Vacuum Technology
Room: 202 C - Session VT-MoM

Vacuum Measurement and Metrology
Moderator: R. Versluis, TNO Technical Sciences, Netherlands

8:20am **VT-MoM1 The Important Role of Vacuum Technology in the Redefinition of the Kilogram, *P.J. Abbott*, NIST** **INVITED**

The kilogram is the sole remaining unit in the International System of Units (SI) that is still defined by a physical artifact, namely, the International Prototype Kilogram (IPK). There are two motivations for redefinition: To comply with a "New SI" that realizes units from invariant natural constants, and to address the discovery of a divergence in the mass values between the IPK and its official copies that was discovered during the third periodic verification of national prototypes of the kilogram (1988-1992). Because mass is such an important area of metrology for commerce, any redefinition of the kilogram must not hinder the metrological community in terms of unacceptably large uncertainties compared to what is currently available through traceability to the IPK. After careful consideration, in October of 2011 the General Conference on Weights and Measures (CGPM) adopted a resolution to redefine the kilogram in terms of the Planck constant, *h*. The Consultative Committee for Mass and Related Quantities (CCM) has recommended that the Planck constant be known to within a standard relative uncertainty of 2 parts in 10^8 before redefinition occurs in order to address the metrological concerns mentioned above. World-wide, several efforts that measure the Planck constant are in progress, and more are expected to begin in the next few years. The two major apparatus used to measure the Planck constant are the Watt balance and the X-ray crystal diffraction (XRCD) experiments. Though these methods use very different physical principals, they have in common the necessity to operate in medium to high vacuum conditions in order to mitigate contamination and reduce uncertainties. Therefore, the new kilogram will be realized in a vacuum environment, which obviates the need for transferring this realization to air where it can easily be disseminated via conventional mass metrology. This transference from vacuum to air requires precision mass metrology under vacuum, an understanding of adsorption and desorption phenomena related to mass artifacts, transportation of mass artifacts under vacuum between experiments for inter-comparisons, and an understanding of the effects of long-term storage of mass artifacts in air, inert gases, and under vacuum. In short, application of many of the fundamentals of vacuum technology is absolutely essential in the realization and dissemination of a kilogram that is defined in terms of the Planck constant. This talk will provide details of the many experiments that are underway to address the vacuum technology challenges presented in the redefinition of the kilogram.

9:00am **VT-MoM3 Reinventing Pressure and Vacuum Metrology: Development of an Optical Pressure Standard, *J.H. Hendricks*,** *J.A. Stone, G.F. Strouse, D.A. Olson, J.E. Ricker, P. Egan, G. Scace,* NIST, *D. Gerty*, Sandia National Laboratories

We have now concluded the first year of a five year program that aims to fundamentally change the method for realizing and disseminating the SI unit for pressure. The innovative technique represents a paradigm shift in the way the unit for pressure and vacuum is realized, creates new measurement infrastructure for NIST, and has the potential to create exciting spin-off technology that will have large impacts for US manufacturing and world metrology. We will move from primary standards based on artifacts for pressure and temperature and move to standards based on quantum-chemistry calculations of helium's refractive index. The underlying metrology behind this advance is the ultra-accurate determination of the refractive index of gases by picometer optical interferometry. The optical-based primary pressure standard will improve accuracy and allow the complete replacement of all mercury-based pressure standards which are expensive to operate and have environmental and health hazards. We describe our progress in designing and building our fixed length and variable length optical cavities and will discuss the uncertainty budget and technical challenges associated with this project to build an optical primary pressure standard.

9:20am **VT-MoM4 Uncertainty of a NIST Transfer Standard for Inter-Laboratory Comparison of National Metrology Institutes, *J.E. Ricker*,** *J.H. Hendricks*, NIST

For over a decade, NIST has been developing portable Transfer Standards Packages (TSP) which can disseminate pressure at significantly lower uncertainties than commercially available transfer standards. Because of this experience, NIST was tasked with piloting an International Inter-laboratory Comparison of seven countries. From April 2012 to June 2013, a NIST designed TSP circled the globe visiting each National Metrology Institute as a reference to provide an International Inter-laboratory comparison from 1 Pa to 10 kPa. The most important aspect of the TSP was to have an uncertainty value ranging from 0.5 % at 1 Pa to 0.01 % at 10 kPa.

Key to reaching the uncertainty goal was using special techniques to improve the uncertainty of commercial gauges. These techniques include temperature stabilization, maintaining level, and improving the calibration stability of the gauges. The crucial advantage of the NIST TSP is the ability to exploit the advantage of the Capacitance Diaphragm Gauge's (CDG) unbeatable resolution at lower pressures (typically 1 part in 10^6 of full scale range) and the Resonance Silicon Gauge's (RSG) drift uncertainties of 0.01% (k=2). Each gauge type individually cannot achieve the necessary uncertainty, with the CDGs subject to up to 0.5% uncertainty (k=2) due to long term stability (drift uncertainty) and RSGs low resolution/inability to measure low pressures. However, the short term stability (< 8 hours) of a CDG is excellent (less than 0.01%) and has been found to drift in a correctable manor. Because of these characteristics, it is possible to calibrate the CDGs using the RSG just before use and wind up with a very low uncertainty measurement. The talk will cover primary gauge stability data on two transfer standard packages and will discuss some of the technical challenges in running an international key comparison.

9:40am **VT-MoM5 Fully Automated Flowmeter for Low Gas-Flows Based on Pinhole Apertures, *J.A. Fedchak*,** National Institute of Standards and Technology (NIST)

We report results from a new flowmeter built at NIST that based upon gas flow through a laser-drilled pin-hole orifice. Dubbed the orifice flowmeter (OFM), it is base on a relatively simple principle: A pinhole orifice with a known conductance can be used as a secondary flow standard; the gas flow is determined from the known conductance and the upstream pressure and temperature. A flowmeter based upon an appropriate set of orifices is easy to operate and automate. We are primarily interested in using the OFM as a standard to produce nitrogen gas flows into vacuum in the range of 10^{-11} mol/s to 10^{-6} mol/s (10^{-7} to 10^{-2} cm^3/s; STP) for vacuum gauge calibrations. Commercially available laser-drilled pinhole orifices with diameters from 1 µm to 50 µm can have molecular-flow conductances ranging from about 0.1 µL/s to 230 µL/s for N_2 at 23 °C, and can be used to produce gas flows in the range of interest by applying an upstream pressure in the range of 10 Pa to 100 kPa (0.1 to 760 torr). Accurate measurements of the orifice conductance, or gas flow, as a function of pressure are required to use the pinhole orifice as a basis of a flowmeter. This was performed using the NIST bellows flowmeter, a primary gas flow standard, to directly measure the conductance of a pinhole orifice over the entire pressure range of interest. We have constructed a fully automated flowmeter based upon conductance measurements of two pin-hole orifices that can be used for nitrogen and other gas flows. In this presentation, the construction and characterization of the OFM will be described and recent results will be presented.

10:40am **VT-MoM8 Evaluation and Discussion of Performance Characteristics of Modern-Day Cold Cathode Ionization Gauges, *P.C. Arnold*,** *T.C. Swinney, B.J. Kelly*, Brooks Automation, Inc., Granville-Phillips Products

Cold Cathode Ionization Gauges (CCIGs), as in all high and ultrahigh vacuum gauges, possess a myriad of idiosyncrasies which will be discussed. The basic physical electronics of the CCIG will be the basis for discussion of gauge characteristics. The physical electronics source of these characteristics will be pursued in terms of geometry, electric fields, magnetic fields, and common methods of use. The CCIG is found to solve many user environment operation issues and has many good points. The discussion of causes and possible theoretical remedies will address various issues at many regions of the common pressure-use regimes, including both the high and low ends of use. The role of magnet design and its contribution to magnetic fields internal to the gauge will be evaluated in interaction with the applied electric field. Computer simulation of these interactions will be displayed to aid in the understanding of the CCIG operation.

11:00am **VT-MoM9 An Inverted Magnetron Pirani Combination Gauge with Low Magnetic Stray Fields, *M. Wüest*,** *B. Andreaus, J. Marki, R. Enderes, D. Oertel*, INFICON Ltd, Liechtenstein

Electromagnetic interference from low-intensity static magnetic fields has been observed to affect the operation of pacemakers and other medical electronic devices. The ICNIRP Guidelines [1] recommend that those devices are not adversely affected by static magnetic fields below 0.5 mT.

This recommendation has been incorporated into the Semiconductor Manufacturing Standard SEMI S2-0302 [2] and requires that the magnetic field at exterior surfaces of the equipment (2 to 3 cm from the surface) has to be smaller than 0.5 mT or a pacemaker warning needs to be posted. For these reasons, presently available cold cathode gauges should (but most do not) carry a pacemaker warning label, because they do not fulfill the SEMI S2 standard. We have developed an inverted magnetron that has a novel magnetic field design with exterior magnetic stray fields below the threshold set by the SEMI norm. Therefore, this device does not need to carry a warning label. A low external magnetic field is also of benefit to analytical instrumentation, where the external magnetic field might influence the trajectories of ions. We will present the magnetic design and other pertinent features of this inverted magnetron gauge. [1] Guidelines on Limits of Exposure to Static Magnetic Fields, International Commission on Non-Ionizing Radiation Protection, 2009. [2] Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment, Semi S2-0302, Appendix 5, 2002.

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