Vacuum Technology Division
Room 203B - Session VT-MoM

Vacuum Measurement

Moderators: Marcy Stutzman, Thomas Jefferson National Accelerator Facility, Alan Van Drie, TAE Technologies

8:20am **VT-MoM1 Pharmaceutical Freeze-Drying and Vacuum-Drying: Challenges and Opportunities*, Evgenyi Shalaev,*** Allergan **INVITED**

Many drugs are unstable in aqueous solutions, and drying is commonly used to improve their storage stability and shelf life. Freeze-drying is the most common drying method for parenteral pharmaceutical dosage forms, including both small molecular weight drugs and biologicals. Alternative vacuum drying technologies have also been introduced, although predominantly for research and development purposes. The presentation focuses on freeze-drying, starting with a brief overview of lyophilized (freeze-dried) products and corresponding manufacturing processes. The importance of pressure control during all three stages of freeze-drying (i.e., freezing, primary drying/ice sublimation, secondary drying / desorption of non-frozen water) is emphasized.

9:00am **VT-MoM3 Fixed Length Optical Cavities for Primary Traceability to the Pascal*, Jay Hendricks,*** *J.E. Ricker, K.O. Douglass,* National Institute of Standards and Technology*; G. Brucker, E. Fuchs, A. Ocepek, P. Sullivan, S. Venkatesan,* MKS Instruments, Inc., Pressure and Vacuum Measurement Group

Over the past 5 years, NIST has worked to develop a new pressure standard based on the fundamental properties of gas refractive index that will replace mercury manometers at national metrology institutes and has potential to be developed as a commercially manufactured product. The new pressure standard is based a first-principles quantum-chemistry calculations of gas refractive index and is a new route to realizing the pascal. NIST has now built and tested a fixed-length optical cavity (FLOC), which consists a pair of Fabry–Pérot cavities within a single block of ultralow-expansion glass. The change in optical path length between the two cavities (one at vacuum and one at the pressure to be measured) depends on the gas refractive index, density, and atomic or molecular properties. Helium's atomic properties were calculated from first principles, so the refractivity measurement leads to a determination of density, which provides a determination of pressure. While helium's refractive index has now been calculated by theory, the value of nitrogen refractive index remains too difficult for current computational theory to handle. Using the NIST mercury manometer along with helium's theoretical value of refractive index in a FLOC has resulted in a new experimental value for nitrogen refractive index to be determined. This enables the FLOC to be used with nitrogen as a pressure standard with direct primary traceability to NIST. Moving forward, the FLOC technology is so promising as a pressure standard, that NIST has joined with MKS under a Collaborative Research and Development Agreement (CRADA). The aim of this partnership is technology transfer to the market place, with the aim to develop a small, portable prototype need for real world metrology operations for industrial applications in gas pressure metrology. The current status of NIST-MKS CRADA will be briefly presented and discussed.

9:20am **VT-MoM4 Fundamental Quantum-based Vacuum Metrology at NIST*, Julia Scherschligt,*** National Institute of Standards and Technology

NIST has developed and characterized a variety of vacuum standards over the last several decades. Much effort, particularly recently, has been placed into developing standards based on optical methods and fundamental quantum properties. In this talk, I will present an overview of these efforts, focusing on the more recent advances in vacuum metrology. These span a wide range of pressures and employ a variety of nascent methods. However, our most recent methods focus on developing absolute standard based on fundamental physical properties, particularly quantum properties. At the low vacuum, we probe the pressure-dependent index of refraction of a gas in a fixed-length optical cavity (FLOC). At the middle range from the viscous flow regime to the high vacuum, we relate the ring-down time of a membrane to pressure ("Brane" gauge). At the ultra and extreme high vacuum (UHV and XHV), we use the loss-rate of ultra-cold atoms from a magnetic trap to measure background particle energy density in the cold-atom vacuum standard (CAVS). Each of these techniques presents unique technical challenges, I will put these challenges in context and briefly describe the research ongoing to address them. These include techniques to measure the refractivity of gases and distortion characterization for the FLOC, optomechanics and nanophotonics for the Brane gauge, and collision cross section measurements for the CAVS.

9:40am **VT-MoM5 Moving the FLOC to the Telecom*, Kevin Douglass,*** *J.E. Ricker,* National Institute of Standards and Technology*; J. Hendricks,* National Institute of Standards and Technology (NIST)

Towards the goal of quantum based traceability of the SI, NIST has developed an optical pressure standard where traceability is achieved through accurate quantum mechanical calculations of the refractive index and virial coefficients of helium. To achieve widespread adoption of this novel optical pressure measurement technology we leverage the various technologies that have been developed to support the telecommunications industry. We have begun characterizing the performance of our Fixed Length Optical Cavity (FLOC) at 1542 nm. At this wavelength an acetylene stabilized laser can be used to measure the wavelength to better than a ppm, which is one of the requirements of the measurement. The new optical setup and methodology for achieving high accuracy will be discussed along with future challenges and a detailed look at the sources of uncertainty and methods for calculating pressure from the change in refractive index.

10:00am **VT-MoM6 Transient Method of Permeability Measurements for Microporous Media*, Martin-Victor Johansson,*** Aix Marseille University, France*; M. Wuest,* INFICON, Liechtenstein*; P. Perrier, I.A. Graur Martin,* Aix Marseille University, France

The gas flow through the low permeable porous media have a great interest, especially in vacuum technology for filtering, separation process, protection and flow control. It can combine high mass flow rate and a high level of rarefaction. This property makes it particularly suitable as a leak element, by taking advantage of the constancy of conductance in free molecular regime, for example for calibration of ionization gauges or mass spectrometer [1]. The transient experimental technique, developed previously for the mass flow rate measurements through the microchannels [2], is generalized to obtain the permeability directly from the pressure variation measurements. The present experimental methodology, allowing for step by step data verification, leads to higher accuracy than the similar and commonly used method such as "pulse-decay" techniques [3]. The measured data are fitted according to the exponential function with the pressure relaxation time as a single fitting parameter. The new expression for the permeability is proposed involving besides of the geometrical parameters, the ratio between the gas relaxation time (inverse of the gas collision frequency) and the pressure relaxation time. The permeability of the microporous media with the characteristic pore size of 0.2 and 0.5 microns is measured for different gases. It was found that the permeability at low pressure (3 Torrs) increases 50 times compared to atmospheric pressure permeability . This permeability increasing depends essentially on the gas nature.

References:

[1] Hajime Yoshida, Kenta Arai, Hitoshi Akimichi, and Tokihiko Kobata. Newly developed standard conductance element for in situ calibration of high vacuum gauges. *Measurement,* 45(10):2452 – 2455, 2012. Special Volume.

[2] M Rojas Cardenas, I Graur, P Perrier, and J G Meolans. Thermal transpiration flow: a circular cross-section microtube submitted to a temperature gradient. *Phys. Fluids,* 23:031702, 2011.

[3] W. F. Brace, J. B. Walsh, and W. T. Frangos. Permeability of granite under high pressure. *Journal of Geophysical Research,* 73(6):2225–2236, 1968.

10:40am **VT-MoM8 Beamline Technology and Current Modeling Capabilities for Ion Implantation*, Svetlana Radovanov,*** Applied Materials, Varian Semiconductor Equipment **INVITED**

Ribbon beam technology have been used in semiconductor ion implantation for past three decades. Over the years these ion implanters have become highly sophisticated tools incorporating the use of energy filters, collimators, quadrupoles, scanning systems and more recently molecular plasma sources, cryogenic and elevated implant temperature capabilities. One of the features that made these tools so successful in device fabrication is the high degree of control of the dopant depth profile. By selecting a unique ion mass, ion charge, ion energy and implant angle, a beam line tool offers highly automated control over the beam transport and implanted ion dose [1]. These beam lines operate with a large variety of species, several orders of magnitude energy and dose range. The wafer processed per hour reach 500 wafers/hour for a standard high current implanter. In recent years, some very high dose applications have been enabled by plasma doping systems [2]. For example, some dynamic random-access memory applications require incredibly high doses ~$5x10^{16}$ /cm^2 that can be done by plasma doping systems. Unlike the beam line tools, ions are not mass analyzed, but instead the wafer is processed within the plasma chamber or in an adjacent vacuum chamber. The wafer is pulsed negatively by a bias supply with a square wave T~50ms and f~5-50 kHz. Implant energy is controlled by the bias voltage which can exceed 10 kV. The plasma is generated by an inductively coupled rf coil. When the bias voltage is on, a plasma sheath forms in front of the wafer surface, across which ions are accelerated and are implanted into the silicon.

In this paper, we will discuss electrostatic focusing, filtering and steering of an ion beam and modeling associated with it. This will include low energy beam acceleration, deceleration and transport. We also describe the 2D and 3D codes that are used to model beam line optical elements.

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J. England and W. Moller, Nucl. Inst. Methods, 365, 105 (2015)

11:20am **VT-MoM10 Design of a New Thermal Vacuum Chamber for Space instrument Calibration***, **Freek Molkenboer**, R. Jansen, R.G. Veraar, G.C.J. Otter, W.P. van Werkhoven, N.B. Koster, F.P.G. Driessen,* TNO, Netherlands

TNO is investing in a new facility for calibration of optomechanical Space instruments. This facility, called Calibration Space Instruments (CSI) should be operational early 2021. To meet this deadline the conceptional design phase has started early 2018.

The facility has three major sub system; a Thermal Vacuum Chamber (TVC), an Optical Ground Support Equipment (OGSE) and a Mechanical Ground Support Equipment (MGSE).

The OGSE system will provide all the optical stimuli that are required to perform an optical calibration of a Space instrument.

During a calibration of a Space instrument many relative positions between the OGSE and the instrument must be tested. The MGSE is responsible for the high accuracy, and highly reproducible manipulation of both the OGSE and the instrument. It is expected that some of the manipulation is done in vacuum, leading to the corresponding challenges.

The calibration of the instrument must be performed at the temperature in which it will operate in orbit. The TVC needs to provide these conditions. Beside the operational temperature the instrument also needs to be tested at non-operational temperatures, which increases the temperature range. It can be expected that some parts of the instrument will require LN2 temperatures. The CSI facility will focus on calibration of mid-size instruments, this results in a chamber with a volume up to 15 cubic meter

The vacuum pressure during a calibration shall be below 10-5 mbar. The challenge is that the materials used in a Space instrument and the TVC absorb a lot of water when exposed to air, resulting in a high pumping speed needed to reach the required pressure.

Future Space instruments will have higher resolution, which will directly impact the calibration facility. To be able to perform a calibration, pointing accuracies of 0.0015° are needed, which might result in for instance active shielding of vibrations from the TVC system and the floor towards the instrument and the OGSE.

Space instruments represent a lot of money, therefore instrument safety is crucial in the design of the facility.

During the oral we will discuss challenges that come with the design of the TVC for Space instrument calibration, and the measures that are taken to ensure safe and successful calibration campaigns.

11:40am **VT-MoM11 Pressure Measurements from Combining Non-evaporable Getter Pumps and a Novel Extreme High Vacuum Cryopump***, **Marcy Stutzman**,* Thomas Jefferson National Accelerator Facility*; A. Segovia Miranda,* Universidad Aut´onoma de Zacatecas*; P.A. Adderley, M. Poelker,* Thomas Jefferson National Accelerator Facility

The Jefferson Lab polarized electron source requires vacuum approaching extreme high vacuum for long operational lifetime for the GaAs photocathodes. Currently the system is pumped with a combination of non-evaporable getter (NEG) pumps, ion pumps, and a NEG coating on the chamber walls. Exploring further improvement of the vacuum for the system, we have assembled a system using an array of NEG modules and a novel cryopump with Boron Nitride Nanotubes (BNNT) instead of the traditional charcoal. The BNNT has been mechanically attached to the cryosorption surfaces of a commerical cryopump, and the system fully baked to remove water with no adhesive present in the system. We report here on the pump speed of the BNNT cryopump, and characterize the base pressure achieved in the combined NEG/cryopump system using both an extractor gauge and a Watanabe 3BG XHV ionization gauge which has reached at least the x-ray limit of the extractor gauge.

Vacuum Technology Division
Room 203B - Session VT-MoA

Pumping and Outgassing

Moderators: James Fedchak, NIST, Giulia Lanza, SLAC National Accelerator Laboratory

1:20pm **VT-MoA1 Gas Adsorption and Desorption Properties of 3D Printed Objects***, **Matt Hartings,*** American University*; J. Scherschligt, J.A. Fedchak, Z. Ahmed,* National Institute of Standards and Technology **INVITED**

Additive manufacturing processes are enabling technologies, supporting advances in a number of applications where either controlled gas uptake and release or the maintenance of a good vacuum environment are critical. In each of these scenarios, a detailed understanding of how a 3D printed object interacts with gas molecules is necessary to advancing how these objects can be used in a technical setting. I will describe two 3D printed systems and their outgassing properties. In the first system, we have compared traditionally machined vacuum chambers, made of either steal or titanium, with their 3D printed counterparts. We have evaluated hydrogen outgassing at low pressures for each of these systems and analyze how the surface micro- and nano-scale structure affects these measurements. In doing so, we assess how different printing parameters can affect outgassing of the object of interest. In the second system, we have studied the gas uptake, retention, and controlled gas adsorption of polymer composites that contain metal organic framework (MOF) particles. MOFs are a relatively new class of materials that have been implicated in a number of gas storage and delivery applications. We have 3D printed objects with our polymer-MOF composite materials and have evaluated the dynamics with which they adsorb and desorb hydrogen and nitrogen. We have found that chemical interactions between the MOF and the polymer can help to support or diminish the capacity to effectively store gas. Our work in both of these areas has shown how additive manufacturing processes can help to further technological goals while delineating the work that remains to successfully incorporate 3D printing objects into commercial devices.

2:00pm **VT-MoA3 Outgassing, Desorption, and Gas Uptake of 3D-Printed Materials***, **James Fedchak,*** NIST; J. Scherschligt, Z. Ahmed,* National Institute of Standards and Technology*; M. Hartings,* American University

We are investigating the outgassing, gas uptake, and gas desorption properties of novel 3D-printed composite materials, 3D-printed metals, and heat-treated metals. Materials we have investigated include 3D-printed titanium, stainless-steel, and composites of acrylonitrile butadiene styrene (ABS) melt-blended with metal-organic framework (MOF) materials. We have performed measurements of the outgassing into vacuum, the gas absorption of atmospheric gases such as H_2, N_2 and water at pressures greater than 50 kPa, and the desorption of the gases into vacuum. There are three motivations behind these investigations: first, we are interested in producing ultra-high vacuum (UHV) and extreme-high vacuum (XHV) pressures in small devices for quantum sensor and quantum science applications, such as our cold-atom vacuum sensor (CAVS). Second, we are interested in using novel new materials for gas sensing and, third, we are interested in using these composite materials for gas storage and separation. We will present our most interesting and recent results from these studies. For example, the ability of MOFs to store gas is now well-known, but our studies show that the MOFs retain their gas-absorption properties within the 3D-printed MOF-ABS composites.

2:20pm **VT-MoA4 Performance Prediction Approaches for Liquid Ring Vacuum Pumps with Mercury as Working Fluid***, **Santiago Ochoa Guaman,** T. Giegerich,* Karlsruhe Institute of Technology, Germany*; C. Dahlke,* HERMETIC-Pumpen GmbH, Germany*; C. Day,* Karlsruhe Institut of Technology (KIT), Germany

In the European fusion reactor (DEMO) development program, continuous working vacuum pumps are foreseen to pump the reactor. The pumps have to process large amounts of tritium, a radioactive and chemically very active gas. In a systems engineering approach, a pumping solution based on liquid ring pumps (LRPs) and diffusion pumps has been identified. Mercury is the only fluid perfectly tritium compatible and will be applied as working fluid.

LRPs exist for around 130 years and several mathematical approaches have been developed for its 1D modelling. Diagrams and tables also have been produce from experiments for fluid densities between 800 kg/m^3 to 1200 kg/m^3 but mostly for water as working fluid and with air as pumped gas. Modern 3D simulation tools have not been applied so far for analyzing these pumps. Thus, in order to design and analyze the operating behavior of LRPs with mercury as working fluid, it is necessary to design a special code for the prediction of the thermodynamic and operational behavior of LRPs operating with high density working fluids.

This great challenge is presented in this work, starting with the development of a simulation code based on three already existing methods. For its benchmarking against literature data, water as working fluid and air as pumped gas will be used. In a follow-up step, the code will be run considering mercury as working fluid. These results will be discussed against experimental results produced at the THESEUS vacuum pump test facility at KIT.

In the second part of this work, a two-phase three-dimensional CFD model will be performed using a more detailed pump geometry. Goal of this activity is to achieve a more accurate description of the pump performance without the use of empirical parameters. This requires extensive modelling and high computational effort. The status of this task will be presented in this paper and first results will be shown and benchmarked against experiments and the code.

2:40pm **VT-MoA5 Particle Emission from Ion Pumps: Optimized Shielding without Severe Conductance Limitation***, **Mauro Audi,** C. Paolini,* Agilent Technologies, Italy*; P. Manassero,* Agilent Technologies

Charged particle emission from ion pumps is a potential major concern in sensitive applications such as Electron Microscopes , Particle Accelerators and Synchrotron Light Sources .

In fact , emitted positive ions and electrons can affect the performance of the machine or the resolution of the instrument.

Optical shield can be used to limit the number of emitted particles , but standard existing solutions have major conductance limitations as an unwanted side effect .

A test campaign on various shielding designs was carried out with a Faraday Cup powered at different bias voltage at the inlet of the ion pump , and the tests were repeated at different operating pressures and voltages .

Test results demonstrate that it is possible to reduce the number of charged particles by three orders of magnitude with minor conductance limitation and consequently maintaining a high fraction of the original ion pump pumping speed .

3:40pm **VT-MoA8 VTD Early Career Award Invited Talk: The Development of the Spacecraft Atmosphere Monitor***, **Steven Schowalter**[1],* Jet Propulsion Laboratory **INVITED**

In this talk I will focus on our team's recent development of the Spacecraft Atmosphere Monitor (SAM), a miniaturized Gas Chromatograph Mass Spectrometer slated to be commissioned as a Technology Demonstration Unit on the International Space Station in early 2019. The sensor system for this instrument consists of a quadrupole ion trap mass spectrometer coupled with a MEMS preconcentrator, gas chromatograph, and valve system. The SAM has been designed to monitor major constituents as well as trace organic contaminants in the atmospheres of crewed spacecraft. The requirements of spaceflight have placed stringent constraints on the instrument design which have led to a highly-intentionally designed vacuum system. The vacuum chamber is manufactured by a custom additive process and is equipped with novel differential pumping and gas inlet architecture. The design of this vacuum system will be detailed and preliminary data will be presented.

[1] **VTD Early Career Award**

Vacuum Technology Division
Room 203B - Session VT-TuM

Large Vacuum Systems and Accelerator Vacuum Technology

Moderator: Yevgeniy Lushtak, SAES Getters USA

8:00am **VT-TuM1 Design of Vacuum Control System for the Linac Coherent Light Source II (LCLS-II) at SLAC National Accelerator Laboratory**, ***Shweta Saraf***, *S. Kwon, G. Lanza, D. Gill,* SLAC National Accelerator Laboratory **INVITED**

The LCLS-II (Linac Coherent Light Source II), a revolutionary new X-ray laser, is currently being built at SLAC National Accelerator Laboratory. The LCLS-II Vacuum System consists of a combination of particle free and non-particle free areas and includes the beamline vacuum, RF system vacuum, cryogenic system vacuum and supporting systems vacuum. The Vacuum Control System includes the controls and monitoring of different types of gauges, pumps and residual gas analyzers (RGA). The Vacuum Control System uses Allen Bradley PLC (Programmable Logic Controller) to perform interlocking to isolate bad vacuum areas. In particle free areas, a voting scheme is implemented for slow and fast shutter interlock logic to prevent spurious trips. Additional auxiliary control functions and high level monitoring of vacuum components is reported to global control system via an Experimental Physics and Industrial Control System (EPICS) input output controller .This paper will discuss the design and status of the LCLS-II Vacuum Control System.

8:40am **VT-TuM3 Vacuum System Design for Advanced Light Source Upgrade (ALS-U)**, ***Sol Omolayo,*** Lawrence Berkeley Lab, University of California, Berkeley

A project is underway to upgrade the existing Advanced Light Source (ALS) synchrotron. The goal of the project is to lower the horizontal emmitance to <75pm resulting in a 2 orders of magnitude increase in soft x-ray brightness. The design utilizes a multi-bend achromat (MBA) lattice which requires a small magnetic aperture of about 24mm. Consequently the vacuum aperture is very small down to 6mm in some areas. This narrow posses a challenge to the vacuum design due to the conductance limitation and space constraints for vacuum chambers. We present the conceptual vacuum design for the ALS-U.

9:00am **VT-TuM4 Vacuum System for CHESS-U: Design, Manufacturing, and Installation**, *X. Liu, D.C. Burke, A.T. Holic,* ***Yulin Li,*** *A. Lyndaker,* Cornell University

A sextant of Cornell Electron Storage Ring (CESR) is currently being upgraded with Double Bend Achromat (DBA) lattice and CHESS Compact Undulators (CCUs) in order to significantly boost the performance of Cornell High Energy Synchrotron Source (CHESS). With this upgrade, dubbed CHESS-U, CESR is converted from a counter-propagating two-beam ring to a single-beam ring, and the beam energy will be increased from 5.3 GeV to 6 GeV. The beam current for normal operation will also be increased, from 120 mA to 200 mA. The beampipe aperture of this new section is much smaller than the rest of CESR, and therefore the beam pipes and vacuum pumping are quite different from the rest of CESR too.

The beam pipes are mainly made of three types of aluminum extrusions, fitting inside quadrupole magnets, dipole magnets, and undulators respectively. The dipole extrusion includes an ante-chamber for distributed pumping using NEG strips (SAES St 707). An exception is the dipole chamber from which the undulator X-ray beam exits. This chamber is instead made of two machined halves that are welded together.

In this presentation, we will give a brief overview of the design of the vacuum system, and then show some important details in chamber production and installation, such as extrusion bending by stretch forming, chamber welding and distortions, NEG strip pumping, etc. Base vacuum performance will be reported as well. Details regarding the crotch absorber will be reported in a separate presentation.

9:20am **VT-TuM5 Design and Fabrication of CHESS-U Crotch Absorbers**, *Y. Li,* ***Xianghong Liu,*** *A. Lyndaker, K. Smolenski, A. Woll, L. Smieska,* Cornell Laboratory of Accelerator-based Sciences and Education

A major upgrade project (CHESS-U) will elevate performance of Cornell High Energy Synchrotron Source (CHESS) to a state-of-the-art 3rd generation light source. In the CHESS-U project, ~80 meters of Cornell Electron Storage Ring (CESR) will be upgraded with a Double Bend Achromat (DBA) lattice and CHESS compact undulators (CCUs), together with new CHESS front-ends and X-ray beamlines. Tremendous progresses have been made in the design, construction, and test of all required new accelerator components (such as magnets, vacuum chambers, etc.), and we are on schedule for the CHESS-U installation in late 2018.

One of the most challenging vacuum components is the crotch absorbers at the synchrotron radiation (SR) exit ports at the ends of dipole bending chambers. CHESS-U is designed for 250-mA maximum beam current at 6-GeV beam energy. The crotches need to safely absorb 5.1 kW of SR power generated by the dipole magnets at small angles of incidence, while allowing the undulator beams produced by the canted CCUs to pass. We present a design for a compact crotch which can effectively dissipate this high SR power and will be compatible with the ultra-high vacuum system of CESR.

The crotch is a composite of a 5-mm thick beryllium outer ring, which acts as a SR diffuser, and an axially water cooled copper cylinder, similar to the existing CHESS crotches that have been in operation for decades. The outer beryllium ring is bonded to the copper cylinder via vacuum furnace braze using Cusiltin (60% Ag - 30% Cu - 10% Sn) braze alloy. Thermal analysis has shown no surface temperatures higher than 325°C. However, the calculated maximum thermal stress (on the surface of the beryllium) is near beryllium's ultimate strength. As a practical validation of the CHESS-U crotch design, an existing CHESS crotch was removed from CESR for microscopic inspection. Though the CHESS crotch was exposed to slightly higher SR power (5.7 kW) during operations, no sign of fracture, surface melting, or other visible defect was detected on the beryllium surface. To ensure the good bonding of the beryllium diffuser ring to the copper cylinder, scanning X-ray fluorescence (XRF) inspections of the brazed crotches were performed at CHESS A1 beamline. The XRF inspection verified the presence of a continuous braze layer (corresponding to 10-30 µm thickness of Cusiltin) between the beryllium and the copper, indicating good braze joint. Five CHESS-U crotch assemblies have been successfully fabricated and XRF inspected, to fulfill the need for 4 crotches required for the CHESS-U project.

9:40am **VT-TuM6 Simulation and Measurement of the Tritium Retention in the Beamline of the KATRIN Experiment**, ***Joachim Wolf,*** Karlsruhe Institute of Technology, Germany

The objective of the KATRIN neutrino experiment is the determination the effective mass of electron anti-neutrinos with an unprecedented sensitivity of 0.2 eV/c^2 by measuring the energy spectrum of b-electrons from tritium decays close to the endpoint of the spectrum. The decays take place in a high-intensity windowless gaseous tritium source (WGTS). The electrons are guided by strong magnetic fields through a beamline with super-conducting solenoids to the huge main spectrometer for energy measurement. Since only a fraction of $2\cdot10^{-13}$ of all electrons have a kinetic energy within 1 eV below the spectral endpoint, the sensitivity of the measurement depends on a low background rate in the spectrometer. Therefore the tritium flow from the source (10^{-3} mbar) has to be reduced by at least 14 orders of magnitude before it reaches the spectrometer section. This large reduction in the 90-mm-diameter beamline is achieved with a combination of a differential pumping section (DPS), using turbo-molecular pumps (TMP) and a cryogenic pumping section (CPS) with an argon frost layer at around 3 K.

This talk describes the Test Particle Monte Carlo (TPMC) simulation of the beamline for the differential and cryogenic pumping sections both for the non-radioactive gas deuterium and for tritium with MolFlow+. Since the gas flow through the CPS is reduced by far more than 7 orders of magnitude, the simulation is done in several consecutive steps. The results are combined in the post processing of the TPMC results. In the post processing algorithm we also investigate the time dependence of the reduction factor by considering a finite sojourn time of the molecules on the cryogenic argon layer. This leads to a slow migration of deuterium in downstream direction. In a final step the half-life and migration of tritium is taken into account by a reduced sojourn time.

After finishing the construction of the KATRIN setup, the final commissioning of the experiment started in October 2016. The results of the commissioning measurements with deuterium will be compared with the TMPC simulations. First traces of tritium are planned to be admitted into the beamline in May 2018. This work has been supported by the German BMBF (05A17VK2).

11:00am **VT-TuM10 NSLS-II Beamline Vacuum Challenges: Design, Commissioning, and Operations***, **Robert Todd**, C. Hetzel,* Brookhaven National Laboratory

The NSLS-II facility now has 23 beamlines in operation and 5 others nearing operational readiness. This talk will focus on general vacuum requirements common to all synchrotron beamlines as well as hardware and design considerations needed to meet them. Topics to be covered include: beamline vacuum system design, leak checking, bakeout, commissioning, and operation. Particular attention will be given to the successes and challenges experienced to date.

11:20am **VT-TuM11 Thin film Heterostructures for Superconducting Photocathode Applications***, **Mark Warren**,* Illinois Institute of Technology

In the application of high pulse rate (100 MHz) CW light sources, superconducting RF guns serve as ideal photoinjectors as they dissipate significantly less power than normal metal Cu. An integral component of a photoinjector, the photocathode, must produce an electron beam with stringent requirements on emittance, temporal response, and quantum efficiency (QE). The photoinjector wall material is most commonly Nb which itself has a low QE (10-6). So, it is proposed that Nb photocathodes be coated with thin films of Mg which have a much higher QE (0.1% with laser cleaning) and can be induced into the superconducting state via the proximity effect. Results on the fabrication and testing of Nb/Mg bilayers including the resiliency of thin films in high RF fields (up to 60 MV/m) will be presented. In addition, the study of semiconducting overlayers is presented including promising QE values in ultra-thin layers of Cs2Te on Nb.

11:40am **VT-TuM12 TPD Results on Electrode Materials for Pulsed Power Vacuum Environments***, **Ronald Goeke**, S.C. Simpson, K.R. Coombes, M.K. Alam, D.P. Adams,* Sandia National Laboratories

Next generation pulsed power systems require a better understanding of current loss and the ability to predict the scaling of current coupling. Plasma formation occurs in these devices at both the anode and cathode at high current densities. These plasmas are formed from desorbed and ionized surface and bulk electrode contaminants, expand into the anode-cathode gaps of the transmission lines (a phenomenon referred to as plasma closure), and potentially lead to shunting of current away from the fusion targets. Contaminants are pervasive on typically manufactured hardware and common on pulsed power vacuum systems. Understanding the physics of neutral desorption from electrode surfaces is a critical requirement for accurately predicting plasma formation (current loss) in pulsed power machines, We will present Temperature Programmed Desorption (TPD) results of common electrode materials, including machined wrought stainless steel and additively manufactured 304L stainless steel.

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Vacuum Technology Division
Room 203B - Session VT-TuA

IoT Session: Vacuum System Design and Automation & Flash Networking Session

Moderators: Julia Scherschligt, National Institute of Standards and Technology, Martin Wuest, INFICON

2:20pm **VT-TuA1 Vacuum Chamber Design and Fabrication.***, Steve Greuel,* Nor-Cal Products **INVITED**

The Vacuum Chamber Design and Fabrication presentation will provide insights and considerations for those who are involved with the design and specifications of vacuum chambers. Proper vacuum chamber design, materials, machining, welding and other processing fundamentals will be discussed, as well common pitfalls to avoid during the design phase.

3:00pm **VT-TuA3 The Importance of Vacuum Cleanliness in Semiconductor Process Control SEM Tools***, **Irit Ruach Nir**,* Applied Materials, Israel*; M. Eilon, K. Luria, G. Eytan,* Applied Materials **INVITED**

In the semiconductor manufacturing process, integrated circuits are formed by many layers, and hundreds of process steps are required to produce a single wafer. If any problem occurs at any step of the production process, a huge amount of defective products will be produced. Therefore, inspecting the wafers during the production process is essential in order to discover any problem and solve it as early as possible.

Scanning electron microscopes are playing an important role in process control and yield management of the semiconductors process. Defect review (DR) SEMs are used for defect identification, review and classification, enabling the semiconductor fabrication plant (fab) yield management system to identify failures or problems at an early stage in the process flow and to point on possible root cause. The Critical Dimension (CD) SEM is used to measure critical dimensions of the fine patterns formed on the semiconductor wafer, enabling verification of process quality. Since the SEM tools are in-line tools it is essential that they will not affect the scanned wafer.

Organic contamination is one of the main challenges in vacuum systems and hence in e-beam based metrology systems. Organic molecules adsorbed on the wafer surface during SEM inspection may cause yield loss in the following process steps or affect the CD measurement. In addition, with decrease in design rules the processes become more and more sensitive to organic contamination and therefore the ability to control vacuum cleanliness is crucial. In this paper, we will specify some of the challenges involved in the design of clean SEM based metrology tools, possible contamination sources and possible effects of such contamination molecules on the wafer.

4:20pm **VT-TuA7 Compact Ultra High Vacuum Systems for Applications of Cold Matter***, **Evan Salim**, S. Hughes, M.A. Perez, D.Z. Anderson,* ColdQuanta Inc. **INVITED**

Cold and ultracold states of matter offer tremendous potential to disruptively impact in the fields of timekeeping, inertial sensing, EM field sensing, and information science. Currently, however, the complexity of high-performing cold atom systems constrain them to laboratory environments. As the enabling technology matures these states of matter are beginning to make the transition from pure science to becoming critical engineering tools. For that transition to be successful, it is necessary for the building blocks of cold atom systems be simplified, stabilized, and ultimately commercialized. At the heart of all of these cold atom systems lies an ultra-high vacuum (UHV) package. In this talk we present on the progress towards miniaturized UHV technologies that support the specific requirements of atomic systems, such as high-quality optical access, non-magnetic structures, and exquisite control of local electromagnetic fields. Our approach takes advantage of compatible material systems, such as glass and silicon, to produce monolithic chambers that eliminate the need for flanges and similarly bulky components. We will also present on how these novel vacuum systems will enable future applications, including clocks and quantum computers, and will help to define a standard set of integrated UHV platforms for cold atoms.

5:00pm **VT-TuA9 Plasma Window as Vacuum Atmosphere Interface for Various Applications***, **Ady Hershcovitch**,* Brookhaven National Laboratory **INVITED**

The Plasma Window is a novel apparatus that utilizes a stabilized plasma arc as an interface between vacuum and atmosphere or pressurized targets without solid material. In addition to sustaining a vacuum atmosphere interface, the plasma has a lensing effect on charged particles. The plasma current generates an azimuthal magnetic field, which exerts a radial Lorentz force on charged particles moving parallel to the current channel. With proper orientation of the current direction, the Lorentz force is radially inward. This feature can be used to focus in beams to a very small spot size, and to overcome beam dispersion due to scattering by atmospheric atoms and molecules

The best results to date have been the following:

1. Vacuum (pressure of ~ 10^{-6} Torr) was successfully separated from atmosphere and from a gas target pressurized up to 9 bar.

2. A 2 MeV proton beam was propagated from vacuum through the plasma window into atmospheric pressure with no measurable energy loss or beam degradation.

3. A 175 KeV electron beam was transmitted from vacuum through the plasma window to atmospheric pressure.

4. Successful transmission of X-rays from a light source to atmosphere.

5. Compatibility tests for transmission of electromagnetic radiation indicated that the plasma window does not generate electromagnetic interference, and that X-rays (away from resonance) are transmitted with negligible attenuation.

6. Electron beam welding in atmosphere (by an electron beam passing from vacuum through a plasma window) was accomplished with electron beams of unprecedented low power. Weld quality for the non-vacuum plasma window electron beam welding matched the quality of in-vacuum electron beam welding.

7. Internal gas stripper of ½ atmosphere helium confined by 2 plasma windows in accelerator vacuum.

Many industrial processes like electron beam welding and melting, as well as, ion material modification have low production rates due to required pumping time, and limits on the size of target objects. Utilization of the plasma arc as a window for targets removes these limitations and increases production rates. Other applications that can greatly benefit from plasma windows are those involving transmission of intense radiation or particle beams like high power lasers or deep ultraviolet photolithography sources, internal gas targets and beam dumpds. Plasma windows are practically completely transparent to high-energy particles and radiation, and unlike conventional windows, plasma windows are completely impervious to thermal damage.

5:40pm **VT-TuA11 Applications of IoT in Vacuum Technology***, **Jacob Ricker**, J. Hendricks,* NIST

Automation has become a necessary tool for scientists as they are expected to do more with less time and money. NIST is currently utilizing IoT (internet of things) in several applications to evaluate and control processes that benefit from continuous monitoring while simultaneously freeing up staff time. The presentation will feature two examples to highlight how IoT is changing how we monitor sensors and process data for real-time automation of vacuum technology. First, NIST's utilization of IoT to automatically protect and monitor primary pressure standards, and second, the use of IoT to monitor encasements holding historical documents such as a draft of the emancipation proclamation in Lincoln's handwriting.

Primary pressure standards require continuous pumping and must be monitored as failures can cause water vapor to contaminate the ultra-pure vacuum systems and monometer fluids. Additionally, it can cause damage to expensive vacuum pumps and cause significant down time of the system. Microcontrollers and circuits were designed and constructed to monitor pressure in the system, rotation of the pump, and to control shutoff valves if necessary. Additional controllers monitor for cooling water failures to protect diffusion pumps from overheating and for compressed air failure which would disable the automated valves. All these systems work simultaneously and report issues back to the operator.

In collaboration with the Smithsonian, Library of Congress, National Archives, and other agencies around the country, NIST has worked to fabricate encasements that protect historical documents such as the Declaration of Independence, US Bill of Rights, and Emancipation

Proclamation. All these encasements have featured sensors to monitor gas quality/stability; however recently IoT has enabled real-time monitoring of these readings to prevent operators from having to make manual readings of these sensors. The latest version of the encasement monitors Temperature, Humidity, O2 content, encasement pressure, and barometric pressure which are all reported and processed on cloud data storage. IoT has enabled instantaneous feedback and ensured these documents are preserved for future generations.

Vacuum Technology Division
Room Hall B - Session VT-TuP
Vacuum Technology Division - Poster Session

VT-TuP1 Characterization and Imaging of Surface Acoustic Waves on GaAs with Raman Spectroscopy*, **Brian Rummel**,* University of New Mexico*; M.D. Henry,* Sandia National Laboratory*; S.M. Han,* University of New Mexico

Surface acoustic wave (SAW) devices are commonly found in sensors and RF filters, and utilizing a facile technique to image the transmitted signal would prove useful in characterizing device operation and optimization. We show how Raman spectroscopy can offer analytical insight into the mechanical strain imposed by SAWs traveling along the surface of various III-V substrates. SAWs are generated using a single port interdigital transducer (IDT) design, modified to produce free surface standing waves. These standing waves provide a means to differentiate between nodes and antinodes of the acoustic wave. The temporal period of the SAWs does not easily allow *in-situ*, real-time measurement of the waves; however, a broadening of the Raman peaks corresponds to an averaging of the peak shifts over the integration time of the spectrometer. An analytical fitting model has been derived to effectively calculate the maximum strain induced by the acoustic waves, thus allowing one to characterize the SAWs. IDTs were deposited onto a GaAs (110) substrate to study the potential of Raman analysis for SAW devices. Wavelengths ranging from 3.2 µm to 10 µm were used to study insertion loss, attenuation, diffraction parameters, and the mechanical coupling coefficient. Future applications of this technique to probe growth defects in ScAlN/Si substrates will also be discussed.

VT-TuP2 Sapphire MEMS based Capacitance Manometer for Vacuum Freeze-Drying Device*, **Masashi Sekine**, M. Soeda, T. Ishihara, M. Nagata,* Azbil Corporation, Japan

New capacitance manometer which has high durability against Clean in Place (CIP) and Sterilization in Place (SIP) cleaning processes for vacuum-freeze drying equipment have been developed.

Vacuum-freeze drying equipment used for manufacturing of medicines or fine chemicals, CIP and SIP processes must be executed to ensure the sterilization of inside of the equipment according to International Organization for Standardization (ISO). The first CIP process, equipment inside is cleaned by water splay at room temperature and then cleaning is followed by SIP process with water vapor of 200-300kPa. To ensure whole cleaning, devices attached to equipment cannot be removed from the equipment. Also protecting valves for devices are not allowed because that inside of devices must be cleaned and stabilized. Therefore devices for these application should have durability of these water spray or vapor environments. Generally pressure range of a manometer for vacuum-freeze drying process is 100Pa absolute and it is heated up to 125 degree C for sterilization.

Authors have developed entirely sapphire-based capacitive pressure sensor chips utilizing MEMS (Micro Electro Mechanical Systems) processes, which are operated at up to 200 degree C with from 0-13 to 0-133k Pa pressure range mainly for semiconductor manufacturing. Cross sectional view of sensor package is shown in Fig.1. Cross sectional view of sensor chip is shown in Fig.2. Deformation of sapphire diaphragm due to pressure change is measured as capacitance change between sensor diaphragm and base-plate.

In the process of adopting this manometer into vacuum-freeze drying process, zero point shifts were found after CIP and SIP processes. Detailed investigation revealed the mechanism of these zero shifts as follows.

Once CIP and SIP processes are conducted, sensing diaphragm is contacting onto base-plate due to over pressure load, such as atmospheric pressure or 200-300kPa. Then diaphragm is mechanically deformed due to temperature change caused by cleaning water or devolatilized vapor. Then diaphragm slides on base-plate to cause friction. Since sapphire is highly electrically insulating material, this friction results in charg ing up on contacted surface s of diaphragm and base - plate (Fig.3).

To solve this problem, we have developed a new electrode configuration which discharges static electricity. Also, improved diaphragm and sensor package structure to suppress thermal deformation have been designed (Fig.4). In actual CIP and SIP processes with this improved sensor structure, the zero point shifts were reduced to under 0.1% Full Scale, which is sufficient for this application (Fig.5).

VT-TuP3 Development of Vacuum Equipment Trainer (VET) Systems for Off-site Students*, **Delmer Smith**, N. Louwagie,* Normandale Community College

While the shape of the Internet of Things (IoT) is still evolving for manufacturers and consumers, its arrival is not in doubt. In addition to a strategic research and development plan, businesses must have a workforce with the knowledge and skills to respond to new directions. Normandale Community College in Bloomington, Minnesota, offers a 12-credit Vacuum Technology Certificate that can be completed in a year. The Vacuum and Thin Film Technology program (Part of the Engineering Technology Department) has provided local education in vacuum science for over 20 years at Normandale Community College. Utilizing technology and curriculum developed with the support of the National Science Foundation division of Advanced Technological Education (DUE 1400408 and Due 1700624), the college now has the capability to reach students at multiple locations throughout the United States. Courses are delivered locally or via a telepresence interface to students throughout the United States. Students receive hands-on practice with Vacuum Equipment Trainer (VET) systems. The VET systems are modular. As students progress through courses, capability is added to increase system functionality. Normandale Community College currently has eight copies of the VET systems. This means that students, both onsite and offsite, can complete a Vacuum Technology Certificate in a year. The first remote student certificates were awarded in the spring of 2018. This paper describes the VET system functionality and how it is used to support the technical content students learn in class.

VT-TuP4 Vacuum System of the SuperKEKB Main Ring in the Phase - 2 Commissioning*, **Yusuke Suetsugu**, K. Shibata, T. Ishibashi, M. Shirai, S. Terui, K. Kanazawa, H. Hisamatsu,* KEK, Japan

The SuperKEKB is an electron-positron collider with asymmetric energies in KEK aiming a high luminosity of 8×10^{35} cm^{-2} s^{-1}. The main ring (MR) consists of two rings, that is, a positron ring with an energy of 4 GeV (Low Energy Ring, LER) and an electron ring with 7 GeV (High Energy Ring, HER). Both rings have the same circumference of 3016 m. In the Phase-1 commissioning from February to June 2016, the vacuum system of the MR worked well as a whole at stored beam currents of approximately 1 A. However, several problems were found, and various countermeasures were taken against these during a long shutdown period before starting the Phase-2 commissioning. For example, permanent magnets were placed around the beam pipes to suppress the electron cloud effect (ECE) in the LER. Other than these works, new beam pipes and components were installed in the main ring, such as six beam collimators required for reducing the background noise of the particle detector. The Phase-2 commissioning of the MR started in March and will be continued until July 2018. By the end of April, the total beam dose (integrated beam currents) are approximately 52 Ah and 57 Ah, and the maximum beam currents are 0.32 A and 0.26 A for the LER and HER, respectively. The pressures recovered soon after starting the commissioning to the level at the final stage of Phase-1 commissioning, and further decreased steadily. The pressure rise normalized by a unit beam current are approximately 1×10^{-6} Pa A^{-1} and 2×10^{-7} Pa A^{-1} for the LER and HER, respectively. The beam lifetime of the HER is approximately 500 min. at 0.22 A, and is almost determined by vacuum pressure. On the other hand, that of the LER, approximately 90 min. at 0.3 A, seems to be mainly limited by the Touschek effect rather than the vacuum pressure. The results of various countermeasures taken in the shutdown period and the effect of permanent magnets or solenoids against the ECE will be investigated soon. The performances of the new vacuum components will be also checked at higher beam currents. Reported here will be the status and the major results of the vacuum system of the MR during the Phase-2 commissioning, and problems for the next Phase-3 commissioning.

VT-TuP5 Smart Diagnostics for Dry Vacuum Pumps Running in Semiconductor Processes*, **Wan-Sup Cheung**, J. Lim,* KRISS, Republic of Korea*; N.K. LEE, J.B. LEE, T.J. Park, T.H. Kim,* SK Hynix, Republic of Korea

This paper addresses logical and smart ways of diagnosing the operation conditions of dry vacuum pumps in the semiconductor processes of the SK Hynix company. In the last four years, SK Hynix has been attempting to complete the 'production data logging' systems, including even the collection of the state variables of dry vacuum pumps running in the semiconductor processes. Recent attempts have been added to exploit the logged state variables to diagnose individual dry vacuum pumps operating in the highly tough and risky production processes since their failures always accompany much time and cost. Adaptive parametric modelling

(APM) approaches developed by the KRISS research team were considered to analyze the trend and statistical properties of the logged state variables of vacuum pumps. APM approaches are illustrated to provide merits of dramatic (more than 100 times) data reduction for the construction of 'normal operation condition (NOC)' reference batches from the beginning part of the logged state variables. The singular value decomposition (SVD) is exploited to decompose the selected NOC reference batch matrix into the sore and projection matrices, which are shown to enable the evaluation of two diagnostic indicators for each vacuum pump, the Hotelling's T-squared (T2) value and the sum of squared residuals (Q). Both scalar values T2 and Q are demonstrated to play critical roles in diagnosing the current operation conditions of individual vacuum pumps, more specifically the similarity and difference of the current process state in reference to the NOC reference batches. In this work, several attempts have been carried out to improve the reliability and robustness of the diagnosis of vacuum pumps. The use of vibration measurements was the first selected candidate. Field tests are now in progress. It is expected that field test results are to be illustrated in the presentation of this paper.

VT-TuP6 Commissioning of Vacuum System for Positron Damping Ring for SuperKEKB*, **Kyo Shibata**, Y. Suetsugu, T. Ishibashi, M. Shirai, S. Terui, K. Kanazawa, H. Hisamatsu,* KEK, Japan

The SuperKEKB, which is an upgrade of the KEKB B-factory, is a high-luminosity electron-positron collider. To satisfy the requirements of high beam quality for positron injection into the SuperKEKB, a new damping ring (DR) with a circumference of 135.5 m was constructed in an upgraded injector system. The positron beam extracted from the injector linac with an energy of 1.1 GeV is stored in the DR for more than 40 ms, where the beam emittance is damped. Subsequently, the low-emittance beam is extracted and sent back to the linac to be accelerated to 4 GeV and injected into the SuperKEKB. The maximum stored beam current is 70.8 mA.

The vacuum system of the DR is divided into five sections. Main sections are two arc sections with a length of ~110 m in total. Since there is synchrotron radiation irradiation in the arc sections (critical energy: 0.8-0.9 keV), the average pressure over the entire ring during the beam operation is determined mainly by the pressure of the arc sections. The material of the beam pipes is aluminum alloy. The required beam lifetime determined by the residual gas scattering is longer than 1000 sec and it is expected that the average pressure should be lower than $1x10^{-5}$ Pa. Non-evaporable getter (NEG) pumps are mainly used with auxiliary ion pumps.

The construction of the DR was completed by the end of January 2017. It took more than two weeks from the start of the evacuation process from atmospheric pressure to the end of the activation of NEG pumps because of the small conductance of the beam pipes. The commissioning of the DR commenced in February 2017. When the beam was accumulated for the first time, the pressure exceeded $1x10^{-5}$ Pa with a beam current of ~1.5 mA. However, the pressure decreased quickly below $1x10^{-5}$ Pa. Subsequently, the pressure decreased gradually while the beam current was increased. The maximum stored current reached 11 mA on February 23. The residual gas composition of the pressure with the stored beam was typical of that expected for a vacuum system pumped by NEG pumps. Vacuum scrubbing has progressed smoothly thus far, and a beam lifetime of longer than 1000 sec was obtained with a stored beam current of 8 mA, when the beam dose was 0.7 Ah. The pressure distribution in the beam pipes was calculated using the Molflow+, and it is estimated that the photon stimulated desorption rate for CO at that time was reduced to ~$1x10^{-4}$ molec./photon.

After beam tuning of the DR, the beam injection into the SuperKEKB commenced on March 27. No problems have been identified for the vacuum system to date.

VT-TuP7 Development of a Measurement System for Pressures in Vacuum Regions using an Optical Method*, **Yoshinori Takei**, K. Arai, H. Yoshida, Y. Bitou, S. Telada, T. Kobata,* National Institute of Advanced Industrial Science and Technology (AIST), Japan

Future primary standards of pressure based on optical measurement are being developed in national metrology institutes (NMIs) [1]. Pressure is proportional to refractive index according to both the equation of state of gas and the Lorentz-Lorenz equation. Refractive index can be measured using an optical method based on frequency measurement. Therefore, pressure measurements with a small uncertainty and a wide-range can be achieved. The purpose of this study is developing a pressure measurement system using an optical method for pressure range from 1 Pa to 100 kPa.

A Fabry-Perot interferometer was used for measuring the refractive index of the fulfilled gas in a chamber. The chamber, whose volume was around 7.6 L, was evacuated by a turbo molecular pump and a diaphragm pump. The background pressure and the pressure increase rate after closing the valve were respectively 1×10-3 Pa and 2×10-8 Pa/s, which cause one of uncertainty factors in a low pressure measurement. Pure nitrogen gas was used to fulfill the chamber. The pressure in the chamber was stabilized using a pressure balance from 10 kPa to 100 kPa or by simple accumulating from 1 Pa to 10 kPa. A commercially available external-cavity laser diode (ECLD) was used as frequency-tunable laser light source in order to measure wide-range frequency. The laser frequency was locked to a resonant line of an optical resonator installed in the chamber using the Pound-Drever-Hall (PDH) method. The locked frequency was measured by a beat signal comparing with the reference laser. Aluminum was used as the chamber material to reduce the temperature distribution around the optical resonator. Temperatures of the chamber were measured using several calibrated platinum resistance thermometers and several thermistors. The developed system measured fluctuations in the atmospheric pressure. The evaluated linearity and its uncertainty between refractive index of nitrogen and pressure from 1 Pa to 100 kPa gas are presented.

[1] Jay H. Hendricks et al., ⅩⅪIMEKO,1574-1577, (2015).

VT-TuP8 Study on a Performance of a Sniffer Leak Detector based on EN 14624*, **Kenta Arai**, H. Yoshida,* National Institute of Advanced Industrial Science and Technology (AIST), Japan

Recent years, a portable type sniffer leak detector plays an important role for searching leaks of refrigerant gases from air-coordinators to prevent the global warming. In general, a standard leak, from which a small continuous gas (order of sub-g/year to ten-g/year) flows out, is used to check the performance of the leak detector for a reliable leak test. For the purpose, there are two methods to check the detector. One is that a probe of the detector is moved in front of the standard leak (method A) and the other is that the probe and an exhaust of the standard leak are closed and almost touched (method B). For method A, several standards have been published, i.e., SAE J1627:2011 and its related standards, EN 14624:2012[1], and ANSI/ASHARHE 173-2013. In those standards, the prove velocity and the distance between the probe and the exhaust of the standard leak are given and for EN 14624, 20 mm/s and 3 mm, respectively. For method B, it is explained in a manual of several leak detectors. In this study, we have measured the response of the leak detector against the standard leak by those two methods and compared their results.

A sniffer leak detector in which a pump equipped is tested. For method A, the detector was set on an electric actuator and its probe was set to face an exhaust of a standard leak. The moving velocity of the electric actuator was changed from 5 mm/s to 40 mm/s and the distance between the probe and the standard leak changed from 1 mm to 20 mm. For method B, the velocity was set at 0 mm/s and the distance at 0 mm, respectively. Prior to the tests, the leak rate of the standard leak was calibrated to be 5 g/year by a pressure rise method [2].

Both at the beginning and at the end of the experiments, the response of the leak detector was obtained by method B. Between them, the response of the leak detector was obtained by method A. The detector output obtained by method B between two measurements was stabilized within 10 %. For method A, the detector output was decreased with an increase of both the probe velocity and the distance from the probe to the standard leak. Above both the probe velocity of 20 mm/s and the distance of 10 mm, the detector output was disappeared. The detector output obtained by method B was about 5 times as high as that obtained by method A with the velocity of 20 mm/s and the distance of 3 mm given in EN 14624. Thus, for the properly use of the sniffer leak detector, it is important to clear the conditions for its performance check.

[1] EN 14624:2012 Performance of portable leak detectors and of room monitors for halogenated refrigerants.

[2] Kenta ARAI *et al*., Metrologia **51** (2014) 522.

VT-TuP9 Elimination of Electron-Beam-Induced Carbonaceous Contamination in SEMs and the new RGM 10100 NIST Contamination Testing Artifact*, **Andras Vladar**, K. Purushotham,* National Institute of Standards and Technology (NIST)

Electron and ion beam-induced contamination could be a severe problem of scanning electron microscopes. The carbonaceous material deposited in a dynamic process of adsorption and desorption at the irradiated area can easily disturb imaging and lead to erroneous measurement results. The sources of contamination are usually both the SEM and the sample. Cleaning of the SEM can be carried out with a low-energy (oxygen) plasma cleaning process using commercial devices [1], but without a for-sure-clean sample, it is not possible to determine whether potentially time-consuming cleaning of the SEM is indeed necessary. The RGM 10100 sample with its associated cleaning and evaluation procedures, combined with appropriate cleaning processes offer an effective solution for this problem.

Figure 1 in the supplement shows three levels of SEM cleanliness. The energetic primary electrons can "purge" the center of the sample from carbonaceous contaminant molecules. The center brightening is due to slight oxidation caused by electron irradiation at 40 times the typical dose. With a clean RGM 10100 in a SEM there is no perceivable carbonaceous contamination even after many hours of continuous electron bombardment.

RGM 10100 can be cleaned with acidic piranha solution and can stay clean for months in a semiconductor grade plastic container. The necessary SEM cleaning time, depending on the cleanliness of the SEM, varies from 10 minutes to a couple of days. It is common that the contamination "comes back" after some time. As the SEM gradually becomes free of the source molecules of contamination, the time between needed cleanings could increase to months. RGM 10100 is available from the NIST Office of Reference Materials.

[1] http://evactron.com [http://evactron.com/], http://ibssgroup.com [http://ibssgroup.com/], http://www.piescientific.com [http://www.piescientific.com/]

+Author for correspondence: andras@nist.gov [mailto:andras@nist.gov]

VT-TuP11 Extreme 2 Million Liter/sec Hydrogen Pump Speed Measurements of C-2W Divertors*, **Ernesto Barraza-Valdez**, A. Van Drie,* TAE Technologies

TAE Technologies (TAE) has completed building and commissioning its latest machine, C-2W. C-2W has four 15m3 divertors which require the capability to pump out H2 neutral particles at a rate of 2,000 m3 /s and D2 neutral particles at 1,500 m3 /s. To achieve this, TAE has developed LN2 cooled titanium getter cryobox pumps each with a pump speed of approximately 110 m3 /s and 85 m3 /s for hydrogen and deuterium respectively. These cryoboxes are arrayed in the divertors to achieve the high pump speeds required to keep the plasma conditions optimal during C-2W operations. Experimental pump speed and density measurements using fast ion gauges and residual gas analysis of C2W's four divertors will be presented.

VT-TuP12 KICT Dirty Thermal Vacuum Chamber: design, fabrication, and performance test*, T. Chung,* Korea Institute of Civil Engineering and Building Technology, Republic of Korea*; **Jong Yeon Lim**,* Korea Research Institute of Standards and Science, Republic of Korea*; Y. Yoo, hss. Shin,* Korea Institute of Civil Engineering and Building Technology, Republic of Korea

KICT is designing and building a large thermal vacuum chamber with a simulant regolith test bed inside, named Dirty Thermal Vacuum Chamber (DTVC), capable of performing characteristics evaluation of extraterrestrial exploration drill tools, rovers, and 3D printing tools , as well as investigating the physics and effects of thermal radiation. The DTVC system consists of a D-shape main chamber, ϕ 4 m x 4 m, and a preliminary chamber of ϕ4 m x 2 m enabling of preparing and conditioning samples. The extension of the simulant bed to 6 m in length is also possible with opening the gate valve between two chambers for a rover maneuvering test through both chambers.

To successfully establish the DTVC system, a vacuous, cryogenic, and anhydrous (no water) soil environment, simulation of the lunar and Mars surfaces was first proposed with physics requirements of -190 ^oC ~ 150 ^oC in the pressure range of 10^{-4} mbar ~ 10^{-5} mbar. In order to realize the desired pressure of 5 x 10^{-8} mbar without any components inside, the baseline exhaust system has been equipped with two 2,000 L/s TMPs and two 28,000 L/s cryopumps as well as one 3,000 m^3/h roots pump for roughing and two 300 m^3/h dry pumps for backing. The s amples then can be exposed to thermal radiation on the simulant regolith with UHV background vacuum quality.

Since about 25 tons of simulant regolith are necessary for the bed, the regolith outgassing rate of <5 x 10^{-8} mbar.L/(s.g) is to be strictly regulated to satisfy the physics requirement. For this purpose a smaller scale chamber, called Pilot DTVC, was simultaneously built to realize the outgassing rate of the regolith. An amount of 125 kg of KLS-1, simulant regolith developed by KICT, was pumped down to about 0.1 mbar to remove water content down to <1 x 10^{-4} mbar.L/(s.g). Previous TDS study of the KLS-1 regolith shows the most content of the regolith ingredient adsorbed is water, and the H_2O dose was about 1.2 x 10^5 mbar.hours during nine month exposure to 50 % RH ambient environment at 300 K average.

This presentation will focus on the brief introduction of the vacuum architecture, and design implementations of the DTVC and Pilot DTVD system for both qualitative and quantitative analyses to satisfy all the strict vacuum requirements.

Vacuum Technology Division
Room 203B - Session VT-WeM

Vacuum Technology Developments

Moderators: Jason Carter, Argonne National Laboratory, Yulin Li, Cornell University

8:00am **VT-WeM1 Trace Helium Effects from High Pressure Swing Adsorption Nitrogen Generator on Semiconductor Capital Equipment Manufacturer**, ***William Johnson,*** Applied Materials, Varian Semiconductor Equipment

A High Pressure N2 Pressure Swing Adsorption (HPN PSA) N2 generator was installed to replace the three LN2 bulk storage tanks on the AMAT VSE campus. An Ion Implanter has many multi-stage roots, exhaust lines and turbomolecular pumps that use GN2 as a purge gas. It was found that He introduced by the PSA GN2 generator was of sufficient quantity to raise the background level of many devices under test to the 10^{-6}sccs range, desensitizing the leak testing processes. This work will describe the basic PSA N2 generation process, the methods by which errant He entered the process and the method used to alleviate the excess He.

8:20am **VT-WeM2 Remote Handling Clamps for Flange Connections in Vacuum Service**, ***Ryan McCall,*** Technetics Group

Sealing a vacuum connection remotely in a hostile or radioactive environment can present a difficult challenge for scientists and engineers. This critical application requires easy assembly and disassembly of the flange connection while reducing the number of individual components that must be handled. The QDS or Quick Disconnect System uses a contiguous chain clamp mechanism with two conical flanges and a customized seal that eliminates the need for loose bolts and nuts. In addition, the clamp connection can be fitted to a guide plate that ensures the clamp is always properly aligned. The QDS is of all metal construction and utilizes a spring energized metal seal to provide Helium leak rate performance with little or no permeation or outgassing. Typically, the QDS will require less space than a bolted flange and often requires less torque to create a tight seal.

9:00am **VT-WeM4 Role of Rotor Surface Conditions on Calibration Constant of Spinning Rotor Gauges**, ***Tim Verbovsek,*** Institute of Metals and Technology, Slovenia

In spinning rotor gauges, measured pressure is inversely proportional to the tangential momentum accommodation coefficient (TMAC), a quantity which is affected by interactions between gas molecules and the rotor surface. This is why control over surface conditions of the rotor is extremely important, in order to accurately determine pressure. In our study, surface of rotor spheres were altered by various treatment steps, and changes in the TMAC with respect to the initial condition. For this purpose three different treatment steps were taken, each done over 24 hours. First the rotor sphere was vacuum baked at 300 °C. Next, the rotor sphere was heated again at 300 °C in oxygen at 1e-2 Pa. Finally, it was heated at 300 °C in pure hydrogen at 1e-2 Pa. In order to examine reproducibility of the method, two rotor spheres were simultaneously treated, while one rotor sphere was used as a control. TMAC of the untreated spheres and after each treatment step was determined using primary static expansion calibration system which was developed at Institute of Metals and Technology. Additionally, in order to determine the dependence of TMAC on the gas used, measurements were repeated for six pure gases; helium, methane, neon, nitrogen, argon and krypton. Results obtained showed a relative change in TMAC of up to 7% after heating in oxygen. Furthermore, a strong dependence on the gas used was observed, where largest change of the TMAC was observed for helium and neon.

9:20am **VT-WeM5 Condensation-based Low-grade Heat Powered Dual-chamber Vacuum Technology**, ***Tony Guo,*** New Jersey Institute of Technology

Vacuum processing technologies are widely used in general industrial applications. Most of the current vacuum technologies such as positive displacement pumps, momentum transfer pumps, entrapment pumps and ejectors have to rely on electricity and /or compressor as the prime power source to generate the vacuum. Our technology provides an economic method to generate the vacuum by only using low-grade energy like waste heat, realized by steam condensation mechanism and dual-action piston-cylinder design. Our vacuum system is composed of 4 parts: one actuator-vacuum generation pump, where steam will be filled into and condensed to generate the vacuum environment; one extracting pump, deliver the vacuuming process, driven by the actuator through a linear connected piston; one boiler, to supply the steam to actuator as the prime energy source; an application chamber, connected with the extracting pump, to evaluate the vacuuming performance.

A system design of our technology will be presented and the vacuuming process will be demonstrated by 3D animation. A lab-scale prototype will be demoed via photos and video. The dynamic process of vacuuming for both actuator and driven pump has been mathematic modeled via MATLAB. For model correction, the tricky problems in the process, such as gas leakage and discharge, have been studied via CFD.

Key words: vacuum generation, low grade heat utilize, dynamic process model, CFD

9:40am **VT-WeM6 Vacuum Design and Testing of the ARIEL Radio Frequency Quadrupole Buncher and Cooler (ARQB)**, ***Geoff Hodgson,*** *B. Barquest,* TRIUMF, Canada

The ARQB is an installation on the RIB (Radioactive Ion Beam) beamline in the new ARIEL (Advanced Radioactive IsotopE Laboratory) facility. The ARQB accepts continuous radioactive beam from future proton and electron-excited targets in the basement of ARIEL, and from existing targets in TRIUMF's ISAC facility. The buncher creates 10 to 100 Hz bunches for injection into the EBIS (Electron Beam Ion Source) for charge breeding. The ARQB is held at roughly +60 kV to electrostatically deaccelerate the beam to 150 keV at the injection optics. Between the ARQB and the EBIS, is a pulsed drift tube that reduces the ground potential beam energy to roughly 15 keV.

The cooling and bunching takes place in the core of the buncher in 0.05 mbar and ~80K helium. Helium is supplied through a stepper-controlled variable leak valve. Cooling is provided by a cryocooler thermally bonded to a copper jacket around the quadrupole core. The quadrupole electrodes and support structures create a differential pumping barrier between the core and the body of the ARQB chamber, which is expected to be held at 7e-4 mbar with one turbo pump. The injection and extraction electrodes create a second layer of differential pumping volumes, where pressure is expected to be 5e-5 mbar.

The design is based on the BECOLA beam cooler and buncher at Michigan State University. Vacuum testing is expected to start May 2018, and first stable isotope beam injected in October 2018. First radioactive beam from ISAC is expected in early 2019, and first beam from the ARIEL target in 2021.

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