Vacuum Technology Division
Room 301 - Session VT-MoM

Vacuum Measurement and Gas Analysis and Vacuum Technology for Quantum Applications

Moderator: James Fedchak, National Institute of Standards and Technology

8:20am **VT-MoM-1 "Much to Do About Nothing:" Advancing Compact UHV Packages for a "Quantum Everywhere" Future***, **Alex Tingle,*** ColdQuanta **INVITED**

The burgeoning quantum industry demands scientific and engineering innovation at a breakneck rate. Beyond invention and supply chain challenges of current and near-term laboratory-scale quantum systems, the not-so-distant future of compact, field-deployable, quantum products (such as computers, clocks, inertial sensors) will require cost-effective and mass-producible packages. Cold atom quantum technology is well-positioned to serve a wide variety of quantum applications, and advances in vacuum technology are enabling this cold atom quantum future. ColdQuanta strives to support the quantum ecosystem and cultivate a technology base that serves many emerging applications with a common underpinning technology, namely a compact cold atom UHV package: the Quantum Core. Advancing the Quantum Core will pave the way to diverse quantum products at scale. We will overview vacuum technology's crucial role in the quantum industry, dive into some specific technologies, and gaze into the future of commercialized Quantum Cores powering quantum products in diverse applications.

9:00am **VT-MoM-3 Non-Magnetic UHV Chambers and Feedthroughs for Quantum Applications: A Challenge for Vacuum, Optics and Mechanics***, **Klaus Bergner**, J. Hertel, A. Trützschler, M. Flaemmich,* VACOM Vakuum Komponenten & Messtechnik GmbH, Germany

Quantum technology is currently experiencing a huge push towards commercialization. This means that basic experiments are more and more transferred into industrial applications. This means that enabling technologies must meet new quality criteria. In particular, the interplay between vacuum technology, mechanical and optical requirements must be taken into account. Vacua in the UHV/XHV range have to be achieved and several optical access ports for different optical tools have to be positioned in the range of a few µm to each other and.

In order to fulfill all this demands efficiently, aluminum CF components offer the possibility of providing customized solutions with high geometrical accuracy, reduced weight, outgassing rates of 1E–14 mbar*l/s/cm² as well as non-magnetic properties.

The talk covers the design of non-monolithic and monolithic CF vacuum chambers made from aluminum by using AluVaC®-technology. By discussing customized chamber designs, the talk shows that a monolithic design leads to a paradigm shift, since a monolithic chamber can be designed much more compactly, manufactured faster and without welding seams.

In combination with different optical components, the talk addresses the UHV compatibility of AluVaC®-viewports as well as VACOM made optical feedthroughs. Thorough different tests prove the UHV suitability with low outgassing rates shine light on product-relevant changes under extreme conditions.

9:20am **VT-MoM-4 Comparison of Quantum and Classical Vacuum Standards***, **Daniel Barker**, N. Klimov, E. Tiesinga, J. Fedchak, J. Scherschligt, S. Eckel,* National Institute of Standards and Technology

We present a comparison of NIST's cold atom primary vacuum standard and a dynamic expansion vacuum standard. The cold atom vacuum standard (CAVS) converts the background-gas-induced loss rate of atoms from a magnetic trap into vacuum pressure using atom-molecule collision cross-sections calculated from first-principles quantum scattering theory. An extreme-high-vacuum (XHV) flowmeter and dynamic expansion system generate low-uncertainty partial pressures within the CAVS atom trap. To validate the CAVS, we compare its measured pressure to the pressure set by the dynamic expansion vacuum standard. We will present comparisons using a variety of noble gases and common vacuum contaminant species colliding with two species of sensor atoms. Our results open the way to vacuum gauge calibrations in the XHV and deployable pressure sensors with embedded traceability.

9:40am **VT-MoM-5 Direct Comparison of Two Portable Cold Atom Vacuum Standards***, **Stephen Eckel,*** National Institute of Standards and Technology (NIST)*; L. Ehinger,* Seattle University*; D. Barker, J. Fedchak, J. Scherschligt,* National Institute of Standards and Technology (NIST)

We demonstrate the operation of the portable cold atom vacuum standard (pCAVS) by directly measuring the same vacuum with two independent devices. The pCAVS, designed as a replacement to the Bayard-Alpert ionization gauge, measures the loss rate of atoms from a magnetic trap, and converts that loss rate into a vacuum pressure using *ab initio* quantum-scattering calculations. Our pCAVS devices share the same laser system. Loss rate measurements are interlaced between the two, allowing for simultaneous readout. When initially assembled, the two pCAVS together detected a leak on the order of 10^{-6} Pa L/s. After fixing the leak, the two pCAVS measured the same pressure of 41.8 nPa with approximately 2 % uncertainty. Operation of the pCAVS was found to cause some additional outgassing in the vacuum, raising the base pressure approximately 1 nPa. With improved thermal management and better modeling of other loss mechanisms, we expect that the uncertainty can be decreased sufficiently to allow primary pressure measurements in the extreme-high-vacuum range (< 10^{-9} Pa).

10:00am **VT-MoM-6 Reference Ionization Vacuum Gauge***, **Martin Wüest**, F. Scuderi,* INFICON Ltd., Liechtenstein*; J. Šetina,* Institute of Metals and Technology, Slovenia*; K. Jousten, M. Bernien,* Physikalisch-Technische Bundesanstalt - Berlin, Germany*; C. Illgen,* Physikalisch-Technische Bundesanstalt - Berlin, Germany*; N. Bundaleski,* Nova School of Sciences and Technology, CEFITEC, Portugal*; B. Jenninger, A. Stöltzel,* CERN, Switzerland

In the framework of the EURAMET project 16NRM05 a novel ionization gauge was developed. The goal was to develop a stable gauge suitable as a reference standard in the high vacuum range. A robust design eliminates many of the weak points of present day Bayard-Alpert gauges. Results of performed measurements show sensitivity spread within an interval ± 1.5 % at 95 % confidence level. Due to its simple geometry, sensitivity values can in principle be computed for any gas with a known ionization cross section. Known and stable relative sensitivity factors are important properties for the calibration of mass spectrometers. We will present some aspects of the gauge design and performance in conjunction with an associated controller.

10:40am **VT-MoM-8 Towards an Ionization Vacuum Gauge Suitable as a Reference Standard***, **Nenad Bundaleski,*** CEFITEC, NOVA School of Science and Technology (FCT-NOVA), NOVA University Lisbon, Portugal **INVITED**

Ionisation vacuum gauges are the only pressure measurement devices covering a pressure range from high vacuum down to extremely high vacuum. However, these instruments lack precision, accuracy and stability, which is a misfortunate fact knowing the importance of these pressure ranges in both science and high technologies. Calibration of mass spectrometers and measurement of pumping speeds are examples of tasks that are particularly vulnerable in that respect. There are two major sources of problems with the operation of ionisation gauges: maintaining stable path lengths of primary electrons throughout the ionisation volume, and contribution of secondary particles emitted from electrodes (photons, electrons, ions and neutrals) to the pressure reading. These phenomena will be analysed in some detail in the frame of this talk, including the solutions applied in different available gauges to handle them. In the second part of the talk, we will present a design of a novel ionisation gauge recently developed for metrology applications in high vacuum, and discuss solutions aiming to suppress the above mentioned issues. However, the proposed design may potentially have problems with space charge effects, which limits its range of operation at the lowest pressures.

11:20am **VT-MoM-10 Evaluating low Pressure Resolution Limits for Optical Refractometry***, **Jacob Ricker**, K. Douglass, J. Hendricks,* National Institute of Standards and Technology (NIST)*; S. White, S. Syssoev,* MKS Instruments, Inc.

NIST with a collaboration research and development partnership with MKS Instruments has created a portable Fixed Length Optical Cavity (FLOC) pressure standard based on gas refractivity. The NIST team is now working to push the limits of pressure measurement into the UHV range. The goal for the new device would be to fill the gap in quantum-based traceability that currently exists between the FLOC and the Cold Atom Vacuum Standard, from 1 Pa to 10^{-5} Pa. To achieve the measurement goals, several sources of noise and drift need to be studied and eliminated. The desired sensitivity requires a frequency measurement (heterodyne signal between two 194 THz cavities) to have noise on the order of 1 Hz. To achieve this, the portable FLOC must be redesigned with state-of-the-art lasers and cavity mirrors, vibration isolation, and improved thermal control. The current FLOC low pressure performance will be estimated and initial testing results along with our proposed pathway to ultra-high vacuum measurements will be presented.

11:40am **VT-MoM-11 Vacuum Fixed Length Optical Cavity (VFLOC): Optical Pressure Measurements Approaching Ultra-High Vacuum***, **Kevin Douglass**, J. Ricker, J. Hendricks,* NIST

With the goals of achieving quantum traceability over a broad pressure scale NIST is developing a Vacuum Fixed Length Optical Cavity (VFLOC) that will have a base pressure in the ultra-high vacuum range.The current FLOC operates in the 1 kPa to 150 kPa pressure range and the Cold Atom Vacuum Standard (CAVS) has an upper limit near 10^{-5} Pa.The main limitation for pressure resolution and ultimate base pressure is the fractional frequency stability or frequency noise of dual cavity heterodyne signal.For operation at 1542 nm, hertz level frequency noise is required for achieving pressure noise floor on the order of 10^{-6} Pa (10^{-8} Torr).We will discuss current system status, design and recent results.

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