Vacuum Technology
Room 104C - Session VT-MoA

Gas Dynamics, Simulation and Partial Pressure Analysis

Moderators: Steve Borichevsky, Applied Materials,Varian Semiconductor Equipment, Ted Martinez, SLAC National Accelerator Laboratory

1:40pm **VT-MoA1 Vacuum System Analysis of a Next Generation Light Source with Synrad and MolFlow+***, **Jason Carter**,* Argonne National Laboratory **INVITED**

CERN's SynRad and MolFlow+ vacuum analysis programs continue to be valuable tools for accelerators as vacuum system design challenges increase. The trends for future accelerator vacuum systems, including the APS-Upgrade project, are towards narrower, conductance-limited vacuum chambers which allow for stronger magnets and lower beam impedances but restrict effective pumping and photon shielding. UHV pressure requirements remain fixed or become tighter to increase beam lifetimes and user access which leads to the need for a more thorough vacuum analysis to ensure designs are suitable to many needs. SynRad and MolFlow+ are catered to addressing these challenges and both ease of use and the understanding of their capabilities continues to grow.

SynRad/MolFlow+ users may have been limited in the past by their 3D CAD abilities, however recent improvements to mainstream CAD software such as 'direct modeling' methods have made it easier and faster to build or reverse engineer models with high complexity and precision. This allows for better understanding of complex conductance and quicker iterations on ray tracing schematics. Some examples from the APS will be discussed.

The APS-Upgrade uses SynRad and MolFlow+ extensively for vacuum system calculations and has been digging further into the programs' inputs to build confidence in their predictions. The two programs share a coupling function which predicts dynamic photon stimulated desorption (PSD) outgassing and allows for calculations of dynamic pressures and beam conditioning times. The APS-U is studying this coupling in order to build confidence that their vacuum system design will reach low pressures with reasonable conditioning. Work for this includes studying the sensitivity of the program's inputs and applying the work to existing APS vacuum systems.

2:20pm **VT-MoA3 Simulations of Vacuum Pumping and Beam Conditioning for CHESS-U Vacuum System***, **Yulin Li**, X. Liu,* Cornell Laboratory for Accelerator-Based Sciences and Education*; J.S. Mershon,* The College of Wooster

A major upgrade project (dubbed CHESS-U) is planned to elevate performance of Cornell High Energy Synchrotron Source (CHESS) to the state-of-art 3rd generation light sources. As a critical part of the CHESS-U project, about 80-m of Cornell Electron Storage Ring (CESR) is to be replaced with double-bend achromat (DBA) lattice to significantly reduce electron beam emittance. In this presentation, we will describe the conceptual design of the CHESS-U vacuum system, with emphasis on the vacuum pumping design and considerations. In the DBA lattice, multifunction dipole magnets with complex magnet poles prevent use of distributed ion pumps as in current CESR vacuum system. Instead, non-evaporable getter (NEG) strips are used to provide distributed vacuum pumping in the dipole vacuum chambers, as well as in the undulator vacuum chambers. Discrete pumps are used in the straights at available spaces between quadrupole and steering magnets. A test-particle Monte-Carlo simulation program, MolFlow+, is employed to evaluate pumping performances of the CHESS-U vacuum system in two aspects. First, we demonstrate that the planned vacuum pumping system can achieve and sustain required ultra-high vacuum level in CHESS-U operations. In addition, we will explore beam commissioning processes of the new vacuum chambers, and simulate the saturations of the NEG strips during the commissioning. These simulations will aid continuing design optimization for the CHESS-U vacuum system.

2:40pm **VT-MoA4 MFIG, A New Vacuum Sensor for Yield Enhancement***, N.B. Koster, F. de Graaf, **Michel van Putten**, P.M. Muilwijk, E. Nieuwkoop, O. Kievit, D.J. Maas,* TNO Technical Sciences, Netherlands

This contribution addresses the introduction of a new type of sensor that can disruptively enhance the yield of manufacturing and inspection tools where ultraclean vacuum and control is needed.This includes tools working with high energy photons, ions or electrons.

In 2007, the development of TNO's mass-filtered-ion-gauge (MFIG) started when experts realized that IC manufacturing with EUV needs extremely clean vacuum, while existing sensors are either too slow, expensive or insensitive for real-time monitoring of vacuum cleanliness. The promising results of a "quick-and-clean" test were well-received at the AVS meeting in 2008. Hence TNO incubated the concept in an EU project, in which both instrumentation was improved and application requirements were clarified by interacting with the consortium partners. In 2015 TNO has been awarded a NanoNextNL valorization grant to further mature the instrumentation and prepare for MFIG's market introduction in 2017.

This presentation will update the audience on MFIG's latest performance in laboratory and field tests as well as tell the story how an idea advanced into a product. A short explanation of the technology and new design will be part of the presentation.

3:00pm **VT-MoA5 Dynamic Process Modeling on a Condensation-based Depressurization System***, **Bo Zhang**, G. Guo, C. Zhu, Z. Ji,* New Jersey Institute of Technology

A near-vacuum state in an enclosed chamber can be achieved by vapor condensation on a cooling surface. This near-vacuum chamber can function as a vacuum sink for a sustained operation of application that requires depressurization in an open flow environment. To realize such a sustained operation of gas extraction, a complete cycle of regenerating vacuum in the chamber may consist of multiple stages, including a vapor filling process, the vacuum generation by cooling-controlled condensation, a process of gas extraction from depressurization-required application, and a process of flushing non-condensable gas out of the condensation chamber. A dynamic process model is established to describe the thermodynamic characteristics of the entire cycle. The transient and non-equilibrium characteristics in the condensation-induced vacuum generating process is reasonably captured by our computational fluid dynamics (CFD) model, with modified boundary conditions accounting for the complicated coupling mechanisms of heat and mass transfer during the condensation. The CFD simulations for the entire processes are obtained using FLUENT with user-defined functions. In addition, a pseudo-equilibrium-based parametric model is further developed to evaluate various parametric effects for the system design and optimized operation. The CFD simulation results and parametric modeling predictions are partially validated through our experimental measurements.

4:00pm **VT-MoA8 Vacuum Adventures Encountered Towards a Field-Portable Helium Isotope Detector***, **Gary McMurtry**,* SOEST, University of Hawaii*; J.R. DeLuze,* Fusion Energy Solutions of Hawaii*; D.R. Hilton,* Scripps Institution of Oceanography, UCSD*; J.E. Blessing,* MKS Instruments **INVITED**

The ^{3}He/^{4}He ratio in volcanic emissions and dissolved gas in groundwater is often co-seismic with, and sometimes precursory to, volcanic unrest and earthquake activity. Because of the extremely low abundance of primordial ^{3}He to radiogenic ^{4}He, and difficulties in resolving ^{3}He in the presence of hydrogen isobars such as HD, the measurement of this ratio has so far been confined to the laboratory. A field-portable He isotope instrument must overcome these analytical hurtles and be small, compact, lightweight and low enough in power consumption to deploy in critical locations.

We use two compact mass spectrometers, an MKS ion trap and a frequency-modified MKS quadrupole MS, with a full-range pressure gauge and waste pumps based upon noble diode ion or turbo-rough pumping. These are coupled to a high-purity quartz glass port that is heated under high vacuum. Gas samples can be separated from waters or directly analyzed by pumped circulation through a sample chamber. We monitor vacuum quality with the ion trap and use the quadrupole MS to obtain sensitive determination of hydrogen and helium isotopes. Two methods of isobaric separation are utilized: a statistical mass-2 vs. mass-3 regression intercept, and an adjusted (threshold) ionization mass spectrometry (AIMS) technique. Comparison of these two independent methods for 44 data pairs in a "blind collection" after heat ramps to a predetermined maximum temperature are completed yields a significant correlation (r = 0.89).

Results on laboratory air are within a factor of 2 of the accepted ratio of 1.40 E-06 (R_a). We can obtain the exact air ratio (R/R_a = 1.0) if we continuously monitor the MS scans during the heat ramps, allowing for differences in the diffusion rates of ^{3}He and ^{4}He. With an established power level, keeping to a constant scan time allows air ^{3}He/^{4}He ratios to be obtained to within 0.1 R/R_a. Adventures in vacuum technology encountered along this developmental pathway include the discovery of temperature-dependent differential diffusion of He isotopes in heated glass, quantum tunneling of ^{3}He, amazing enrichments of ^{3}He from air, and potential industrial applications of a mass-selective fluid bandpass filter.

4:40pm **VT-MoA10 Use Of A Novel Sensor Using Remote Plasma Emission Spectroscopy For Monitoring And Control Of Vacuum Processes***, **Joseph Brindley**, T. Williams, B. Daniel, V. Bellido-Gonzalez,* Gencoa Limited, UK*; F. Papa,* Gencoa USA

Plasma emission monitoring (PEM) has been used for a number of years to either monitor the condition of or actively control vacuum plasma processes. This approach has many advantages such as fast response time, monotonic sensor behaviour and the ability to control uniformity by monitoring different areas of the process. There are however some disadvantages, e.g. there is required a clear line of sight to the plasma that can be obscured by substrate movement, the PEM sensor can become coated by the deposited material and, of course, it can be only be used when the process itself generates a plasma.

A new type of remote plasma generator has been developed, which when combined with advances in miniature spectrometers can be used to perform optical plasma spectroscopy over a wide pressure range of 1 mBar to 1E-6 mBar. Presented are a number of examples of its use as an intelligent pressure gauge (penning pressure measurement in conjunction with plasma spectroscopy), etching process monitoring, vacuum quality monitoring, and reactive deposition control.

A novel, pulsed power, method of enhancing the sputter effect inside the sensor has also been developed. This allows for use of the sputtered cathode emission as a secondary, indirect indicator of the condition of the vacuum and state of the process, enabling monitoring and control of processes otherwise not possible via conventional plasma spectroscopy. Furthermore, this sputter mode of operation has the effect of “cleaning” the sensor’s cathode, allowing for extended operation with processes that would otherwise damage the sensor.

5:00pm **VT-MoA11 Calibration of Quadrupole Mass Spectrometers with a Molecular Flow Gas Source***, **Robert Ellefson**,* REVac Consulting

Insitu calibration of quadrupole mass spectrometers (QMS) after initial calibration is not regularly done. If no calibration gas is available, it requires removal of the QMS from the vacuum system to a calibration test stand where gases and a reference gauge is available. Providing a low-cost calibration gas source dedicated to the QMS enables local calibration checks to qualify the performance of the QMS. This paper describes a molecular flow calibration device that presents known flow rates of gas species to the ion source. The known flow rate produces partial pressures that can be measured with an ion gauge or calculated knowing the conductance of the QMS molecular flow pumping system. The molecular flow in and molecular flow out preserves the gas composition of even a flowing gas mixture prepared in a volume from attached gas sources. The device prepares a known volume of gas (300 cm^3) at low pressure (P_{CDG} <10 Torr) to assure molecular flow through an orifice with flow proportional to $C_{N2}(28/M)^{1/2}$ for each species. With this small volume, the partial pressure depletes for each species in a predictable manner related to the mass of the gas species. By noting the time elapsed since the valve to the molecular leak is opened, the time-dependent partial flow rate, $q_i(t)$ of each species is known and a sensitivity S_i for that species can be calculated as $I_i(t)/[q_i(t)/C_{out}]$ from the measured ion current, $I_i(t)$. Data showing sensitivity of a QMS as a function of ion source pressures provides information to show stability of sensitivity over a range of pressures. The ability to introduce pure gases and blend or introduce gas mixtures gives conditions to measure QMS accuracy for mixture analysis. The simplicity of the system lends itself to automation of the sensitivity measurement process as the basis for archiving S_i values over extended periods of time as quality assurance performance data.

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