Vacuum Technology Division
Room: 111 - Session VT-MoM

Vacuum Measurement, Calibration & Primary Standards, Gas Flow and Permeation
Moderator: R. Garcia, SAES Getters

8:20am **VT-MoM1 Transportable NIST Traceable Vacuum Standards for Secondary Calibration Laboratories and International Key Comparisons**, ***J.H. Hendricks***, *D.A. Olson*, *J.E. Ricker*, National Institute of Standards and Technology

Over the past decade, NIST has designed and built several high-stability transfer standard packages (TSPs) that have proven to be ideally suited for inter-laboratory comparisons in the atmospheric pressure and vacuum pressure range [1]. In the mid 1990's the development and use of micro electro mechanical systems (MEMS) enabled pressure sensor technology to make significant advances in both precision and accuracy. Resonant silicon gauges (RSGs) are MEMS sensors that are manufactured by micromachining silicon to produce silicon diaphragms nominally a few millimeters square by a fraction of a millimeter thick [2]. NIST has found that these gauges are very stable, rugged, and ideally suited as core technology for a high-stability precision pressure and vacuum standard. The RSG sensors with full-scale ranges of 10 kPa and 130 kPa have shown excellent stability [3]. However, one drawback of the RSGs is that they lack the sensitivity and resolution of capacitance diaphragm gauges (CDGs) with full-scale ranges of 133 Pa. The downside of only using these CDGs is their relatively poor calibration stability when compared to 10 kPa full scale range RSGs. The NIST solution has been to combine the high-resolution of the 133 Pa CDGs, with the high-stability of the 10 kPa RSGs into one transfer standard package. The RSG gauges are then used to determine the calibration drift in the CDGs at the time of use. A recently completed set of transportable NIST traceable vacuum standards with a range of 1 Pa to 10,000 Pa will be highlighted. These TSPs consist of pairs of 10 kPa RSGs and pairs of 133 Pa CDGs encased in temperature controlled enclosures that further enhance gauge performance. These standards will be used for an upcoming international key comparison in absolute pressure from 1 Pa to 10,000 Pa.

[1] Hendricks, J.H., Olson, D.A., Physics World, Vacuum Challenges and Solutions (2009) 18-19.

[2] Harada, K. et.al. 1999 Sensors and Actuators 73 261-266.

[3] Hendricks, J.H. et.al. Metrologia 44 (2007) 171-176.

8:40am **VT-MoM2 Extending the Range of the Spinning Rotor Gage for Vacuum Measurements and Calibrations**, ***M.L. Duncan***, *J.A. Keck*, Oak Ridge National Laboratory **INVITED**

The spinning rotor gage (SRG) has long been the primary transfer standard used by metrology laboratories for providing traceability of measurements from field vacuum devices to primary vacuum standards maintained at national measurement institutes. The useful range of the SRG, in its current commercial form, is somewhat limited by several factors including the relatively small change in momentum of the rotating sphere caused by the adsorption/desorption of gas molecules as the gas pressure (and thus number of molecules adsorbing/desorbing) decreases. Current technology limits the low pressure end of this range to about 2E-5 Pa with a K=2 uncertainty of approximately 1-3%.

Efforts are currently underway at the Oak Ridge National Laboratory to increase the range of the commercial SRG by approximately a decade by increasing the sensitivity of the rotor's momentum change to the low number of gas molecules available for adsorption/desorption at the lower pressures. Efforts are also underway to improve the uncertainty of the existing commercial SRG through better measurement and characterization of the thermal expansion of the spinning rotor itself. This paper will report on the progress of these efforts to date, some of the challenges discovered during the development process and plans to address those challenges

9:20am **VT-MoM4 Cold Electron Source Used as Electron Source in Familiar Vacuum Measurement Devices**, ***P.C. Arnold***, Brooks Automation, Inc., *G.A. Brucker*, Brooks Automation, Inc., Granville-Phillips Products

Both a Bayard-Alpert type ionization gauge and a partial pressure analyzer have been fabricated and tested with cold electron sources. These vacuum measurement devices showed performance for their intended use generally similar to operation with thermionically heated hot cathode electron sources. The benefits from a cold cathode electron source are several: reduced heat input to the system, lack of electron emission failure due to detrimental gases of the environment, non-susceptibility to deposits of the chemistry of the environment, non-interaction with the environment which interaction could produce gas species other than that occurring as part of the activity of the chamber, and finally fast turn-on to the electron emitting state. Details of the constructions, using an electron multiplier as the electron source, as well as the methods of controlling the electron emission current itself will be described. Test models, test conditions, and test results will be shown for a recently designed autoresonant ion trap mass spectrometer and an otherwise nearly traditional Bayard-Alpert ionization gauge.

9:40am **VT-MoM5 Review of Thermal Conductivity Vacuum Gauges**, ***M. Wüest***, INFICON Ltd, Liechtenstein

Thermal conductivity gauges are ubiquitous in vacuum industry. In the form of Pirani gauges they are a mainstay of cost-effective measurement in the fine vacuum range. Different realizations of the Pirani gauge will be discussed from the classical heated wire sensor to the newer micromachined sensors. We will review not only basic parameters such as measurement range and sensitivity but also topics interesting for industrial applications such as dynamical response, robustness and inertness in industrial processes.

10:00am **VT-MoM6 Investigation of the Hot Cathode Ionization Vacuum Gauge; Stability and Reliability on the Point of View of Traceability**, ***N. Takahashi***, ULVAC Inc., Japan

Many hot cathode ionization gauges have been developed focused on the lower limit of the pressure measurement. We have also developed the Axial symmetric transmission gauge (AT gauge) which lower limit of the pressure measurement is lower than 10^{-10} Pa.

On the contrast, stability and reliability are important for the industrial field and metrological traceability field.

Traceability of the vacuum gauge in the range of 1 to 10^{-4} Pa is established by the spinning rotor vacuum gauge. The uncertainty of the spinning rotor vacuum gauge includes its stability is estimated 1 % to few %. However, the sensitivity of the ionization gauges, which usually are the calibration item of the reference spinning rotor vacuum gauge, changes few % to few tenth %. Sensitivity change was caused by following; geometry change of the electrodes, change of the electron emission region on the hot cathode, contamination of the electrodes, etc.

We have investigated small all metal sealed triode type hot cathode ionization gauge on the contrast to the conventional glass bulbed triode type hot cathode vacuum gauge and all metal sealed BA gauge. The stability of the sensitivity of the small triode ionization gauge was less than 0.5% for 6 month before the huge earthquake happened in Japan. At the disaster, turbo molecular pump was crashed. We could report the sensitivity change of the gauge after the pump change.

We also demonstrate the benefit of the triode vacuum gauge in the contaminated vacuum system.

We will summarise the triode vacuum gauge is better charactristics than conventional glass bulbed triode vacuum gauge and BA gauge in the field of industrial field and metrological traceability field.

10:40am **VT-MoM8 On the Stability of Capacitance-Diaphragm Gauges with Ceramic Membranes**, *K. Jousten*, Physikalisch-Technische Bundesanstalt, Germany, ***S.P. Naef***, INFICON Ltd, Liechtenstein

Capacitance-diaphragm gauges with ceramic membranes or diaphragms have been on the market for

about 15 years. The long-term stability of these devices with full scales from 13 Pa to 133 kPa

has been tested in the past decade by the calibration of gauges used by the manufacturer as reference

gauges on the production line. These reference gauges were calibrated annually on a primary

standard. It was found that the reproducibility of these devices depends on their full scale. For

13 Pa, the annual reproducibility near full scale varied between 0.02% and 0.05%, and for full scales

of 133 Pa and higher, it varied between 0.005% and 0.03% of full scale. The reproducibility of the

ceramic capacitance-diaphragm gauges for full scales of 133 Pa and 1.3 kPa was significantly lower than the uncertainty of a primary standard applying the static-expansion method.

11:00am **VT-MoM9 Thermal Transpiration Effects in Capacitance Diaphragm Gauges with Helicoidal Baffle System**, ***M. Vargas***, Institute of Mechanics - Bulgarian Academy of Sciences, *M. Wüest*, INFICON Ltd, Liechtenstein, *S.K. Stefanov*, Institute of Mechanics - Bulgarian Academy of Sciences

The Capacitance Diaphragm Gauge (CDG) is one of the most widely used vacuum gauges in low and middle vacuum ranges. This device consists basically of a very thin ceramic or metal diaphragm which forms one of the electrodes of a capacitor. The pressure is determined by measuring the variation in the capacitance due to the deflection of the diaphragm caused by the pressure difference established across the membrane. In order to minimize zero drift, some CDGs are operated keeping the sensor at a higher temperature. This difference in the temperature between the sensor and the vacuum chamber makes the behavior of the gauge to be non-linear due to thermal transpiration effects. This effect becomes more significant when we move from the transitional flow to the free molecular regime (Kn > 0.1). Besides, CDGs may incorporate different baffle systems to avoid the condensation on the membrane or its contamination.

In this work, the thermal transpiration effect on the behavior of a rarefied gas and on the measurements in a CDG with a helicoidal baffle system is investigated by using the Direct Simulation Monte Carlo method (DSMC). This technique is based on the discretization of the number of particles, the space and the time domains, and it combines deterministic aspects for modelling the particle motion with statistical aspects for computing the collisions between particles. The study covers the behavior of the system under the whole range of rarefaction, from the continuum (Kn < 0.01) up to the free molecular limit (Kn > 100), for various temperature differences and different temperature gradient configurations (with radial and axial components). Moreover, in order to analyse the dynamic response of the system to a change in the sensor temperature from an initial isothermal configuration, some non-steady state calculations are performed. In this way the evolution of the macroscopic properties of the gas is studied from the initial moments until the steady state is achieved.

11:20am **VT-MoM10 Direct Conductance Measurements of Laser-Drilled Pinhole Apertures**, ***J.A. Fedchak***, *D.R. Defibaugh*, National Institute of Standards and Technology

A pinhole orifice with a known conductance can be used as a secondary flow standard. We are interested in using pinhole orifices 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 because a flowmeter based upon an appropriate set of orifices is easy to operate and automate. Commercially available laser-drilled pinhole orifices with diameters from 1 µm to 50 µm can have molecular-flow conductances, C_0, 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, C, as a function of pressure are required to use the pinhole orifice as a basis of a flowmeter. The NIST bellows flowmeter is a primary gas flow standard that was used to directly measure the conductance of a pinhole orifice to better than 0.2 % over the entire pressure range of interest. We present results of the conductance measurements for nitrogen and other gases. One might expect that the differences among the gases would be mainly due to their different thermal velocities, and that those differences would disappear when the normalized reduced flow rate (C/C_0) is plotted as a function of inverse Knudsen number. However, this was not the case at higher pressures. For example, the reduced flow rate for nitrogen was smaller than for argon at the same inverse Knudsen number. Following a suggestion by Jitschen (Vacuum 76 (2004) 89-100), the effect of the heat capacity ratio on C/C_0 was investigated.

Vacuum Technology Division
Room: 111 - Session VT-MoA

Optical and Mass Spectroscopy for Gas Analysis and Pump Modeling
Moderator: R. Versluis, TNO Science and Industry, The Netherlands

2:00pm **VT-MoA1 Low Uncertainty Measurements of Trace Water Vapor Based on Cavity Ring-Down Spectroscopy**, ***T. Hodges***, National Institute of Standards and Technology **INVITED**

I will discuss how cavity ring-down spectroscopy (CRDS) can be applied to accurately measure the concentration of residual water vapor which is present in a vacuum system or process gas stream. In CRDS, a monochromatic laser beam is injected into an evacuated or sample-gas-containing optical resonator and the transient decay of light exiting the cavity is monitored to quantify the optical losses. For water detection, the laser wavelength is tuned to probe characteristic rotation-vibration absorption features of the water molecule. The sample absorption coefficient is determined from observations of the ring-down cavity decay time and laser frequency, both of which can be precisely measured. Also, because CRDS uses a resonant optical cavity, extremely long effective optical pathlengths (up to tens of km) can readily be achieved in the laboratory. These properties make CRDS a high-spectral resolution, species-selective method, with relatively small combined uncertainty, and high sensitivity. I will show that when CRDS measurements are combined with first-principles spectroscopic models, this technique can yield concentration measurements with sub-percent-level relative uncertainty for absolute concentrations as low as 10^{11} cm^{-3}. I will present examples of CRDS-based trace water detection in vacuum and ultra-high purity gas systems, and I will talk about recent CRDS measurements of the vapor pressure of ice over the temperature range 0 deg C to -100 deg C.

2:40pm **VT-MoA3 Comparison of Cavity Ring-Down Spectroscopy, Oscillating Quartz Crystal and Electrical Impedance Technologies for Trace Water Vapor Detection below 100 ppb**, ***M.W. Raynor***, *J. Feng*, Matheson

Control of trace water vapor in high purity process gases at low ppbv levels is critical to the performance of many micro-electronic and photonic devices [1]. Consequently a variety of measurement technologies, have been developed to detect water below 100 ppb. However, the performance characteristics of each technology can vary and this is not always well understood by users. In this presentation three different approaches are considered: Oscillating quartz crystal microbalance (QCM), Al_2O_3 based electrical impedance sensor and laser induced cavity ring-down spectroscopy (CRDS). QCM technology, developed in the early 1960's, is still widely applied today. It is based on adsorption of water vapor on the hygroscopic coating of the QCM, which causes an increase in the mass of the crystal, and in turn, decreases its oscillation frequency. CRDS is a laser absorption technique based on the light decay in a high finesse optical cavity. The high resolution laser ~1-2 MHz (~10^{-5} cm^{-1}), high reflectivity mirrors (~ 0.99998) results in a long effective path-length which enables high selectivity and sensitivity for H_2O detection. Impedance-based sensors for trace water vapor detection have typically suffered from drift and equilibration issues. However, recently an impedance-based Al_2O_3 sensor chip with integrated heater for cycling the temperature within 60ºC to 200ºC has been developed. Water vapor is measured dynamically as impedance changes during wet-up of the sensor resulting in rapid response. In this work, we present and discuss data showing the performance of the above detection technologies with respect to sensitivity, speed of response and measurement stability in the <100 ppbv range.

[1] H.H. Funke et al., Rev. Sci. Instrum., 74 (9) 2003, 3909-3933.

3:00pm **VT-MoA4 Commercial Applications and Benefits of Continuous-Wave Cavity Ring-Down Spectroscopy**, ***Y. Chen***, Tiger Optics

Continuous-Wave Cavity Ring-Down Spectroscopy (CW-CRDS) is a laser-based state-of-the-art detection technique. Based on first principles, it directly derives the absolute optical loss due to absorption inside the cavity from a simple time measurement, independent of laser intensity noise and optical detector drift.

This highly sensitive absolute absorption measurement technique was first commercialized by Tiger Optics for sub parts-per-billion (ppb) level detection of moisture in inert gases. More than a dozen national metrology labs now use this technique as their moisture transfer standard. Several of these key national labs recently concluded a multi-year project comparing the performance of their different moisture standard generators by using two Tiger Optics CW-CRDS devices as their "referees", shipping them around the globe across three different continents. Inter-comparison data from this comprehensive study will be presented.

With over 1000 measurement points worldwide, CW-CRDS has gained widespread acceptance and growing use in a series of challenging, real-world industrial applications, well beyond trace moisture in simple matrices. We will demonstrate the strong capability of CW-CRDS for a diverse group of analytes over a large dynamic range and under widely varying application conditions. In addition, starting with ultra-high-purity, sub or low parts-per-billion measurement, this technology is now increasingly sought for higher parts-per-million applications as well. Taking maximum advantage of its exceptional dynamic range, with a variety of flexible configurations, CW-CRDS-based instruments address these various applications with a self-verifying measurement solution that is fast and sensitive, yet extremely robust and simple to operate.

3:40pm **VT-MoA6 Vacuum Quality Measurement at UHV Levels with AutoResonant Ion Trap Mass Spectrometers**, ***G.A. Brucker***, Brooks Automation, Inc., *J. Rathbone, B.J. Horvath*, Brooks Automation, Inc., Granville-Phillips Products

Autoresonant Ion Trap Mass Spectrometers (ART MS) have recently become commercially available and are rapidly finding applications in many areas of the vacuum technology industry. One of the biggest benefits of ART MS sensors is their ability to provide fast and sensitive data at ultrahigh vacuum levels (UHV). The ability to operate the sensor remotely, i.e. with the electronics unit away from the gauge head, has also made ART MS technology the gas analysis instrumentation of choice for hard radiation environments. The performance of ART MS sensors under UHV conditions is discussed. Test results for gas analysis measurements performed under UHV conditions are shown and compared against similar results obtained with legacy instrumentation including quadrupole-based residual gas analyzers. Different approaches available to improve the performance of an ART MS instrument under UHV conditions are explored and explained based on the basic principles of operation of the technology.

4:00pm **VT-MoA7 Reducing Uncertainties for Hydrogen Loading Determination of 1,4-bis(phenethyl)benzene (DEB) Using GC/MS Instead of the Traditionally-used CHN Analysis Method**, ***S.M. Thornberg***, *J.M. Hochrein, M.I. White*, Sandia National Laboratories

Hydrogen getters are used in many industries including aerospace, defense, and electronics (e.g., MEMS packaging) to control levels of hydrogen in sealed atmospheres and vacuum systems. In this research, we explore not only the products formed during the hydrogenation process but also the product distribution resulting from differing rates of hydrogenation. This work focuses on the analysis of hydrogenation products of 1,4-bis(phenethyl)benzene (DEB) using GC/MS and a method for creating samples with known hydrogenation levels. This information can then be used to calculate the remaining capacity of the getter by determining the ratios of saturated, partially saturated, and unsaturated products.

DEB has a molecular formula of C22H14 (MW=278 amu) and has a capacity for four moles molecular hydrogen per mole of DEB. The analysis of pure DEB (unhydrogenated) showed no contamination from partially hydrogenated products and only one chromatographic peak (from DEB). As hydrogenation proceeds, a series of products is formed with nominal masses 280, 282, 284, and 286 amu (282, 286, 290 and 294 amu for deuterium). Hydrogenation experiments were performed from 0% to 100% hydrogenation (calculated by molar ratios) with hydrogen mixed with a buffer gas (nitrogen) to slow the uptake reaction rate. After hydrogenation, the resultant solid was homogenized, dissolved in methylene chloride, and filtered. The stock solutions, diluted appropriately, were then analyzed using gas chromatography (Agilent, model 6890N) for product separation, and a high-resolution mass spectrometer (Jeol MStation, model JMS-700) for product identification.

In this talk, a comparison between the GC/MS method presented here and the traditional CHN analysis method will be presented. Round robin samples between three labs were used to assess the performance of each method.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin company, for the U.S. Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

4:20pm **VT-MoA8 Sampling Equilibration Times of Chemical Species for Different Capillary Surfaces**, ***R. Ellefson***, REVac Consulting, *D. McClelland*, Mound Technical Solutions, Inc.

Gas sampling through long, small-bore capillary tubing has long been used as a method to reduce the atmospheric pressure (or higher pressure) process gas to a low pressure for analysis by a mass spectrometer (MS). With care of sampling system design and operation, the species integrity of the process gas can be preserved in the sampling which enables accurate compositional analysis. The gas dynamics of the gas stream within the capillary tube equilibrating with the capillary wall and measured at the MS leads to a stable composition at the MS when equilibrium is achieved. A model that includes the wall material interaction is presented with prediction of stabilization time for various gas species. Data from four different capillary materials or surfaces are given to show the interaction process. The capillaries tested are: 304SS, 304 Sulfinert® SS, PEEK (polymer) and fused silica tubing. All capillaries have 0.25 mm i.d. and a 2 m length for direct comparisons. Composition profiles versus time are measured for a dry nitrogen sample followed by room air (50% RH) which shows the gas dynamics of the equilibration of adsorbed gases (e.g. H_2O and CO_2)) with the various interior surfaces of each capillary. The effect of capillary length and i.d (defining the surface area to be equilibrated) is included in our model and measurements. Equilibration times of 50 sec for H_2O are seen at room temperature for a 2 m capillary with 10 sccm flow rate. Longer times are needed to reach the low H_2O concentration in the nitrogen (drying the capillary surface). Raising the temperature of the capillary reduces equilibration time as expected.

The exit end of the capillary flows into the low pressure region created by the sampling forevacuum with a port to the MS for analysis. The effect on equilibration time of a Silcotek® surface treatment of interior surfaces of the inlet to the MS is measured and compared with equilibration time for the regular 304SS surface of the machined inlet.

4:40pm **VT-MoA9 Numerical Methods for the Design of Vacuum Systems with Examples**, ***R. Kersevan***, ITER International Organization, France **INVITED**

The paper deals with the issue of the numerical computation of relevant properties of vacuum systems under ultra-high vacuum (UHV) conditions, i.e. when molecular flow conditions are in place. Properties of interest, among others, are pressure profile, angular profiles, conductances, transmission probabilities, effective pumping speed, sputtering deposition profiles.

Many modern research tools need UHV conditions in order to function properly. The size of the system is not an issue, it can be very small (electronic packaging; gauge calibration benches, for instance) or very large (ITER torus, cryostat and ancillary systems; particle accelerators; spectrometers, etc...). The availability of relatively cheap computing power has in recent years brought at the forefront of research new software tools which allow the simulation of complex geometries and working conditions.

The paper quickly reviews the existing algorithms and tools [1], and then moves on to show examples of calculations, with particular emphasis on the Molflow+ code [2].

[1] R. Kersevan, "Analytical & Numerical Tools for Vacuum Systems", Proc. CAS - CERN Accelerator School and ALBA Synchrotron Light Facility : Course on Vacuum in Accelerators, Platja d'Aro, Spain, 2006 - Downloadable at http://cdsweb.cern.ch/record/923393

[2] R. Kersevan, J-L. Pons, "Introduction to MOLFLOW+: New graphical processing unit-based Monte Carlo code for simulating molecular flows and for calculating angular coefficients in the compute unified device architecture environment", J. Vac. Sci. Technol. A 27, 1017 (2009);

5:20pm **VT-MoA11 Numerical Modeling of Compact Siegbahn Molecular Drag Stages**, *H. Telib*, Politecnico di Torino, Italy, *R. Arpa*, Optimad Engineering s.r.l., Italy, *L. Campagna*, ***I.F. Cozza***, *E. Emelli*, Agilent Technologies s.p.a., Italy

In the frame of an optimization of single/multi-stage disk-type vacuum pumps, characterized by spiral channels a comprehensive but efficient numerical analysis of performances has to be founded on a careful modeling of the local gas flow features, such as pump leakage and development of the rarefied gas flow along the curved channels. Here, gas flows are in general considered three-dimensional, because of the spiral groove curvature, and driven by pressure gradients and the applied rotation speed as well as inertial forces (centripetal and Coriolis effects), which play the most important role.

Following the assumptions made for a Holweck model by Sharipov et al., we propose a lower-order model for steady flows in spiral molecular drag stages, based on the solution of the Boltzmann Equation (BE) with a BGK closure, in general curvilinear coordinates (properly fitted to the geometrical design of the channel), where the inertial effects explicitly appear in the governing equation. The order of the 3D original problem is reduced in the physical space (2D), by introducing assumption of "locally" known flow development of the distribution function along the spiral channel. Thus, 2D-BE calculations of the flow rates and stresses will be performed in a finite number of sections, suitably positioned along the spiral channel, from the outlet up to the inlet, in order to recover the pressure and torque distribution. In particular, the 2D Boltzmann equation is linearized in the most significant parameters (local rotation speed and pressure gradients along the pump radial direction), and solved in the reference section. The local valus of pressure and torque are obtained consistently by enforcing the mass flow conservation constraint.

A Discrete Velocity Method (DVM) is used to solve the Boltzmann Equation, with an explicit pseudo-time dependent technique to relax the flow up to its stationary solution. In order to decrease the computational time employed, the solver is designed to work on parallel architectures (MPI).

The performance prediction of the model will be assessed using test cases from the literature and compared to the available experimental data, on both Holweck and Siegbahn geometries. A further verification test will be carried out, to test prediction capabilities in the continuum regime by direct comparison with results obtained by a Navier-Stokes solver, with slip-boundary conditions.

Vacuum Technology Division
Room: 111 - Session VT-TuM

Accelerator and Large Vacuum System Design, Outgassing and Pumping
Moderator: Y. Li, Cornell University

8:00am **VT-TuM1 Continued Work toward XHV for the Jefferson Lab Polarized Electron Source**, ***M.L. Stutzman**, P.A. Adderley*, Thomas Jefferson National Accelerator Facility

The Jefferson Lab DC, high voltage polarized electron source utilizes deep-UHV pressures to limit photocathode damage due to ionization and acceleration of residual gasses into the photocathode, as well as preserve the surface chemistry necessary for electron emission. Continued efforts toward improving and quantifying pressures below $5x10^{-12}$ Torr for electron source vacuum chambers will be presented, including operational experience with the newly available Watanabe Bent-Belt Beam (BBB) gauge, and the incorporation of a bakable cryopump into the pumping configuration.

8:20am **VT-TuM2 Status of National Synchrotron Light Source II Vacuum Systems**, ***H.C. Hseuh**, A. Blednykh, L. Doom, M.J. Ferreira, C. Hetzel, J.P. Hu, S. Leng, C. Longo, V. Radindranathh, K. Roy, S. Sharma, F. Willeke, K. Wilson, D. Zigrosser*, Brookhaven National Laboratory **INVITED**

National Synchrotron Light Source II is a new medium energy, ultra low emittance, high flux and high brightness synchrotron radiation facility. NSLS-II consists of a 200-MeV linac, a 3-GeV booster synchrotron, and a 3-GeV 500-mA storage ring with a circumference of 792 meter and over 60 beam lines. The construction of NSLS-II started in 2009 and will be ready for users in 2014. The storage ring vacuum chambers are made of extruded aluminium, with ante-chamber for photon extraction and for distributed NEG pumping. The precision machined extrusions are welded to aluminium-to-stainless bi-metallic flanges using robotic welding machines. Due to the high heat loads, all the photon absorbers are made of GlidCop. The details of the storage ring vacuum system will be presented and compared with those of similar facilities. The challenges encountered in the fabrication of vacuum chambers, photon absorbers and RF shielded bellows will be described. The status of the project will also be summarized.

9:00am **VT-TuM4 The Large Cryopump System for the Heating Neutral Beam Injection of ITER**, ***S. Hanke**, M. Scannapiego, X. Luo, C. Day,* Karlsruhe Institute of Technology (KIT), Germany*, F. Fellin, P. Zaccaria*, Consorzio RFX, Italy

The ITER Neutral Beam Injection system (NBI) is one of the heating systems to achieve the required plasma temperatures to start the fusion process. Thereby, the NBI system is basing on the principle of provision and acceleration of deuterium and protium ions and the re-neutralization of the high energy ions to be injected into the plasma through the confining magnetic fields. Each heating NBI is designed to insert 16 MW of heating power to the plasma and presents major technical and physical challenges.

In order to solve these and to demonstrate the achievement of the required parameters, a robust R&D program is under way. A central milestone for this development is the establishment of a full scale test facility, which will be built on site of Consorzio RFX, Padova. Part of this test facility is MITICA (Megavolt ITER Injector and Concept Advancement), the test bed for the entire neutral beam injection system. Karlsruhe Institute of Technology (KIT), which is the lead party in design and R&D of the ITER cryopumps since more than a decade, is supporting this project with the development of a customized cryopump design which ensures that the requested density profiles for optimum beam performance can be produced.

The main operational task which has to be provided by the cryogenic pump at a speed of ~5000 m^3/s is to handle very high gas loads of protium and deuterium. As basic pumping concept, cryosorption was chosen and the cryopump is operated with supercritical helium at 4.5 K for the adsorbing and gaseous helium at 80 K for the shielding circuit. As demonstrated in other NBI applications, cryosorption provides a wide and robust operational window at acceptable cryogenic loads to the cryoplant. The design was driven by two competing requirements: The high thermal heat loads ask for a closed pump, whereas the need for a high pumping speed asks for an open structure. To reconcile both objectives in an optimized geometry, modeling simulations were performed using the Test Particle Monte Carlo code MOVAK3D. To properly describe the density distribution in the NBI vessel with large thermal and pressure gradients, the time-of-flight cell code ProVac3D was developed.

Additional to the design activities for an optimized cryopump, a considerable effort has been spent to investigate the thermal hydraulic properties of the cryopump during the different operational and failure modes.

9:20am **VT-TuM5 Design and Construction of the Vacuum System for SuperKEKB**, ***Y. Suetsugu**, K. Shibata, H. Hisamatsu, M. Shirai, T. Ishibashi, K. Kanazawa*, KEK, Japan

The upgrade project of KEKB B-factory, that is SuperKEKB, has started last year. The SuperKEKB is a two-ring electron-positron collider with 7.0 GeV electrons and 4 GeV positrons aiming a goal luminosity of $8.0x10^{35}$ $cm^{-2}s^{-1}$, which is approximately 80 times higher than that of KEKB. In order to realize the unprecedented luminosity, the stored beam currents are increased to 2.4 A and 3.6 A for electrons and positrons, respectively. The vertical beam sizes at the collision point are also squeezed to approximately 60 and 50 nm with the beam emittances of 5/13 and 3/9 nm/pm (horizontal/vertical) for electrons and positrons, respectively. The vacuum system is accordingly improved to achieve the challenging goal. Beam pipes with antechambers are adopted for the reduction in the beam impedance of beam channel and also in the irradiation power density of synchrotron radiation from intense stored beams. Various vacuum components adaptable to the antechamber scheme with low beam impedance and high thermal strength had been developed. The bellows chambers, for example, have a comb-type RF-shield, and the main vacuum pump is NEG strips inserted into one of antechambers. Special attention is paid for the mitigation of the electron cloud issues in the positron ring to avoid unwanted increase in the beam emittance. In order to reduce secondary electron emission, the inner surface of beam pipes is coated with TiN, the grooved surface is prepared in dipole magnets, and the newly developed clearing electrodes are introduced in wiggler magnets. The antechamber scheme is also effective to suppress the photoelectron effect. The beam pipes in drift spaces, furthermore, are winded by solenoid coils. The design of vacuum system has been mostly completed, and the mass production of beam pipes has started. Copper beam pipes with clearing electrodes for wiggler magnets had been already delivered. Aluminum beam pipes for arc section of positron ring are under manufacturing, together with bellows chambers, gate valves, NEG pumps, and so on. The installation to the ring will start next year after TiN coating, expecting the start of commissioning from 2014. The overall vacuum system design and some key issues for SuperKEKB together with the present status will be reported here.

9:40am **VT-TuM6 New Perspectives in UHV-XHV via a Novel Combination of NEG and Sputter Ion Pump Technologies**, ***F. Siviero**, A. Conte, L. Viale, A. Bonucci, P. Manini, L. Caruso,* SAES Getters, Italy*, L. Di Giacomo, G. Santella*, SAES Advanced Technologies, Italy

Current vacuum trends driven by end users requirements are demanding vacuum pumps with better performance in smaller packages. This is driving pump manufacturers to redesign their pumps and/or to consider new ways to combine pumping technologies more efficiently. In response to this trend it has been found it may be advantageous in UHV-XHV systems to use Non Evaporable Getter (NEG) pump as the main pumping element and complement it with a small ion pump to remove inert gases and methane. A novel design of such a combination, called NEXTorr®[1], was first introduced in 2010 at this conference.

Since the introduction, extensive studies have been carried out indicating the success of this configuration. Also, a broader range of pump models has been introduced, featuring pumping speed from 100 to 500 l/s (H2).

The result of the vacuum characterization carried out on the pumping performances for a variety of gases of interest for UHV-XHV applications is discussed in this paper. Pumping speed measurements, pump down, rate of rise and out-gassing tests have been conducted and in some cases compared with traditional pumping approaches based on large sputter ion pumps. The advantages coming from the synergic integration of the NEG and the ion pump elements are highlighted and discussed. Examples of applications showing how this novel family of pumps can simplify the design and operation of vacuum systems are also presented and critically reviewed.

[1] NEXTorr is an International Trademark registered by the "Madrid System" property of SAES Getters S.p.A.

10:40am **VT-TuM9 Modeling Hydrogen Outgassing in a Small Vacuum Chamber**, ***R.F. Berg***, National Institute of Standards and Technology

Reports of hydrogen outgassing usually involve large vacuum chambers made of stainless steel. Typically, the chambers were baked at temperatures up to 400 °C, but the outgassing was measured only at room temperature. In contrast, the chamber used for the present measurements had a volume of only 29 cm^3, with a correspondingly large surface-to-volume ratio, and the outgassing rate was measured at temperatures as high as 250 ° C.

The present outgassing measurements were compared with a numerical model that included (1) diffusion of hydrogen atoms in the steel, (2) recombination at the surface into hydrogen molecules (plus the reverse process), and (3) release of hydrogen from traps. A trap is a site, such as a dislocation or a grain boundary, where the hydrogen is bound more strongly than in the surrounding metal. Traps allow stainless steel to hold much more hydrogen than implied by the small solubility of hydrogen in pure iron. The larger binding energy means that increasing the temperature does more than speed up diffusion; it also increases the amount of mobile hydrogen in the steel.

The model used the values obtained by Grant, Cummings, and Blackburn for the diffusivity, recombination, and permeation of hydrogen in stainless steel. If one assumes a plausible value for the initial hydrogen concentration, it gives outgassing rates in rough agreement with the measurements.

11:00am **VT-TuM10 Modelling and Simulation of the ITER Cryopumping Systems**, ***C. Day***, Karlsruhe Institute of Technology, Germany **INVITED**

A cryopump is probably the most versatile and flexible vacuum pump. In large R&D applications where cryoplants are anyway available and high pumping speeds at high throughputs are requested, it is often advantageous to exploit a directly cryogen-supplied cryopump. The nuclear fusion project ITER is a perfect example for such a project, which triggered the development of customized cryopumps. To name just two advantages of this approach, a cryopump can be designed to perfectly fit the available space, and can be installed in-situ without any conductance losses, if regeneration frequency allows for that.

Karlsruhe Institute for Technology (KIT) is developing tailor-made cryosorption pumps for fusion applications over the last 20 years. This has been associated with an extensive design supporting R&D programme which has provided a broad parametric database and stimulated the development of modeling and design tools.

This paper will delineate the essential steps one has to consider when designing a cryosorption pump. The design process of a customized cryopump starts with the proper identification of the set of requirements, which defines the requested integral pumping speed at the given pump location and space. The tools needed for individual cryopump design are described and typical examples are given. This includes the calculation of capture coefficients and distributed pumping on the cold surfaces by means of Test Particle Monte Carlo methods.

Cryopump examples are taken from the area of large cryopumps for ITER, such as the torus cryopumps (~ 80 m^3/s) and the cryopumps for high energy neutral beam injection development (~ 5000 m^3/s). Although being cryogenic pumps, these applications are characterised by relatively moderate vacua due to the high gas throughputs during pumping. This also leads to the fact that transitional flow conditions prevail inside the pump, which results in additional challenges with regard to modelling and operation. Both pump types are currently in the stage of build-to-print design finalization and prototypes will be manufactured to validate this design in dedicated testbeds at KIT and Padova, Italy.

11:40am **VT-TuM12 Design and Construction of the Ultrahigh Vacuum System for the 3 GeV TPS Accelerator**, *G.Y. Hsiung, **H.P. Hsueh**, C.L. Chen, J.R. Chen*, National Synchrotron Radiation Research Center, Taiwan, Republic of China

The ultrahigh vacuum system for the electron storage ring of the 3 GeV Taiwan Photon Source (TPS) accelerator has been started the construction since 2010. The critical vacuum components with lower impedance design including the bellows with spring-finger rf-contact, the metal gate valves with comb-finger rf-contact, pulsed magnet kicker ceramic chambers, beam position monitors, crotch absorbers, and the precise machined sector bending chambers and BPM chambers, have been manufactured. The large aluminum alloy (Al-) bending chambers for the arc-cells have been precisely machined with oil-free machine tools in the clean room, and undergoing the ozonate water cleaning after with the precisely in-house welding. Mass production of the vacuum equipments including the ion gauges, ion pumps, NEG pumps, and gate valves, has been contracted out and partially delivering following the schedule of the cell assembling. Each cell, contains two short Al-straight chambers and two Al-bending chambers, has been started the assembling and on-site welding on the pre-aligned girders in clean room forming an one-piece vacuum vessel about 14 m in length following by the vacuum baking to the ultra-high vacuum. The progress of prototyping development and the status of construction for the TPS ultrahigh vacuum system will be described in this paper.

Vacuum Technology Division
Room: 111 - Session VT+MN+NS+SS+AS-TuA

Surface Science for Future Electronic Materials and Accelerator Applications
Moderator: M. Wüest, INFICON Ltd, Liechtenstein

2:00pm **VT+MN+NS+SS+AS-TuA1 New UHV Low Temperature Scanning Probe Microscopy Facility for the Study of Future Electronic Materials**, ***J.A. Stroscio***, National Institute of Standards and Technology **INVITED**

Since the beginning of the last century new frontiers in physics have emerged when advances in instrumentation achieved lower experimental operating temperatures. Notable examples include the discovery of superconductivity and the integer and fractional quantum Hall effects. New experimental techniques are continually adapted in order to meet new experimental challenges. A case in point is scanning tunneling microscopy (STM) which has seen a wealth of new measurements emerge as cryogenic STM instruments have been developed in the last two decades. In this talk I describe the design, development and performance of a scanning probe microscopy facility operating at a base temperature of 10 mK in magnetic fields up to 15 T [1]. The STM system can be connected to, or disconnected from, a network of interconnected auxiliary UHV chambers used for sample and probe tip preparation. Results from current measurements on graphene and topological insulators will be described.

[1] *A 10 mK Scanning Probe Microscopy Facility*, Y. J. Song, A. F. Otte, V. Shvarts, Z. Zhao, Y. Kuk, S. R. Blankenship, A. Band, F. M. Hess, and J. A. Stroscio, Rev. Sci. Instrum. **81**, 121101 (2010).

2:40pm **VT+MN+NS+SS+AS-TuA3 Contact Resistance of RF MEMS at a Randomly Rough Surface in the Presence and Absence of Adsorbed Organic Monolayers**, ***D. Berman***, *J. Krim, M.J. Walker*, North Carolina State University

Understanding of current flowing through the asperities is interesting for many applications: in RFMEMS, Molecular electronics, Nanotube tunneling etc.

Previous results [2] suggest that the films are displaced from the contacts themselves, but remain present in nearby regions. The increase in resistance is associated with elimination of vacuum electrical tunneling currents in those regions. This raises the question of the relative proportions of contact resistance (Rc) and effective tunneling resistance (Rt).

Measurements on the gold on gold contacts adhered in the closed position, where the contamination film cannot possibly be placed inside the contacts are reported, to investigate vacuum tunneling current contributions to the total current at the contact. Electrical Contact Resistance measurements are reported for RF micro-electromechanical switches with Au/Au and Au/RuO_2 contacts, situated within an ultrahigh vacuum system equipped with *in situ* oxygen plasma cleaning capabilities. Fused Au/Au switch resistance increases by 3-5% (which corresponds to 20W tunneling resistance in parallel) after adding pentane to the switch environment. Moreover, the results are repeated with a different substrate (Ruthenium rather than Au), known for higher resistance, to change the resistance values with almost the same work function. If this is tunneling, the same effective tunneling resistance is expected, because tunneling depends on the work functions of the tip and substrate, which are close for gold and ruthenium oxide. In addition, the results are investigated for two different adsorbates, pentane and dodecane. Measurements have been recorded as the function of film coverage and the same tunneling resistance impact is observed. This is consistent with elimination of vacuum tunneling when adsorbed films are present.

Theoretical analysis of two possible mechanisms of the impact of molecular uptake is performed to interpret the experimental results: a) parallel connection of contact resistance and effective tunneling resistance before molecular adsorption, followed by molecules blocking the tunneling current; b) in series connection of contact resistance and pentane layer after adsorption. The data are more consistent with model a).

This work was supported by US National Science Foundation, AFOSR MURI and DARPA. We are grateful to C. Nordquist at Sandia National Lab and J. Hammond at RF Micro Devices for providing the experimental switches.

[1] D. Berman, M. Walker, C. Nordquist, J. Krim, *in preparation for Journal of Applied Physics*

[2] M. Walker, C. Nordquist, J. Krim, *in preparation for Tribology Letters…*

3:00pm **VT+MN+NS+SS+AS-TuA4 Surface Issues for Solid Niobium SRF Accelerator Cavities**, ***M. Kelley***, College of William and Mary

The world-wide physics community looks forward to a slate of accelerator projects of unprecedented magnitude and diversity. Certainly its sheer size makes the International Linear Collider the most visible to the public eye, with 16,000 solid niobium cavities performing at historically high gradient, and built (and operated) for historically low unit cost. Net performance makes superconducting radiofrequency (SRF) technology the approach of choice.

Solid niobium is the material most widely used for construction of SRF cavities because it has the highest critical transition temperature (T_c = 9.2 K) of the pure metals, sufficiently high critical magnetic field (H_c > 2 k Oe) for SRF applications, and metallurgical properties adequate for fabrication and service load. Studies of the SRF performance of niobium cavities began to be reported more than 30 years ago and continue now with the application of improved experimental techniques. Niobium metal superconductivity is a nanoscale, near-surface phenomenon because of the shallow RF penetration. Considerable evidence indicates that cavity interior surface chemistry and topography strongly impact SRF accelerator performance, motivating investigation of how they are affected by post-fabrication treatments.

Current status and prospects are discussed with respect to accelerator needs and opportunities.

4:00pm **VT+MN+NS+SS+AS-TuA7 Examples of Surface Related R&D on Nb Samples and SRF Cavities for Particle Accelerators at JLab**, ***A.T. Wu***, Thomas Jefferson National Accelerator Facility

This contribution will review some examples of surface related R&D on small and flat niobium (Nb) samples and single cell Nb superconducting radio frequency (SRF) cavities done at Jefferson Lab in the past few years. Most of the surface measurements were performed via the experimetal systems available in the surface science lab that was set up[1] at JLab to study the various problems on the Nb surfaces in the SRF field.

The first topic is about a new Nb surface polsihed technique called buffered electropolishing (BEP) that was developed at JLab[2]. This technique can produce the smoothest surface finish ever reported in the literature[3]. It was also demonstrated that under a suitable condition, a Nb removal rate higher than 10 μm/min could be realized. Efforts have been made to try to understand the polishing mechanism through experiments with a well defined experimental geometry on small flat Nb samples. A unique versatile vertical polishing system was constructed to perform BEP on Nb single cell cavities. Small flat samples, Nb dumbbells and Nb single cell cavities were also studied and treated at CEA Saclay in France and Peking Universty in China and the cavities were RF tested at JLab. Experimental results will be analyzed and summarized. It is showed that BEP is a very promising cadidate for the next generation surface polishing technique for Nb SRF cavites.

A second topic will deal with a new Nb surface cleaning technique employed gas cluster ion beam (GCIB)[4]. This is a result of collaboration with Epion Corporation, Fermi Lab, and Argonne Lab. Beams of Ar, O_2, N_2, and NF_3 clusters with accelerating voltages up to 35 kV were employed in this technique to bombar on Nb surfaces. The treated surfaces of Nb flat samples were examined by sevral surface experimental systems such as SEM, EDX, AFM, SIMS, and 3-D profilometer. The experiments revealed that GCIB technique could not only modify surface morphology of Nb, but also change the surface oxide layer structure of Nb and reduce the number of field emission sites on the surface dramatically. Computer simulation via atomistic molecular dynamics and a phenomenological surface dynamics was employed to help understand the experimental results. A system was set-up at Epion Corporation to do treatments on Nb single cell cavities and then RF-tested at JLab. The experimental results will be summarized and the perspective of this technique for real appliactions is discussed.

Finally, I will show two typical examples of surface studies of Nb using a high resultion transmission electron microscope[5] and a home-made scanning field emission microscope[6] respectively.

4:20pm **VT+MN+NS+SS+AS-TuA8 Early Stages of Nb Growth on Cu for SRF Accelerator Applications**, ***C. Clavero***, The College of William and Mary, *N.P. Guisinger*, Argonne National Laboratory, *R.A. Lukaszew*, The College of William and Mary

Among the large range of possible applications for superconducting Nb thin films, coatings for superconducting radio-frequency (SRF) cavities in linear accelerators have greatly aroused the interest of researchers in the last years[1]. Superconducting thin films and multilayer coatings are expected to increase further the maximum field gradients that SRF cavities can withstand, pushing them above 100 MeV/m [2]. In this regard, Nb coated Cu cavities have been proposed as a prototypical system for this purpose since they combine the better thermal stability of Cu due to its much higher thermal conductivity and the superconducting properties of Nb thin films [3]. Nevertheless, it is well know that structural dislocations and localized surface resistive defects on the thin films have a dramatically negative influence on their superconducting properties and resonator quality. Indeed, the quality of the films is strongly conditioned by the growth mode bellow the single atomic layer coverage at the very early stages of growth, and thus special attention needs to be devoted to this range. Here we present a complete study on the early stages of growth of Nb on Cu(111). Different growth and annealing temperatures ranging from room temperature (RT) to 600 ºC were used in order to investigate the characteristic growth mode of Nb in the sub-monoatomic coverage range. Scanning tunneling microscopy (STM) and scanning tunneling spectroscopy (STS) were used to investigate morphology and chemical composition of the surfaces with atomic resolution. Growth of sub-monolayer coverages at RT leads to amorphous Nb islands with 1 and 2 AL heights. Annealing at 350 ºC gives rise to crystallization of the islands pseudomorphically with the substrate, *i.e.* Nb(111). Further annealing at 600 ºC promotes interdiffusion of Nb atoms into the Cu substrate and alloying of the islands. Growth of higher coverages above 1 AL at 350 ºC reveals preferential Volmer-Weber growth mode.

1. H. Padamsee, Annual Review of Nuclear and Particle Science , 635 (1993).

2. A. Gurevich, Applied Physics Letters (1), 012511 (2006).

3. C. Benvenuti, S. Calatroni, I. E. Campisi, P. Darriulat, M. A. Peck, R. Russo and A. M. Valente, Physica C: Superconductivity (3-4), 153-188 (1999).

4:40pm **VT+MN+NS+SS+AS-TuA9 Epitaxial Niobium Thin Films for Accelerator Cavities**, ***W.M. Roach****, D. Beringer, C. Clavero,* College of William and Mary*, C. Reece,* Thomas Jefferson National Accelerator Facility*, R.A. Lukaszew*, College of William and Mary

The currently proven superconducting radio frequency (SRF) technology used in linear accelerators is based on bulk niobium cavities. Since this has a high cost and these cavities are approaching the maximum field gradients that they can withstand [1], development of a suitable, reliable, cost effective alternative to bulk niobium SRF cavities is needed. Attempts have been made to replace bulk niobium cavities with niobium-coated copper cavities since the thermal conductivity of a suitable base material such as copper is better than bulk niobium [2]. Coating niobium on SRF cavities is a promising but also challenging path, since there are several difficulties associated with various thin film deposition techniques and a lack of systematic studies pertinent to niobium thin film nucleation and growth leading to surfaces of greatest benefit.

Our systematic studies show that the transport properties, in particular the residual resistance ratio (RRR), are improved when niobium is epitaxially grown on crystalline ceramic substrates such as MgO and Al2O3, compared to niobium grown on (001) copper templates. Since grain boundaries are typically one of the main obstacles to superconducting transport, we show how the increased number of crystallographic domains that can occur during epitaxial niobium growth onto copper surfaces leading to higher density of grain boundaries can explain our results. We will discuss a route to improved transport properties while maintaining thermal efficiency by using alternative seed-layers grown on copper templates that can limit increased grain boundary density. We will show our correlated studies of microstructure and surface morphology (RHEED and AFM) and the resulting transport/magnetic properties (four point probe and SQUID magnetometry) illustrating possible mechanisms to improve SRF cavity performance of such niobium films.

This work is funded by HDTRA1-10-1-0072 from the Defense Threat Reduction Agency as well as a subcontract from Thomas Jefferson National Accelerator Facility under contract DE-AC05-06OR23177 from the Department of Energy as supplemented by ARRA funds.

References:

[1] P. Kneisel *et al*., Proceedings of 2005 Particle Accelerator Conference, Knoxville, TN, TPPT076 (2005).

[2] S. Calatroni, Physica C **441**, 95 (2006).

5:00pm **VT+MN+NS+SS+AS-TuA10 Development via Energetic Condensation of Niobium Thin Films Tailored for Superconducting RF Applications**, ***A.-M. Valente-Feliciano***, Jefferson Lab

For the past three decades, bulk niobium has been the material of choice for SRF cavities applications. In the recent years, RF cavities performances have approached the theoretical limit for bulk niobium. For further improvement of RF cavity performance for future accelerator projects, an interesting alternative has been recently proposed by Alex Gurevich with the Superconductor-Insulator-Superconductor multilayer approach, using the benefit of the higher critical field H_{c2} of higher-T_c superconductors without being limited with their lower Hc_1.

JLab is pursuing this approach with the development of multilayer structures based on NbTiN via magnetron sputtering and High Power Impulse Magnetron Sputtering (HiPIMS). Insulators such as, AlN, Al_2O_3 and MgO are being investigated as candidates for the insulator layers.

This paper present the the characteristics of NbTiN and insulator layers produced and results on NbTiN-based multilayer structures on bulk Nb and thick Nb films.

5:20pm **VT+MN+NS+SS+AS-TuA11 Evaluation of Secondary Electron Emission Yield Suppression Coatings at CesrTA**, ***Y. Li****, X. Liu, J. Calvey, J. Conway, J.A. Crittenden, M.A. Palmer, J.P. Sikora,* Cornell University*, S.De. Santis*, Lawrence Berkeley National Laboratory

The performance of particle accelerators may be significantly limited due to buildup of electron cloud (EC) in the vacuum chambers. The EC buildup intensity is strongly affected by secondary electron emission from interior surfaces of the chambers. Application of coatings with reduced secondary electron yield (SEY) onto vacuum chamber interior surfaces is one of the most economical EC suppression techniques. As a part of the International Linear Collider (ILC) R&D program, the Cornell Electron Storage Ring (CESR) has been successfully reconfigured as a Test Accelerator (CesrTA) to study EC buildup and suppression techniques. During the CesrTA program, various passive SEY-reduction coatings (TiN, amorphous-carbon and diamond-like carbon thin films) have been applied to diagnostic vacuum chambers in CESR in order to evaluate the efficacy of the EC suppression and the vacuum performance of these coatings in an accelerator environment. These chambers are equipped with both vacuum instrumentation (ion gauges and residual gas analyzers), as well as EC diagnostics (retarding field analyzers and RF-shielded pickups). In this paper, we present the results of studies of the vacuum conditioning and EC mitigation performance of these coatings.

5:40pm **VT+MN+NS+SS+AS-TuA12 Electron Cloud Mitigation for the Large Hadron Collider (LHC)**, *V. Baglin, G. Bregliozzi,* ***P. Chiggiato****, P. Costa Pinto, J.M. Jimenez, G. Lanza, M. Taborelli, C. Yin Vallgren*, CERN, Switzerland

One of the main issues for the vacuum system of the Large Hadron Collider (LHC) is the build-up of electron clouds generated by electron multipacting in presence of beams. The occurrence of spatially distributed negative charges can lead to beam instabilities and emittance blow-up, pressure rises with a consequent background growth in the experimental areas, and increased thermal load in the cryogenic sections. The development of electron clouds depends on beam intensity and structure, magnetic field, and, in particular, the secondary electron emission of the beam pipe walls. With respect to this latter point, electron clouds can be eradicated whenever the maximum secondary electron yield becomes lower than a critical threshold. In the LHC the problem has already been tackled at the design phase by introducing TiZrV non-evaporable getter thin film coatings as the baseline for most of the room temperature sectors of the ring. After activation by in situ heating, this material provides maximum secondary electron yield lower than 1.1. In addition, during operation, dedicated scrubbing runs are carried out by generating intentionally electron clouds and electron impingement onto the non-coated vacuum chambers, in a way to reduce their secondary electron yield. Recently magnetron sputtered carbon coatings have been also studied because they can reach exceptionally low secondary electron emission without any heating; their application in the LHC injectors and future LHC components is under investigation.

The effect of electron clouds in the pressure variations during the first months of LHC operation will be presented, together with the effects ascribed to the mitigation techniques.

Vacuum Technology Division
Room: East Exhibit Hall - Session VT-TuP

Vacuum Technology Poster Session & Student Poster Competition

VT-TuP1 Measurement of Molar Mass and Viscosity of a Viscous Flowing Gas with a Resonant Vibrating Sensor, ***A. Kurokawa***, National Institute of Advanced Industrial Science and Technology (AIST), Japan, *H. Hojo, T. Kobayashi*, VPI Co., Japan

We would show that a quartz tuning-folk type resonator can measure the viscosity and the molar mass of the gas in which the resonator is vibrating. The vibrating resonator has two kind of outputs which are frequency change (Δf) and impedance change (ΔZ). The Δf and ΔZ are defined as the shift from their origin measured at high vacuum. We reported that the Δf and ΔZ given as a function of pressure are independent, and then the measurement of Δf and ΔZ will give the gaseous viscosity with no need to measure the gaseous pressure [1, 2]. In this report we will show that the molar mass of the measurement gas can be given by measurement of Δf, ΔZ and pressure.

In this experiment the temperature controlled measurements were essential because Δf and ΔZ are sensitive to the temperature variation. The measurement apparatus, such as the vibrating sensor, driving circuit for oscillation, mass flow controllers, gas accumulator and the pressure gauges, are in a temperature controlled chamber by 29±0.02ºC. The impedance of the resonator was evaluated by the current passing through the sensor under constant driving AC voltage. The frequency of the resonator was 32kHz. The measured gas was Ne, Ar, N2, O2. The Δf and ΔZ were measured for the pressure between 120 kPa and vacuum. The absolute pressure was measured with a capacitance manometer.

The results showed that the ΔZ(P) and Δf(P), give as a function of pressure, are larger for higher pressure. The ΔZ(P) and Δf(P) for Ar, N2, O2 gases do not have the intersection. However Ne gas, having smaller molar mass but larger viscosity, crossed the other curves. So we cannot distinguish the gas species simply by ΔZ(P) or Δf(P) measurements. To discriminate the gas species with their viscosity the ΔZ-Δf plot is useful. We found that the characteristic curves of ΔZ-Δf lied in the descending order of the viscosity, i.e., Ne, Ar, O2, and N2. These curves do not across each above 1 kPa.

We found the molar mass can be derived with the vibrating sensor. The product of molar mass and pressure can be evaluated without pressure measurement. The molar mass can be given with additional pressure measurement. The results showed that above 10kPa of the gas pressure the deviation of measured molar mass is less than a few percent.

[1] A. Kurokawa, H. Hojo, T. Kobayashi, AVS 57th Int. Sympo. Exhibi. (2010, Albuquerque).

[2] A. Kurokawa, H. Hojo, T. Kobayashi, Appl. Phys. Express **4** (2011) 037201.

VT-TuP3 Pumping Performance of Scroll Pump, ***F.C. Hsieh***, *P.H. Lin, J.C. Lu, F.Z. Chen*, National Applied Research Laboratories, Taiwan, Republic of China

Scroll pumps are widely used in solar-optic and semiconductor industry for backing purpose. The performance of scroll pump could affect significantly the performance of pumping station. The performance of a scroll pump was predicted by using VacTran commercial software and the experiment were conducted to verify the prediction in this study. Specifically, the delivered pumping speed, conductance and delivered throughput of the pump were investigated. The experimental delivered pumping speed increased as the inlet pressure increased and reached to 291.05 L/min at 11.62 mbar. As the inlet pressure increased, the conductance increased to $4.58x10^3$ L/min at $1.18x10^2$ mbar. The analysis delivered throughput increased obvious from $3.77x10^{-2}$ mbar and reached its maximum value at $1.2x10^2$ mbar. The standard deviation between analysis and experimental delivered pumping speed was less than 15% in the pressure ranges from $1.9x10^{-1}$ mbar to 45.3 mbar.

VT-TuP4 A System for Vacuum Gauge Calibration in the Pressure Range of 10^{-5} to 10^5 Pa, ***Y.W. Lin***, *C.P. Lin, C.N. Hsiao*, National Applied Research Laboratories, Taiwan, Republic of China

A vacuum gauges calibration system for wide-range pressure was developed, and the measurement uncertainty associated with the system. The design of the system took into consideration of influencing factors that include uniformity of gas distribution and the geometric location of the gauge to be calibrated. The system operates following the procedure stipulated in the comparison vacuum gauge calibration method. The calibration may range from 10^5 to 10^{-5} Pa. The system makes use of capacitor vacuum gauge, SRG and hot cathode thermion vacuum gauge to estimate the degree of uncertainty associated with the system. The data collected from the gauge calibration tests indicated that if the background pressure of the system had reached 10^{-7} Pa, the uncertainty associated with the system were as follows: less than 4 % in the pressure range of 10^{-5} to 10^{-2} Pa, less than 2 % in the pressure range of 10^{-2} to 10^5 Pa. The present research has demonstrated the high stability of the vacuum calibration system, and its capabilities of conducting calibration for vacuum gauge with great efficacy.

VT-TuP5 Application of AutoResonant Ion Trap Mass Spectrometry (ART MS) to Vacuum Quality Measurement, ***P.D. Acomb***, *G.A. Brucker, J. Rathbone, B.J. Horvath*, Brooks Automation, Inc., Granville-Phillips Products

Autoresonant Ion Trap Mass Spectrometers (ART MS) have demonstrated significant benefits when applied to vacuum quality measurement at ultra-high vacuum (UHV) levels. Vacuum quality monitors based on ART MS technology are known to deliver more accurate gas analysis at UHV levels than any other competitive mass spectrometry technology presently used for residual gas analysis. The speed, accuracy and remote-sensing capabilities of ART MS technology for vacuum quality measurement at UHV levels will be explained and several application examples will be presented. The low outgassing rates associated to ART MS sensors will be justified and explained in terms of surface area and power dissipation considerations. Gas analysis results, data-acquisition rates and detection limit values will be listed and compared against similar results obtained with legacy instrumentation including quadrupole-based residual gas analyzers. Instrument optimization strategies for UHV applications will be disclosed.

VT-TuP6 Combination of NEG and Sputter-Ion Pumps for Particle Accelerator Vacuum Systems, *P. Chiggiato, J.M. Jimenez, S. Meunier, I. Wevers*, CERN, Switzerland, *A. Bonucci, A. Conte*, ***P. Manini***, SAES Getters

NEG and sputter-ion pumps are usually combined in particle accelerators to attain UHV pressure specifications. NEG pumps provide very high pumping speed at a reasonable cost for most of the residual gases except CH4 and rare gases, which amount to less than an hundredth of the total outgassing rate. Sputter-ion pumps remove all gases, though with a lower pumping speed. As a consequence, an optimized design should be based on NEG assisted by sputter-ion pumps for the gases that are not adsorbed chemically. Two examples of such configuration are here described. In the first, a commercial NEG lump pump is installed on a dedicated set-up together with sputter-ion pumps of different nominal pumping speeds. We show that the ultimate pressure achieved in the system does not depend on the applied sputter-ion pump nominal pumping speed in the range 30 to 400 ls-1, and that values in the XHV range can be reached. In the second, we consider the vacuum system of the long straight section of the Large Hadron Collider (LHC) where most of the vacuum pipes were coated by magnetron sputtering with thin Ti-Zr-V films using Kr as discharge gas; the guidelines for the choice of the location and quantity of the sputter-ion pumps are reviewed in term of sectorization criteria and CH4 and Kr outgassing rates.

VT-TuP7 Cryogenic Viscous Compressor Design and Development for the ITER Vacuum System, ***S.J. Meitner***, *L.R. Baylor, C.N. Barbier, S.K. Combs, R.C. Duckworth, T.D. Edgemon, M.P. Hechler, D.A. Rasmussen*, Oak Ridge National Laboratory, *R. Kersevan, M. Dremel, R.J.H. Pearce*, ITER International Organization, France

A specialized cryopump known as a cryogenic viscous compressor (CVC) is being developed for the ITER vacuum system to pump the regenerated, hydrogenic, fusion reaction gases from the torus cryopumps and neutral beam cryopumps, to the tritium exhaust processing facility. Several of these pumps will operate in parallel and are staged to maintain continuous pumping during plasma operation. The CVC's regenerate at a higher pressure (500 mbar) than the torus and neutral beam cryopumps, which allows the regenerated gas to be pumped by a tritium compatible scroll pump train, with sufficient speed to maintain the regeneration duty cycle. The CVC's are cooled to operating temperatures by precooling the inlet gas with a 80K helium cooled chevron heat exchanger, followed by a tube bank heat exchanger cooled with supercritical helium at 4.5K. Hydrogenic gas is frozen on the inner tube bank walls while helium impurity gas, a byproduct of the fusion reactions, passes through the CVC and is pumped by conventional vacuum pumps.

A conceptual design of the CVC has been developed and a representative prototype has been designed, fabricated, and is undergoing testing to verify the concept of a full scale CVC before detailed design is completed. While cooling is provided by either cold helium gas or supercritical helium, hydrogen with trace amounts of helium gas is introduced into the central column of the cryopump at 100 Pa and 80 K at flow rates of 8 mg/s. Heat transfer between the laminar flowing gas and the cold pump tube is being enhanced with the use of internal petal fins. Temperature and pressure measurements are made along the pump gas stream in order to benchmark with design heat transfer characteristics. Comparison with a fluid dynamics code is under way. Modeling of the gas flowing into the pump and through the precooler heat exchanger and freezing zones is accomplished with the CFX computational fluid dynamics code [1]. The flows into the pump are at low pressure (~ 1mbar) and are in a laminar, low Reynolds number regime, (Re < 300) that is handled well with the CFX code. As the gas begins to desublimate in the cold zone of the pump, it reaches a rarified gas regime where the CFX model for flow and heat transfer breaks down. The modeling results are being compared with the prototype testing and will be used to further optimize and ensure reliable operation of the full CVC in the ITER application.

[1] ANSYS CFX, ANSYS, Inc., Canonsburg, PA 15317, USA

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VT-TuP9 Development of Niobium Thin Films Tailored for SRF Applications, ***J.S. Spradlin***, *A.-M. Valente-Feliciano*, Jefferson Lab

Over the years, Nb/Cu technology, despite its shortcomings due to the commonly used magnetron sputtering, has positioned itself as an alternative route for the future of superconducting structures used in accelerators. Recently, significant progress has been made in the development of energetic vacuum deposition techniques, showing promise for the production of thin films tailored for SRF applications. JLab is pursuing energetic condensation deposition via techniques such as Electron Cyclotron Resonance and High Power Impulse Magnetron Sputtering (HiPIMS). As part of this project, the influence of the deposition energy on the material and RF properties of the Nb thin film is investigated with the characterization of their surface, structure, superconducting properties and RF response. It has been shown that the film RRR can be tuned from single digits to values greater than 400. This paper presents results on surface impedance measurements correlated with surface and material characterization for Nb films produced on various substrates, monocrystalline and polycrystalline as well as amorphous.

VT-TuP10 Bulk-like Nb Films might be Possible with Coaxial Energetic Deposition for Superconducting RF Cavities, ***T. Tajima***, High Energy Accelerator Research Organization (KEK), Japan and LANL, *N.F. Haberkorn, L. Civale*, Los Alamos National Laboratory, *E. Valderrama, M. Krishnan*, Alameda Applied Sciences Corporation

B_{pen}, the magnetic field at which magnetic vortices start to penetrate into Nb films prepared by coaxial energetic deposition (CED) technique was measured with a SQUID magnetometer. Unlike the films prepared by conventional sputtering technique that showed B_{pen} ~ 94 mT at 2.5 K, the CED films showed B_{pen} of 180-190 mT at 2.5 K, a value that is very close to the number for bulk Nb used for SRF cavities. This corresponds to an accelerating gradient (E_{acc}) of approximately 45-48 MV/m for the SRF cavities with B_{peak}/E_{acc} ~ 4 mT/(MV/m) such as those for the European XFEL or the ILC projects. These samples were coated on MgO, Sapphire and Borosilicate with RRR ranging between 21(Borosilicate) and 540 (MgO). The next step will be to coat on copper. If it is possible to fabricate Nb coated copper cavities that have similar performance to bulk Nb high-gradient cavities, this will lead to a significant cost saving since the cost of copper is about 2 orders of magnitude less than Nb. It will also have other benefits such as better thermal stability due to high thermal conductivity of copper and less susceptibility to ambient magnetic field than bulk Nb cavities as has already been shown by LEP Nb/Cu cavities at CERN.

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