4500 sensors and its readout will be used in feedback closed control loops. The temperature measurement has very severe constraints imposed by (a) the maximum temperature at which the magnets can operate without losing the superconducting state, (b) by the cooling capacity of the cryogenic system and (c) by the accuracy of the instrumentation and in particular the long term stability of temperature sensors that will be exposed to the hostile environmental conditions present inside the LHC tunnel (nuclear radiation, electro-magnetic interference, etc.). Industry will be responsible for the supply and installation of the LHC machine parts, the "part" size is limited mainly by what a lorry can carry along European roads (e.g. about 15 meter). Technical staff on the industry floor are often unfamiliar with cryogenic techniques related with thermalization of electrical wires and sub-components. Therefore a set of very strict mounting instructions and quality assurance methodologies is required in order to achieve an uncertainty on the measurement of temperature of 0.01 K at 1.8 K. This paper presents the overall strategy for sensor selection, assembly techniques and series production.

H-5, 15:40 Experimental Study of ECDM Process Parameters

Anjali Kulkarni, R. Sharan, G.K. Lal
Indian Institute of Technology, Kanpur-208016, India

To gain insight into the Electrochemical discharge machining (ECDM) process, synchronized time varying current and temperature have been measured. Measurements of these parameters help us to reveal the basic mechanism of formation of discharge and material removal in the process.

H-5, 16:00 Problems of High-Temperature Measurements in Fuel Assemblies of Nuclear Rocket Engines

I.Fedik, V.Deniskin, V.Nalivaev, V.Konstantinov, N.Parshin
FSUE "NII NPO "LUCH", Podolsk, Russian Federation

The report deals with general approach to the problem of high-temperature measurements in fuel assemblies (FA) of nuclear rocket engines (NRE). The approach uses the results of calculation of three-dimensional temperature fields in FA, considers distortion of temperature fields due to installing the thermoelectric temperature transducers (TTT) into FA; calculational analysis of all components of TTT errors.

H-5, 16:20 New Technology to Verify the Attachment of Temperature Sensors and Strain Gauges to Solid Material

H.M. Hashemian
Analysis and Measurement Services Corporation, Knoxville, Tennessee 37923 USA

RTDs and thermocouples in some applications are attached to solid surfaces or imbedded in solid material for measurement of temperature of the solid material or the material within the solid boundary. For example, thermocouples are imbedded in the nozzle of Solid Rocket Motors (SRMs) to measure the temperature of the lining material of the nozzle. These thermocouples must remain intact during SRM firing tests to provide an accurate temperature profile especially under transient temperature conditions. This paper describes a method that was developed for this and a number of other applications. This method is based on heating the thermocouple with an electric current to characterize the heat transfer condition around the measuring tip of the thermocouple. The same principle can also be used to verify the attachment of RTDs and strain gauges to solid surfaces. This is important in such applications as fuel leak detection in space shuttle engines, measurement of fluid temperatures within pressure sensing lines in nuclear power plants, and diagnostics of problems in instrumentation which involve strain gauges.

Thursday, October 24, 2002

7:30 Speaker Breakfast – Location: N426c

8:00 Registration

8:30 – 10:10 Morning Sessions I-1 through I-4

10:10 – 10:30 Break

10:30 – 11:30 Mid-Day Sessions J-1 through J-4

11:30 – 11:45 Break

11:45 – 12:45 Closing Plenary Session

8:30 Session I-1. Thermodynamic Methods

I-1, 8:30 A Ratiometric Method for Johnson Noise Thermometry Using a Quantized Voltage Noise Source

S. W. Nam[1], S. P. Benz[1], J. M. Martinis[1], P. Dresselhaus[1], W. L. Tew[2], D. R. White[3]
[1]National Institute of Standards and Technology, Boulder, CO, USA, [2]National Institute of Standards and Technology, Gaithersburg, MD, USA, [3]Measurement Standards Laboratory, Lower Hutt, New Zealand

Johnson Noise Thermometry (JNT) involves the measurement of the statistical variance of a fluctuating voltage across a resistor in thermal equilibrium. Modern digital techniques make it now possible to perform many functions required for JNT in highly efficient and predictable ways. We describe the operational characteristics of a prototype JNT system which uses digital signal processing for filtering, real-time spectral cross-correlation for noise power measurement, and a digitally synthesized Quantized Voltage Noise Source (QVNS) as an AC voltage reference. The QVNS emulates noise with a constant spectral density that is stable, programmable, and calculable in terms of known parameters using digital synthesis techniques. Changes in analog gain are accounted for by alternating the inputs between the Johnson noise sensor and the QVNS. The Johnson noise power at a known temperature is first balanced with a synthesized noise power from the QVNS. The process is then repeated by balancing the noise power from the same resistor at an unknown temperature. When the two noise power ratios are combined, a thermodynamic temperature is derived using the ratio of the two QVNS spectral densities. We present preliminary results where the ratio between the gallium triple point and the water triple point is used to demonstrate the accuracy of the measurement system with a standard uncertainty of 0.04 %.

I-1, 8:50 Kinetic Temperature and Thermodynamic Temperature

Ingo Müller[1] and Peter Strehlow[2]
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The kinetic theory of rarefied gases is used to show that there is a difference between the kinetic temperature and the thermodynamic one. The former represents the mean kinetic energy of the molecules while the latter is the one measured by a contact thermometer. The argument is based upon a recent paper [1] by Müller and Ruggeri.

I-1, 9:10 A Quantitative Model for the Thermocouple Effect Using Statistical and Quantum Mechanics

Paul Bramley and Stewart Clark
Automatic Systems Laboratories Ltd., 40 Tanners Drive, Blakelands, Milton Keynes, MK14 5BN, UK
Department of Physics, University of Durham, Science Labs., South Road, Durham, DH1 4LE, UK

This paper employs statistical and quantum mechanics to develop a model for the mechanism underlying the Seebeck effect. The conventional view of the equilibrium criterion for valence electrons in a material is that the Fermi Energy should be constant throughout the system. However, this criterion is an approximation and it is shown to be inadequate for thermocouple

systems. An improved equilibrium criterion is developed by applying statistical and quantum mechanics to determine the total flow of electrons across an arbitrary boundary within a system. Dynamic equilibrium is then considered to be the situation where the Fermi Energy either side of the boundary is such that the flow of electrons in each direction is the same. This equilibrium criterion is then applied to the conditions along the thermocouple wires and at the junctions in order to generate a model for the Seebeck effect. The equations involved for calculating the electronic structure of a material cannot be solved analytically, so a solution is achieved using numeric models employing CASTEP code running on a Sun Beowulf cluster and iterative algorithms written in the Excel™ VBA language on a PC. The model is used to calculate the EMF versus temperature function for the gold versus platinum thermocouple, which is then compared with established experimental data.

I-1, 9:30 The Quality Of The Curie Law In Platinum-NMR

D. Hechtfischer and G. Schuster
Physikalisch-Technische Bundesanstalt, Abbestraße 2-12, 10587 Berlin, Germany

The construction of the temperature scale PTB-96 below 15 mK relies on platinum NMR thermometry. The quality of the Curie law for the pure platinum metal and the limitations set by magnetic impurities are discussed. The solution found to overcome the resulting difficulties is described, and an uncertainty budget is drawn up. Measurements with different instrumentation supporting the NMR temperature scale are also presented.

8:30 Session I-2. Contact Thermometry: Calibration Methods & Uncertainties

I-2, 8:30 A Simplified Method for Calibration of PRTs Used in Heat Meters

N.P. Moiseeva[1], D.V. Petrov[2], A.V. Karzhavin[2]
[1]D.I. Mendeleyev Research Institute of Metrology, St. Petersburg, Russia, [2]Industrial company "TESEY", Obninsk, Russia

Many thousands of industrial platinum resistance thermometers are used in heat meters that are devices for measurement of the heat being spent in heat-exchange water systems. That is why it is important to develop an inexpensive, quick and simple method for calibration of the IPRTs. There are standard documents on verification of the heat meters, such as EN 1434 and OIML R75, adopted in several countries. It seems that the method of calibration of the temperature sensors, suggested in these documents is not the optimum one. When developing the method of calibration of the IPRTs, several important characteristics should be considered, such as IPRT's instability, hysteresis, and the small temperature range (0 to 170 °C), in which the IPRTs work. A method for calibration of the IPRTs was suggested, that made it possible to use only two calibration points: 0 °C and 100 °C. The technique was applied to more than a hundred of IPRTs of different designs, which were developed, manufactured and calibrated at Industrial Company "TESEY" (Russia). The main advantages of the two-point calibration of the IPRTs for heat meters over the method of the EN and OIML standards are its simplicity, quickness and a lower cost, as well as a satisfactory accuracy.

I-2, 8:50 NIST Calibration Uncertainties of Liquid-in-Glass Thermometers over the Range from -196 °C to 400 °C

C. D. Vaughn and G. F. Strouse
National Institute of Standards and Technology, Gaithersburg, MD 20899 USA

The NIST Industrial Thermometer Calibration Laboratory (ITCL) is responsible for calibrating several different types of industrial thermometers. One of those types is a liquid-in-glass (LiG) thermometer, which includes both mercury (partial and total immersion) and organic (total immersion) filled models. Over the past two years, improvements in both calibration equipment and software used in the ITCL has led to a new assessment of the uncertainties assigned to the calibration of LiG thermometers covering the temperature range from –196 °C to 400 °C. In total, twenty thermometers from three different manufacturers, six of which are mercury-filled partial immersion, twelve of which are mercury-filled total immersion, and two of which are organic-filled total immersion models were used for the determination of the NIST ITCL LiG thermometer calibration uncertainties over the range from –196 °C to 400 °C.

I-2, 9:10 The "Temperature Divider": an Innovative Application of Pressure-Controlled Heat-Pipes for Calibration by Comparison of PRTs and Thermocouples

E. Renaot, M. Elgourdou, G. Bonnier
BNM-INM/CNAM, 292 rue Saint-Martin, 75141 Paris CEDEX 03, France

At high temperature (from 600 °C to 962 °C) calibration by comparison of PRTs is limited by the instability and the reliability of the standard HTPRT and by uniformity of the temperature in the working volume of furnaces equipped with comparison blocks. To improve the calibration-comparison capability, BNM-INM is studying the possibility to connect several pressure-controlled heat-pipes, filled with different working fluids, simultaneously to the same pressure control system. The experimental apparatus, called "temperature divider", is composed of 3 heat-pipes filled with Sodium (Na), Potassium (K), and Dodecane (Do).

I-2, 9:30 Liquid-In-Glass Thermometers Using Low Hazard Precision Liquids

Charles J. Miller and Deanne Miller Emory
Miller & Weber, Inc., Ridgewood, NY 11385, USA

PerformaTherm® liquid-in-glass thermometers are non-hazardous precision thermometers developed and manufactured by Miller & Weber, Inc. in Ridgewood, NY. PerformaTherm® thermometers give the high precision performance of mercury without the hazards. Unlike any liquid-in-glass thermometer currently available, PerformaTherm® thermometers have the precise tolerances, repeatability, reproducibility and quick response time of mercury instruments. Miller & Weber's PFTB series of blue dyed liquids are safer than both mercury and most traditional spirit thermometer liquids. The proprietary formula is biodegradable, non-caustic, non-hazardous, and considered nontoxic in thermometer quantities. Unlike traditional spirit filled or "environmentally safe" green or blue dyed liquid filled thermometers, there is no negative meniscus or increased lag time in using PerformaTherm® thermometers. Miller & Weber, Inc., always environmentally conscious and on the forefront of innovative manufacturing, developed PerformaTherm® to be able to substitute for mercury instruments in all industries. Our research and development results show that PerformaTherm® thermometers made to ASTM specifications, meet ASTM standards for accuracy and precision and can substitute for mercury thermometers in many ASTM applications previously requiring a mercury thermometer. Many industrial users previously requiring high quality, NIST traceable, mercury-in-glass thermometers, including petroleum and pharmaceutical companies, have begun using our PerformaTherm® thermometers with results similar to those predicted by our research.

I-2, 9:50 An Apparatus for Thermometer Calibration by Comparison at Low Temperatures

Valencia-Rodriguez[1], J. M. Figueroa[1], J. A. Avalos[2]
[1]Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada-IPN, Av. Legaria 794, Col. Irrigación, CP 11500, México, D.F., México., [2]Escuela Superior de Ingeniería Mecánica-IPN
AV. IPN s/n U.P. ""ALM"", Edificio 5, Col. Zacatenco, México, D.F., México

In order to provide calibration laboratories with reliable, low cost, low-temperature calibrations by comparison, we developed at CICATA an apparatus that will accommodate up to four sensors plus the standard thermometer. The apparatus, which is filled with liquid gas, relies in a dead weight system to control its temperature. The amount of gas used ensures the stability of temperature for several hours, so that there is plenty of time for the calibration of a number of sensors. Using different gases it is possible to cover a wide range of temperatures. In this work we reported the calibration results in various temperature ranges, obtained for a series of thermocouples and industrial SPRT's. Such results are compared against these obtained for traditional methods.

8:30 Session I-3. Spectroscopic Techniques

I-3, 8:30 A Fourier-Transform Spectrometer for Accurate Thermometric Applications at Low Temperatures

Juntaro Ishii, and Akira Ono
National Metrology Institute of Japan, AIST, Tsukuba, Ibaraki, Japan

A Fourier-transform infrared spectrometer (FTS) system for accurate measurement of thermal emission at low temperatures has been constructed. The FTS using a Michelson interferometer operated in vacuum covers the wavelength range between 5 μm and 12 μm with a mercury cadmium telluride detector. The FTS has been calibrated against a liquid nitrogen cooled cavity and a variable temperature cavity kept at 100 °C. Calibration formula using the advanced phase correction technique has been

applied successfully. The calibrated spectra of the blackbody radiator in the temperature from -20 °C to 100 °C agree with the theoretical Planckian spectra within relative error of 0.6 %. Additionally spectral-emissivity measurements of metals with coated surfaces, glassy-carbon, and silicon nitride ceramics have been performed as an application of the FTS in thermal measurements.

I-3, 8:50 VNIIOFI Spectroradiometer Based on Circular Variable Filter for the Spectral Range from 2.5 µm up to 14 µm

Morozova S.P., Morozov P.A., Sapritsky V.I., Lisiansky B.E. and Dovgilov N.L.
All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI), Moscow, Russia

VNIIOFI Spectroradiometer (VSR) has been developed for the Medium Background Facility which is intended for the low-temperature sources comparisons and calibration in the temperature range from -60 °C up to +80 °C. The VSR is designed to measure the radiance temperature of the blackbodies sources in the spectral range from 2.5 µm up to 14 µm in cryogenic vacuum environments (liquid nitrogen cooled shroud). The VSR is based on the Circular Variable Filter (CVF) assembly with a slit aperture and InSb-CdHgTe Two Color sandwich detector with integral Sterling Cooler. Circular Variable Filter covers the 2.5 µm to 14.1 µm region in 3 segments. Width of the slit equal to 1.2 mm provides the spectral resolution from 80 nm to 360 nm for the spectral range from 2.5 µm to 14.1 µm accordingly. The Circular Variable Filter assembly is rotated by stepper motor. The Cassegrain Telescope is used as a foreoptic unit. Radiation is going through CVF and focused on the Detector with help of the ellipsoidal mirror. Radiation from Low-Temperature (77 K) Blackbody is used as a reference level of radiation. The instrument has a fixed 8.9 mR field of view with a focal distance 2250 mm. The spectral and temporal characterization of the spectroradiometer are reported. Facility for CVF calibration is described. Temperature resolutions for the calibrated sources with different temperature for different wavelength are given. Brief description of the design, operation principles and specifications of the main parts of the spectroradiometer such as Cassegrain Telescope, CVF and detector assembly are presented. The results of a comparison of the Variable Temperature Blackbody and Ga Fixed Point Blackbody and In Fixed Point Blackbody in the Medium Background Facility with the VSR are also given. The measurement uncertainties radiance temperature associated with spectral bandwidth are discussed.

I-3, 9:10 The Spectropyrometer – a Practical Multi-wavelength Pyrometer

Ralph A. Felice
FAR Associates, 1532 Newport Drive, Macedonia, OH 44056, USA

An expert-system multi-wavelength pyrometer, commercially available since 1997 and using a spectrophotometer as its detector, has been able to overcome many well-known difficulties of pyrometry, including unknown, changing, and/or spectral dependence of emissivity as well as environmental absorption of radiation. In addition to a spectrophotometer and the usual optics, the instrument includes a computer which analyzes each measurement and then returns the temperature, the tolerance (a real-time measure of accuracy), and the signal strength (a quantity linearly related to the emissivity at a chosen wavelength). The computer allows the input data, namely the thermal spectrum for each temperature measurement, to be saved.

I-3, 9:30 Measuring Rocket Engine Temperatures with Hydrogen Raman Spectroscopy

Joseph A. Wehrmeyer[1], Robin Osborne[2], Huu P. Trinh[3]
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Optically accessible, high pressure, hot fire test articles are available at NASA Marshall for use in development of advanced rocket engine propellant injectors. Single laser-pulse UV Raman spectroscopy has been used, in the past, in these devices for analysis of high pressure H2- and CH4-fueled combustion, but relies on an independent pressure measurement in order to provide temperature information. A variation of UV Raman (High Resolution Hydrogen Raman Spectroscopy) is under development and will allow temperature measurement without the need for an independent pressure measurement, useful for flows where local pressure may not be accurately known. The technique involves the use of a spectrometer with good spectral resolution, requiring a small entrance slit for the spectrometer. The H2 Raman spectrum, when created by a narrow linewidth laser source and obtained from a good spectral resolution spectrograph, has a spectral shape related to temperature. By best-fit matching an experimental spectrum to theoretical spectra at various temperatures, a temperature measurement is obtained. The spectral model accounts for collisional narrowing, collisional broadening, Doppler broadening, and collisional line shifting of each Raman line making up the H2 Stokes vibrational Q-branch spectrum. At pressures from atmospheric up to those associated with advanced preburner components (5500 psia), collisional broadening, though present, does not cause significant overlap of the Raman lines, allowing high resolution H2 Raman to be used for temperature measurements in plumes and in high pressure test articles. Experimental demonstrations of the technique are performed for rich H2-air flames at atmospheric pressure and for high pressure, 300 K H2-He mixtures. Spectrometer imaging quality is identified as being critical for successful implementation of the technique.

8:30 Session I-4. Industrial Needs Forum

I-4, 8:30 International Guideline to Specify Radiation Thermometers

Guenther Neuer[1], Ortwin Struss[2]

[1]Institute for Nuclear Engineering and Energy Systems (IKE), University Stuttgart, Germany, [2]HEITRONICS Infrarot Messtechnik GmbH, D- 6520 Wiesbaden, Germany

Both the definition and the determination of specifications of radiation thermometers is an important task which should be harmonised world wide as far as possible. As a first step the specialist committee of the German VDI/VDE-Society for Metrology and Automation Technology (GMA) established the guidelines: "Specification of radiation thermometers". Definitions and examples how to present the data are given for the most important metrological data like measurement uncertainty, stability, repeatability, noise equivalent temperature difference, spectral range, target size, response time, and exposure time. The purpose of the guideline is to improve comparability and testability of radiation thermometers and to help the potential user to define his needs and to select the instrument optimum covering his requirements. Definitions and examples how to present the data are given for the most important metrological data of a radiation thermometer.

I-4, 8:50 Comparison of RTDs and Thermocouples for Industrial Temperature Measurements

H.M. Hashemian

Analysis and Measurement Services Corporation, Knoxville, TN 37923 USA

RTDs and thermocouples have their own distinct place in industrial temperature measurements. For example, air or gas temperature measurements shall almost always be made with thermocouples. This is because of the self-heating error that is inherent in temperature measurement with RTDs. In applications where high accuracy is of main concern, RTDs are almost always a better choice than thermocouples if temperature is in the range of the RTD operation. RTDs can be calibrated to yield accuracies of as good as a few tenths of a degree while thermocouples cannot be trusted to produce accuracies of better than a degree, especially at high temperatures. There are other reasons which make it easy to distinguish the application of an RTD from a thermocouple. These are described in this paper.

I-4, 9:10 Radiation Thermometers in Steel & Metals Processing

G. Raymond Peacock

Temperatures.com, Inc., Southampton, PA 18966-3836

Product processes in steel and other important metals manufacturing depends critically upon accurate and reliable temperature measurement to achieve both product properties and manufacturing efficiencies, e.g. throughput and yield. Radiation thermometry is the only practical temperature measurement techniques for the majority of uses except in well-modeled furnace operations like batch annealing where thermocouples are satisfactory. Most of the process measurement problems that could involve radiation thermometry appear solved. The major sensor problems facing industry appears to be standards development to rationalize the inadequate specifications and varying technologies used by manufacturers for actual devices and to support user needs in education about device selection, testing, commissioning and calibration verification practices. The latter needs have been driven by stringent measurement device control systems now demanded by most customers. Development of appropriate terminology and test practice standards for radiation thermometers used in the steel & metals manufacturing industries will benefit both users and manufacturers by providing a common vocabulary for device specifications, performance and testing criteria. Indeed a case could easily be made to include all radiation thermometric devices used in thermally sensitive manufacturing industries such as glass, ceramics, minerals-processing, cement, petrochemical and so on.

I-4, 9:30 In-Situ Optical Wafer Temperature Measurement

Bruce Adams,[(a)] Chuck Schietinger[(b)], and Patrick Sprinkle[(c)]
(a)Applied Materials, Santa Clara, CA, USA
(b)Toyo Tanso, Troutdale, OR, USA
(c)*Engelhard Corp., Portland, OR, USA*

The dimensions of features within integrated circuits (IC) continue to shrink to the nanometer scale and the number of thermal processing steps is also increasing. The smaller device features including thinner films and shallower junctions is driving the need for increasingly tighter IC process temperature control. Wafer temperature is perhaps the most universally critical process variable in front-end IC manufacturing. The use of pyrometry and optical lightpipes continues to gain widespread acceptance as the standard temperature control method in many processes. Lightpipes are used for controlling temperature in chemical vapor deposition (CVD), rapid thermal processing (RTP), epitaxial film growth (EPI) and physical vapor deposition (PVD). Optical thermometry offers numerous advantages over other forms of wafer temperature measurement. This paper presents the strengths and limitations of optical lightpipes for wafer temperature measurement. As IC junctions become shallower, thermal budget concerns drive process temperatures down. Processing time and ramp rates continue to shorten in particular for implant anneals. Increasingly, process control requires complete thermal histories of wafers throughout IC manufacturing. These factors and new materials (copper and low-κ dielectrics) push tool manufactures and pyrometer vendors toward lower temperatures while still requiring high sensitivity, and accuracy. The accuracy of most in-situ optical temperature measurement continues to be dominated by uncertainty in wafer emissivity. Factors that limit accuracy, e.g., from wafer to wafer and from tool to tool, and advances in the technology are discussed including the issues of stray light.

I-4, 9:50 Industrial Measurements With Very Short Immersion

J. P. Tavener, D. J. Ayres & N. Davies
Managing Director, Deputy Head of Laboratories, Deputy Head of Secondary Laboratory.
Isothermal Technology Limited., Pine Grove, Southport, Merseyside, PR9 9AG, England.

Industrial needs in thermometry measurement or control. One major problem that keeps recurring is the request to calibrate or in some other way to evaluate industrial temperature sensor assemblies which are very short, and hence the sensor does not attain the temperature of its surroundings. Two distinct methods are possible, in method one the assembly is immersed in a comparison bath sufficiently to eliminate the stem conduction effect, even if this method creates a different result than achieved in-situ. Method two attempts to simulate the application in practice and provide a similar stem conduction error as the assembly sees in practice. The two methods are described in some detail and reactions sought from the audience at the end of the presentation.

10:30 Session J-1. The Water Triple Point

J-1, 10:30 Effects of Heavy Hydrogen and Oxygen on the Triple-Point Temperature of Water

D R White[1], T D Dransfield[1], G F Strouse[2], W L Tew[2], R L Rusby[3], J Gray[3]
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The temperature of the triple point of water is dependent on the isotopic composition of the water. The depletion of heavy isotopes arising from the use of fresh water rather than seawater, and distillation and degassing of the water during manufacture of the cells, leads to cells realizing temperatures up to 80 μK lower than the definition. Five cells of varying isotopic composition were compared to evaluate the practicality of applying corrections for isotopic composition. It was found that the correction constants for deuterium and ^{18}O measured previously by Kiyosawa were consistent with the measurements of the cells. Both of the correction constants are larger than predicted by interpolation between the triple-point temperatures of the pure isotopomers. Application of the corrections for isotopic composition eliminates a significant bias in the triple-point temperature and reduces the uncertainty in the triple-point temperature due to isotopic composition from ±40 μK to better than ±10 μK.

J-1, 10:50 Studies on the Behavior of Water Triple-Point Cells

Shu-Fei Tsai
Center for Measurement Standards, Industrial Technology Research Institute, Hsinchu, Taiwan

Several triple point of water (TPW) cells from four different manufacturers were investigated in the same TPW maintenance bath by three standard platinum resistance thermometers. Temperature difference at water triple point among cells was analyzed first and found to be within 0.36 mK and reproducible to 0.09 mK over three to four months' measurements. The variation of temperature with height in different sources of cells were compared each other and also with the expected value of 7.3×10^{-4} $K\cdot m^{-1}$. The effect of environment condition, especially focusing on water levels in the thermometer well together with that of TPW bath, on the water triple-point are studied and discussed here.

J-1, 11:10 Do Different Types of Water Triple Point Cells Have the Same Temperature?

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The temperatures in three different types of water triple points cells have been studied. Some of the cells remained stable for several years, while other cells seem to change as a function of time.

10:30 Session J-2. Pt/Pd Thermocouples

J-2, 10:30 Research on Platinum versus Palladium Thermocouples in the Range 419.527 °C to 1084.62 °C

Zheng Wei, Cheng Weixin
National Institute of Metrology (NIM), China

This paper is about performance of Pd/Pt thermocouple in range of 419.527 °C to 1084.62 °C, 7 pieces of Pd/Pt thermocouples, the purity of Pt elements is issued 99.995% and purity of Pd wires is over 99.99% from two manufactories , are selected to processed . The realization on Zn, Al, Ag and Cu freezing point is test in difference annealing time.

J-2, 10:50 Uncertainty Caused by Inhomogeneity of the Pt/Pd Thermocouple at the Cu Freezing Point

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National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology (NMIJ / AIST), Tsukuba, Ibaraki, Japan

The drift in emf of Pt/Pd thermocouples during successive calibrations at the Cu freezing point was measured. Twelve thermocouples were constructed using the wires from the same manufacturing lot, and different heat treatment was performed to each thermocouple before the calibration. The purity of the wires used were 99.999% Pt and 99.99% Pd, respectively. The magnitude of the drift and the inhomogeneity of the thermocouples depended on the heat treatment. The heat treatment at 850°C or 1030°C for 100 hours resulted in reduction of the drift and inhomogeneity.

J-2, 11:10 Bilateral Comparison of Type S and Pt/Pd Thermocouples between KRISS and NRC

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KRISS and NRC have conducted a comparison to examine the equivalence of thermocouple calibrations carried out in their respective facilities. Type S and Pt/Pd thermocouples having a common welded junction were calibrated at the metal fixed-points of Sn, Zn, Al, Ag through five cycles at each NMI. The immersion properties in the fixed-point cells were also investigated. For the type S thermocouple, the differences were less than the equivalent of 0.15 °C at all fixed points. The equivalent temperature differences for the Pt/Pd thermocouple were within 0.04 °C from the Sn point to the Al point, but a difference of 0.32 °C was obtained at the Ag point. This difference may be attributed to the 12 μV value for the thermoelectric inhomogeneity of the Pt/Pd thermocouple as revealed by the immersion profiles. The comparison confirmed that the fixed-point thermocouple calibrations carried out by the two NMIs are in good agreement, though the results appear limited by the less-than-ideal thermoelectric inhomogeneity of the thermocouples employed.

10:30 Session J-3. Radiation Temperature Comparisons

J-3, 10:30 The European Project TRIRAT. Part II: Results of the Comparison of Local Temperature Scales with Transfer Infrared Thermometers Between 150 °C and 962 °C

Mauro Battuello[1], Ferruccio Girard[1], Teresio Ricolfi[1], Mohamed Sadli[2], Pascal Ridoux[3], Olivier Enouf[3], Jorge Pérez[4], Vicente Chimenti[4], Thua Wekström[5], Ortwin Struss[6], Eduarda Filipe[7], Nuno Machado[7], Eric van der Ham[8], Graham Machin[9], Helen Mc Evoy[9], Berndt Gutschwager[10], Joachim Fischer[10], Volker Schmidt[11], Sonnik Clausen[12], Jan Ivarsson13, Sevilay Ugur14, Ahmet Diril14
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In the course of the EC-funded project TRIRAT ("Traceability in Infrared Radiation Thermometry") an international comparison of local radiation temperature scales took place among fourteen laboratories in the temperature range from 150 °C to 800 °C. Two infrared transfer standard thermometers and a Zn-point blackbody furnace to be used for checking their signal stability were circulated among the participating laboratories which were asked to calibrate the two thermometers according to their local temperature scale from 150 °C to 800 °C and optionally up to 962 °C. In practice, most laboratories performed the calibration in the extended range from 150 °C to 962 °C. The equipment and the procedures adopted by the various laboratories are described in part 1 of this paper, here results of the comparison are presented and discussed. The behaviour of the two transfer thermometers in terms of stability is analysed. The procedures adopted for deriving a "comparison reference value" (CRV), the differences with respect to this CRV and the degree of equivalence of each laboratory with respect to the CRV are then discussed. Additional statistical elaboration of the results, i.e., in terms of QDE, is also presented. The different arrangements adopted for the calibration of the thermometers, i.e., blackbody cavities of different type and design, and additional experimental investigations allowed an analysis on the effect of some influencing parameters, e.g., the SSE, to be performed. From these an indication on the optimal experimental arrangements for minimising calibration uncertainties was obtained.

J-3, 10:50 A Comparison of Size of Source Effect Measurements of Radiation Thermometers Between IMGC and NPL

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The calibration of radiation thermometers requires knowledge of the effect of target size on the thermometer output, namely the size of source effect. Measurement of an instruments size of source effect allows a correction to be applied, or an allowance to be made in the calibration uncertainty. At present no standard exists between National Metrology Institutes for how an instruments response to target size should be defined or measured. To determine the degree of equivalence between measurements made at different institutes transfer standard instruments were exchanged between IMGC and NPL, and their size of source effect measured. Measurements were made by the indirect method at IMGC, and by indirect and direct methods at NPL. Excellent agreement was found between measurements made using the indirect method at the two institutes.

J-3, 11:10 Comparison of the New NPL Primary Standard Ag Fixed-Point Blackbody Source with the Primary Standard Fixed-Point of PTB

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Above the freezing point of silver (961.78 °C), the International Temperature Scale of 1990 is defined in terms of Planck's radiation law. The scale is maintained and disseminated using a validated and linear pyrometer in conjunction with a blackbody reference source at either the Ag, Au (1064.18 °C) or Cu (1084.62 °C) freezing point. In order to realize the scale with the highest precision high quality, well-characterised, reproducible fixed-point blackbody sources are required. Such sources have been maintained at NPL for a number of years, but it was felt that improvements to the design would be beneficial. A new Ag point blackbody source has therefore been constructed. The new design will improve the quality and reproducibility of the melting and freezing plateaux and reduce errors due to the 'out-of-focus' size-of-source effect which is difficult to measure and to eliminate. Full details of the design of the new source, including results of the assessment of its

performance, are described. Critical for the application of fixed-point blackbodies as primary temperature standards is the precise knowledge of the emissivity of the cavity, which causes a correction to the melting and freezing temperature of the ingot. As blackbody emissivities are difficult to access experimentally, two different numerical approaches, one developed at NPL and the other developed at PTB, are used to calculate the blackbody emissivity. In order to further validate the performance of the new Ag fixed-point blackbody it has been compared with the Au primary fixed-point blackbody of PTB. For the comparison the ratios of the spectral radiances of the fixed-point blackbodies were measured at 650 nm and 950 nm using the PTB monochromator-based spectral radiance calibration facility, and at 654 nm and 953 nm using the PTB interference filter-based primary photoelectric pyrometer.

10:30 Session J-4. Contact Thermometers: Stability and Performance Testing

J-4, 10:30 Calibration Monitoring and Residual Life Estimation of Resistance Temperature Detectors

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The results of accelerated thermal aging of resistance temperature detectors (RTDs), and the characterization of the effects of aging on changes in the calibration parameters and other RTD performance parameters, are presented in this paper. Both thin-film and wire-wound RTDs were used, with the furnace temperatures ranging from 500 °C to 900 °C. Strong correlations were observed between the calibration parameters (*Callendar-Van Dusen* equation) and other parameters such as the *self-heating index* and the *resistance drift rate*.

J-4, 10:50 Stable Space-Based Encapsulated Platinum Resistance Thermometry Over The Range –9 °C to 50 °C

Daniel Peters, Bob Watkins
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The High Resolution Dynamic Limb sounder (HIRDLS), is a space-based filter radiometer for atmospheric monitoring between the upper troposphere and the mesosphere. Retrievals of trace chemicals, temperature and geopotential height gradients will be obtained on a global scale. This radiometer uses the two point calibration algorithm in which the radiometer views a cold 'zero radiance' space view, and a high emissivity warm blackbody target, of known temperature. To achieve a high radiometric performance, an accurate thermometry system is used to measure cavity temperature over the range –9 °C to +50 °C allowing the instrument's gain to be measured as required (nominally every 66 seconds). The thermometry error budget for the cavity allows a temperature sensor stability of 25 mK over the mission lifetime of five years in-flight and two years before instrument launch. This high thermometry performance is achieved using two redundant sets of three platinum resistance thermometers (PRTs) to sense the cavity temperature. Due to launch vibration of the spacecraft, high stability PRTs with a loosely wound platinum element's are not suitable and we are forced to use a sensor with a more constrained element with a lower stability. Specifications for the chosen sensor would imply a thermometry drift of <30 mK, necessitating a detailed study of the sensors drift and measures to reduce it. The chosen approach and calibration (traceable to ITS-90) are described and the experimental stability results obtained over a six-month time scale. The sensors were subject to accelerated aging via thermal cycling, and a mounting technique was used to reduce strain-induced drift from differential thermal expansion of the substrate and sensor. Performance after environmental tests (vibration and thermal cycling over the space craft survival temperature range of –40 °C to 60 °C) are also presented.

J-4, 11:10 Temperature Sensors for Extreme Electronics

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We present a new type of diode temperature sensors (DTSs) developed on the base of heavily doped n^+-p and p^{++}-n^+ silicon structures for use in extreme environments. These DTSs are advanced devices with minimized influence of the self-heating and noise to the temperature measurement, enhanced sensitivity in the range of low temperatures, accuracy, reproducibility, radiation resistance, and easily adaptive with electronic equipment when operating in long circuits. The developed DTSs have provided most reliable and accurate temperature measurement for the mode fueling of the rocket Zenit-3SL (within the framework of the International Project "Sea Launch") and temperature monitoring of the object "Shelter" (Chernobyl Nuclear Power Plant) in automatic multichannel systems.

11:30 Break

11:45 Closing Plenary Session

11:45 Remarks
Dean Ripple, Program Chair
NIST, Gaithersburg, Maryland, USA

12:00 ***Life Before, During and After Key Comparisons***
Dr. Terry Quinn, Director
BIPM, Sevres, France

12:45 Adjourn

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