## Vacuum Technology
## Room: Central Hall - Session VT-TuP

### Vacuum Technology Poster Session and Student-built Vacuum System Poster Competition

**VT-TuP2 Pressure Effects in Autoresonant Ion Trap Mass Spectrometers (ARTMS)**, ***P. Acomb***, *G.A. Brucker, J. Rathbone*, Brooks Automation, Inc., Granville-Phillips Products

Autoresonant ion trap mass spectrometers (ARTMS) are gaining rapid acceptance in the vacuum market both as residual gas analyzers as well as process gas monitors. During the course of routine analysis, most ARTMS instruments are required to provide accurate analytical results over a wide range of total pressures and gas compositions. Since the performance of ion traps is pressure dependent, it is important to understand how total pressure impacts gas analysis results and to understand the methodologies available to adjust operational parameters based on present pressure conditions. Important performance specifications that are affected by total pressure conditions include baseline offset, resolving power, sensitivity, dynamic range and fragmentation patterns. The pressure-related physical phenomena presently known to impact ion trap performance are identified and associated to the specific pressure ranges at which they are relevant. The ion trap operational parameters available to the user to optimize trap performance as a function of total pressure are explained. Vacuum practitioners presently using ARTMS instruments for gas analysis can quickly, easily and dynamically apply the concepts introduced in this poster to optimize the performance of their gas monitors as a function of total pressure conditions.

**VT-TuP3 Investigation of a Method for Measurement of Water Vapor Coverage on Technical Surfaces**, ***M. Sefa****, Laboratory Lotric d.o.o., Slovenia, *J. Šetina*, Institute of Metals and Technology, Slovenia

Coverage of a surface by a gas can be determined by desorption method where amount of gas is calculated by integrating the released flux. This can be measured fairly straight forward in a case when desorbed gas don't re-adsorb on surfaces of measurement chamber. Then mass conservation laws are applicable and flux can be determined by measurement of a pressure drop across the orifice of known conductance. In the case of adsorbing gas, like water vapor, the flux through the orifice is not equal to the flux coming from the sample, because significant amount can be re-adsorbed by the surfaces of measurement chamber.To determine surface coverage of water vapor on technical surfaces we have developed a special procedure where adsorption and desorption on the surfaces of measurement chamber can be taken into account. The sample is exposed to water vapor at known pressure (in the range from 0.1 kPa to 2.5 kPa) in a preparation chamber. After equilibration of surface coverage with the gas phase, the preparation chamber is opened to a measurement chamber which is continuously pumped through a known conductance. In the case of water vapor the shape of pressure burst is significantly influenced in the beginning by adsorption and later by desorption in the measurement chamber. However, the time integral of pressure burst over sufficiently long period represents the amount of water vapor coming from preparation chamber. This amount is sum of gas phase, desorbed amount from surfaces of preparation chamber and desorbed amount from the sample surface.In the presentation the measurement system will be described and examples of water coverage measurements on surfaces of Cu, Ni, Al and stainless steel will be given.

**VT-TuP4 Flow of a Binary Gas Mixture Into Vacuum: Experiment, Models, Simulation**, ***M. Vukovic***, Tokyo Electron, US Holdings, *R. Johnsen*, University of Pittsburgh

The flow of gas through a small orifice into vacuum was experimentally analyzed by Fujimoto & Usami (1984). They developed a formula to describe the flow conductance as function of the orifice rarefaction parameter. R. Johnsen and B. K. Chatterjee (2011) measured the flow rate of a minority gas ($H_2$, $O_2$, $CO_2$) in a carrier gas (He, Ar) using the University of Pittsburgh ion drift tube experiment. Using the hard-sphere collision potential they also developed a heuristic formula to model the minority gas conductance rate as function of the carrier gas rarefaction parameter. In this work we generalize their formula to arbitrary intermolecular potentials. We also develop an alternative model and formula that successfully describes the data. We will describe the ion-drift tube experiment, discuss the two models and formulas. We will also present results of DSMC simulations using the Graem Bird's DS2V code (http://www.gab.com.au).

T. Fujimoto and M. Usami, ASME Trans. J. Fluids Eng. 106, 367 (1984).

R. Johnsen and B. K. Chatterjee J. Vac. Sci. Technol. A 29, 011002-1 (2011)

**VT-TuP5 A Calibration System for Helium Leak Calibrator**, ***Y.-W. Lin***, *C.-C. Hung, C.-P. Lin, C.-N. Hsiao, F.-Z. Chen*, Instrument Technology Research Center, Taiwan

A calibration system for helium leak calibrator was developed, and the measurement uncertainty associated with the system. The design of the system took into consideration of influencing factors that include reference standard leak calibrator (ref.), leak calibrator under testing (dut.), vacuum chamber, He leak detector, I/O interface, and computer control. The system operates referring the standard test method for calibration of helium leak detectors by use of secondary standards (ASTM F78). This reference standard leak calibrator (ref.) was calibrated near 23℃ by comparison with Flowmeter of the national institute standards and technology (NIST) primary Leak Standard, using a combination of direct flow and upper to lower chamber flow division technique. The present estimate of the total uncertainty in the measured leak rate of this artifact at 23℃ at the time of test is 5.2%. This includes a systematic uncertainty of 2.0% in Flowmeter of the NIST primary Leak standard and 3.2% random errors in the measured leak rate of this artifact. The errors represent three standard deviations. In order to optimize the overall accuracy in the use of this artifact, it should be stored with any shutoff valve open (a dust cover can be used to protect the vacuum port). The leak artifact should be stored at the temperature at which it will be used for at least 24 hours and pumped for least 3 hours prior to use. Sufficient time should also be allowed for the system on which the leak artifact is to be used to come to equilibrium with 0 the environment. The present research has demonstrated the high stability of the calibration system for helium leak calibrator, and its capabilities of conducting calibration for helium leak calibrator with great efficacy.

**VT-TuP6 Status of the FRIB Vacuum System Design**, ***P. Gibson***, *B. Durickovic, P. Guetschow*, FRIB, *R. Kersevan*, CERN, *M. Leitner, D. Leitner, L. Lingy, F. Marti, G. Morgan*, FRIB, *D. Sanderson*, NSCL, *M. Schein, M. Shuptar*, FRIB

Facility for Rare Isotope Beams (FRIB), Michigan State University, East Lansing, MI 48824 USA

The Facility for Rare Isotope Beams (FRIB), a new national user facility for nuclear science funded by the U.S. Department of Energy - Office of Science and operated by Michigan State University (MSU), is currently being designed and established to provide intense beams of rare isotopes. It will enable scientists to make discoveries about the properties of these rare isotopes in order to better understand the physics of nuclei, nuclear astrophysics, fundamental interactions, and applications for society. The FRIB driver linac accelerates ions as heavy as 238U to energies beyond 200 MeV/u at beam powers up to 400 kW. Machine maintainability requires an average uncontrolled beam loss below 1 W/m. Baseline vacuum levels have been established to support this requirement and pumping systems have been defined. Vacuum levels in high loss regions such as beam stripping and collimation areas have also been evaluated and pumping systems defined. Value engineering has been applied to minimize the number of different vacuum pump and beam box types and sizes where possible. The pumpdown and operating vacuum of large, complex Target System chambers has been analyzed and pumping systems defined. This talk reports on the status of the FRIB vacuum system design.

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**VT-TuP7 PLS-II Vacuum System Commissioning**, ***C.D. Park***, *S. Chung, T. Ha, C.K. Kim, M.S. Hong, H.C. Kwon, Y.D. Joo*, Pohang University of Science and Technology, Republic of Korea

è Pohang Light Source's upgraded machine (PLS-II) has been on commissioning stage since the installation completed in June 2011. PLS-II storage ring vacuum system is designed to maintain a base pressure in the low $10^{-9}$ Torr region for the beam-gas scattering lifetime in excess of 20 hours, and the vacuum components, especially photon absorbers, are designed to endure 3 GeV, 400 mA beam operation. Several issues regarding the vacuum system will be presented, such as BPM stability from mechanical or electrical point of view, vacuum chamber displacement, photon absorbers, and vacuum related events during the commissioning.

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**VT-TuP8 An Application of Electron Stimulated Desorption Technique to Measure the Isotherm and the Mean Residence Time of Hydrogen Physisorbed on a Metal Surface**, ***H. Shimizu****, *N. Inose, T. Miura, I. Arakawa*, Gakushuin University, Japan

Physisorption characteristics of hydrogen on a cold metal surface were investigated in the range of a monolayer for the purpose of establishing a cryopumping technique in extremely high vacuum. Electron stimulated desorption (ESD) technique was applied to measure the adsorption density of hydrogen molecules. Hydrogen was adsorbed on a copper substrate at 3 - 4.2 K of temperature and was irradiated with a pulsed electron beam of a few hundreds nsec pulse width and 45 - 170 eV electron energy. ESD ions, H+, H2+, and H3+, were mass-separated by a time-of-flight measurement with the acceleration bias of 100 V. In submonolayer range, the signal intensity of ESD H+ was a useful measure for the amount of physisorbed H2 and the monolayer completion of H2, which was accompanied by two dimensional phase condensation, was detected by the rapid rise of H+ intensity followed by its saturation.

An adsorption isotherm was obtained as the ESD signal intensities of H+ as a function of the hydrogen pressure, which was gradually increased from 10-9 to 10-4 Pa so as to keep adsorption equilibrium. The observable lower end of the isotherm was 1x10-8 Pa of the equilibrium pressure and 0.001 of H2 coverage, which was limited by back ground signal of H+ originated from water or hydrocarbons adsorbed on the metal substrate. Though the validity of the assumption that the H+ desorption yields is proportional to the H2 physisorption density should be further examined, the H+ yield curve between 1x10-8 and 2x10-6 Pa represents the adsorption isotherm between 1 and 0.001 of H2 coverage.

Two transient methods were applied to measure the mean residence time, $\tau$, of physisorbed H2. A time development of ESD H+ intensity was monitored after either (1) a stepwise H2 pressure rise to a certain fixed value or (2) YAG laser cleaning of the substrate under a constant H2 pressure. In either case, the time constant of the increase of ESD H+ intensity is the direct measure of the mean residence time of H2. Typical value of $\tau$ obtained by the method (1) at nearly monolayer and at 4.2 K was 62±3 sec, which corresponds to 1.19 kJ/mol of the adsorption energy on assumption of $\tau 0 = 10\text{-}13$ sec.

The adsorpion isotherms and the close examinations of the dependency of $\tau$ on the temperature and the coverage can reveal the fundamental properties of the hydrogen physisorption in low pressure and low coverage range.

**VT-TuP9 Radiative Heating from a Magnetically Levitated Turbo Pump**, ***H. Bull†,*** CNSE, *A. Antohe,* SEMATECH, *G. Kane, G. Denbeaux*, CNSE

Thermal management within vacuum chambers is sometimes a concern for temperature dependent vacuum processes. We describe a phenomenon in which using a magnetically levitated turbo molecular pump causes internal heating of a chamber. We measured the heat load based on a thermocouple inside the vacuum chamber, exposed line of sight to the magnetically levitated turbo pump. The measurements showed a temperature change of more than 10C based on the heat load from the pump. We also measured the effect of any heating due to gas flows and found that the dominant effect was not related to gas flows and was likely simply radiative heat transfer from the pump. The source of the heating of the pump is likely Ohmic heating due to eddy currents in the turbo pump.

**VT-TuP10 Novel Light Sputter Ion Pump with Neodymium Iron Boron Magnets and the Low Outgassing Body**, ***T. Ha****, S. Chung, C.D. Park*, Pohang University of Science and Technology, Republic of Korea

A light sputter ion pump for ultra high vacuum was fabricated using 5-mm-thick neodymium iron boron (NdFeB) magnets. The weight of the pump was reduced by 30%, compared with conventional sputter ion pumps using ferrite magnets. For the sake of uniformity of magnetic field, three pieces of magnet were combined into a 100 mm x 150 mm magnet block for the 30 l/s pumping element. The authors coped with the low working temperature (below 150oC) of the NdFeB magnets by forming a pure and dense chromium oxide film on the inner surface of the stainless steel pump body. With this vacuum thermal oxidation, the outgassing rate of water and hydrogen was considerably reduced so that a high temperature bakeout was unnecessary. The ultimate pressure achieved by the developed pump was much lower than 10-10 mbar even with a low bakeout temperature at 100oC.

**VT-TuP11 Expanded Capability of Measuring Pumping Speed of Dry Vacuum Pumps Using Calibrated Sonic Nozzles**, ***W.S. Cheung****, S.H. Nam, W.J. Kim, J.Y. Lim*, KRISS, Korea

This paper addresses technical issues in expanding the capability of measuring the pumping speed of dry vacuum pumps using a built-up block of multiple calibrated sonic nozzles. The first challenging issue comes from the technical limit that their calibration results available from the flow measurement standard laboratories do not fully cover the low vacuum measurement range of 10 ~ 1000 mbar although the use of sonic nozzles for precision measurement of gas flow has been well established in national metrology institutes. In order to tackle the first technical issue, the constant volume flow measurement method dedicated for the vacuum range of 10 ~ 1000 mbar is exploited to calibrate the discharge coefficient multiplied by the cross-section area of each sonic nozzle used in the built-up block of sonic nozzles. On the other hand, the discharge coefficient multiplied by the cross-section area of each sonic nozzle in the upstream pressure range of 2 ~ 10 bar is calibrated in the gas flow standard laboratory. These combined calibration methods are illustrated to enable each sonic nozzle to cover the three decade measureable range 10 mbar ~ 10 bar.The second technical issue comes from a logical way of stacking multiple sonic nozzles to expand the capability of measuring the pumping speed of dry vacuum pumps. A target value of the upper limit of pumping speed in this work was selected to be 4,500 $m^3$/h as the Korean flat display manufacturers requested to KRISS. On the onset of this work, sonic nozzles of 5 mm throat diameter were machined to fulfill the upper limit pumping speed by stacking three or four nozzles in the built-up block. Of course, small sized nozzles (0.1, 0.16, 0.5, and 1.0 mm throat diameter) were also machined in this work to cover the low and mid range of the throughput of 0.1 ~ 100 mbar-l/s. A prototype of the built-up block with the capacity of installing six sonic nozzles simultaneously is under test. Its design throughput was to be about 125,000 mbar-l/s. This prototype is expected to provide a possible 'on-line pumping speed tester' with the capability of 4,500 $m^3$/h or more, applicable not only to the on-site flat display processes but also to the semiconductor processes.

**VT-TuP12 Study on Improvement of Predictive Maintenance of Dry Vacuum Pumps Using an Adaptive Parametric Model of State Variables**, ***S.H. Nam†,*** *W.J. Kim, J.Y. Lim, W.S. Cheung*, KRISS, Korea

This paper introduces unique statistical features extracted from the measured state variables of dry vacuum pumps in the semiconductor processes. They were found to have three distinctive means and overlapped distributions, not a single normal distribution. More specifically, two distinctive distributions near the upper and lower asymptotic bounds are obviously observed from the gas-loaded states of the vacuum pump and the third one from the idle states. These observations have provided new motivations of not only separating the pump operation state into the gas-loaded and idle states but also modeling the upper and lower bounds as a separated distribution. A linear adaptive parametric model (APM) is proposed such that their linear trends of each state variable are shown to be mapped onto their model parameters. Those estimated model parameters are used to construct the batch data obtained after each process. The APM-based batches are also exploited to construct the batches under the normal operating conditions (NOC) such that the major eigenvectors of the NOC batches are used to diagnose the current process batch data. It should be noted that the APM-based batch provides a dramatic reduction of memory usage and computation time (for example, 1~2 % memory usage and 10 times faster computation time) in comparison to the conventional dynamic-time wrapping methods. The feasibility of the proposed APM for the predictive maintenance of dry vacuum pumps is demonstrated to be successful by illustrating test results obtained from the six dry vacuum pumps.

This paper proposes the use of two statistics, the Hostelling's $T^2$ and the sum of squared residuals, in order to improve the reliability of the predictive maintenance and self-diagnostics of vacuum pumps. The first one is exploited to examine what amount of similarity the current process batch has in reference to the normal operation conditions and, furthermore, the second is to examine what contribution the current process batch provides to the noise space. The two proposed statistics are examined to quantitatively analyze the reliability and improvement of the predictive maintenance and self-diagnostics developed in this work.

**VT-TuP13 Modeling of Energy Consumption Characteristics of Low Vacuum Dry Pumps**, ***W.J. Kim†,*** *S.H. Nam, W.S. Cheung,* KRISS, Republic of Korea, *M.K. Ko,* Konyang University, Republic of Korea, *J.Y. Lim*, KRISS, Republic of Korea

This presentation addresses measurements related to energy, utilities and materials usage on dry vacuum pumps. A particular course of action was taken into account with regard to the measurement into equivalent energy suggested by SEMI Document 4399.

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Recent SEMATECH and SEMI studies showed that 50 ~ 60 % of equipment power is used for vacuum pumps. Currently vacuum pump suppliers have responded by reducing power consumption and cooling water flow requirement in energy consumption at the component level. Actual process studies showed that for some processes, the energy consumption level did not change significantly during idle and processing operation modes. However, specified studies in experimental scale to characterize the energy consumption pattern have not been reported yet.

We have performed a simulation study to characterize energy consumption pattern in the idle and process modes.

The pressure range of about 0.1 to 50 mbar for 7 minutes was assigned to the simulated process mode, meanwhile the pressure of <0.1 mbar for 3 minutes to the idle mode. The integrated characteristics evaluation system for dry vacuum pumps has been utilized to gather the dry pump characteristics data for the simulation. Roots, claw, classical screw, and multi-stage type vacuum pumps supplied from the manufacturers have been evaluated using the evaluation system in terms of ultimate pressure, pumping speed, power consumption, vibration, sound power as well as nitrogen purge, cooling water rate from the single pump monitoring system in time-synchronized mode. This study includes the application of the SEMI S23-0705 standards – A Guide for Conservation of Energy, Utilities and Materials Used by Semiconductor Manufacturing Equipment.

The estimated power consumption per pump per year was ranged from 10 to 30 MWh and 15 to 50 MWh for 600 ~ 1200 $m^3$/h dry pumps in idle and processing modes, respectively. The utility energy consumption was also ranged from 5 to 10 MWh and 10 to 30 MWh, respectively. More specific energy consumption patterns with respect to the pressure are also presented.

In this work we suggest that the correlation mechanism dependant on the actual process lines should be carefully analyzed and furthermore understood, for example, the relationship between cooling water flow rate and temperature variation during processes. Simple characteristic modeling of energy consumption patterns dependent on dry and roots pump types are also discussed.

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**VT-TuP14 Dry Vacuum Pump**, ***J.Y. Lim***, *W.J. Kim, S.H. Nam,* KRISS, Republic of Korea, *S.Y. In,* Korea Atomic Energy Research Institute, Republic of Korea, *D.Y. Koh,* Korea Institute of Machinery and Materials, Republic of Korea, *W.S. Cheung*, KRISS, Republic of Korea

Advanced industrial processes such as semiconductor and display manufacturing continuously requires the precise measurement and control of the low mass flow of gases. The requirements include very low mass flows of less than 1sccm or 2 x $10^{-2}$ mbar·l/s. However, the lower limit of traceable mass flow ranges are not well defined even in the sophisticated NMIs (National Measurement Institute). Since the primary standard for mass flow (kg/s) must provide a method for deriving mass flow directly from its base units, almost all mass flow systems heavily rely on the gravimetric method. Current technical measurement limit of mass flow rate with the gravimetric method is 2 x $10^{-8}$ kg/s ($10^{-2}$ ~ $10^{-3}$ mbar·l/s).

Ensuring mass flow traceability ability in the range of greater than $10^2$ mbar · l/s with the Korea Research Institute of Standards and Science (KRISS) standard system, an attempt to trace the lower mass flows down to $10^{-4}$ mbar · l/s has been undertaken with constant volume flow meters (CVFM), sonic nozzle systems, and orifice method. In this work we briefly demonstrate the systematic attempt for the completion of the traceability chain from $10^4$ to $10^{-4}$ mbar · l/s.

Meanwhile the most effective way of ensuring completion of the traceability chain is, to say, characteristics monitoring of the mechanical rotary machines such as vacuum pumps used in advanced industry since these pumps have normally clean and smooth pumping capabilities during their stable operation.

Utilizing the combined mass flow systems mentioned above, the measurement of pumping speed has been performed with the throughput and orifice methods dependent on the mass flow regions. However, in the HV range of the molecular flow region, the high uncertainties of the gauges, mass flow rates, and conductance are too critical to precisely accumulate reliable data. In order to solve the uncertainty problems of pumping speeds in the HV range, we introduced an SRG with 1 % accuracy and CVFMs to measure the finite mass flow rates down to $10^{-3}$ mbar · l/s with 3 % uncertainty for the throughput method. In this way we have performed the measurement of pumping speed down to less than $10^{-6}$ mbar with an uncertainty of 6 %. In this article we suggest that the CVFM has an ability to measure the conductance of the orifice experimentally with flowing the known mass through the orifice chambers, so that we may overcome the discontinuity problem encountering during introducing two measurement methods in one pumping speed evaluation sequence.

**VT-TuP16 An Evaluation of the Outgassing Rates of Stainless Steel Vacuum Chambers Subjected to Different Heat Treatments and Coatings**, ***M.A. Mamun****, Old Dominion University, *P.A. Adderley, M.L. Stutzman, M. Poelker*, Thomas Jefferson National Accelerator Facility

We present the results of an extensive study of the outgassing rates of four nominally identical stainless steel vacuum chambers. Chambers were either heat treated (semi-vacuum) at 400°C, coated with TiN, coated with $SiO_2$ (SilcoGuard™), or heat treated then coated with $SiO_2$. The outgassing rates were measured at a variety of room temperatures to determine the temperature dependence and compare to theoretical models of diffusion- or recombination-limited outgassing. In addition, outgassing rates were evaluated following venting to air and re-baking at 150°C and 250°C to simulate the impact of putting a chamber into service.

**VT-TuP17 A Quantitate Examination of Venting Trapped Volumes Due to Fasteners**, ***C. Bryson***, Apparati Inc.

**Why we care**

The need addressed here is the problem of pumping out internal volumes in vacuum systems that may be blocked by construction methods. Vented screws are a common approach to reducing this problem. This discussion will focus on evaluating the magnitude of the problem and various solutions. Calculations on conductance for vented and unvented screws and some accessories will be given. These conductance values will be used to model different common configurations that have different amounts of trapped volumes.

The conclusions are clear; vented screws and venting accessories are essential.

**Summary**

The direct measurements on un-vented screws were flawed because the screws tended to seal to varying degrees by the head of the screw. A use of a vented washer helped but the leak rate was hard to measure because of variability. Direct comparison to calculations is difficult because the tolerances in screw fasteners. There are large differences in conductance given the dimensions of the clearance between the screw and the mating fixtures. Calculating the ranges of conductance that can be expected for unvented screws, venting channels and internal volumes were done for different applications in vacuum systems. Ranges in excess of a factor >15 were encountered for a single divinition of a particular fastener. Some comparisons with data shed insight to the nature of the task.

The result is a "set of ground rules for design" based on the quantitative information derived. Examples are given for different designs with different parameters in terms of vacuum performance.

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