Monday Morning, November 9, 2009

Vacuum Technology
Room: C1 - Session VT-MoM

Vacuum Contamination and Pumping
Moderator: M. Wüest, INFICON Ltd., Liechtenstein

8:20am **VT-MoM1 Silicon-based Surface Treatments for Improved Vacuum System Throughput, Inertness, and Corrosion Resistance**, ***D.A. Smith***, SilcoTek Corporation, *B.R.F. Kendall*, Elvac Associates **INVITED**

Tests of stainless steel components with a silicon-based deposition have shown significantly lower outgassing rates when compared with stainless steel components without a surface deposition. A variety of experiments illustrate the beneficial aspects of a silicon-based deposition in process vacuum systems. For outgassing performance, experimentation was developed for comparing otherwise identical samples having various surface treatments and/or coating types. The samples are heated and cooled in turn while the outgassing rates are recorded at temperatures up to 250 degrees C. For inertness performance, chromatographic and gravimetric data will illustrate the lack of adsorptive and catalytic behavior of a substrate with a silicon-based deposition. These depositions can also serve as an anti-corrosive barrier for processes hindered by frequent maintenance after exposure to environments that are corrosive to base materials. ASTM corrosion testing methods will be presented and discussed to better understand the anti-corrosive nature of these deposited surfaces. Process vacuum systems requiring rapid pumpdown, minimal metallic substrate exposure and contamination, and/or reduced corrosive attack may benefit from the characteristics capable with silicon diffusion coatings.

9:00am **VT-MoM3 Modeling Decontamination of Vacuum Chambers by Downstream Plasma Cleaning**, ***C.G. Morgan***, *R. Vane*, XEI Scientific, Inc.

Downstream plasma cleaning is an effective means for removing carbon contamination from vacuum chambers. The downstream plasma cleaning device is mounted on an unoccupied port on a vacuum chamber. When in use, the device creates oxygen radicals using a small leak of oxygen containing gas and a low power (5-20 W) radio frequency (RF) plasma. The oxygen radicals then flow through the vacuum chamber, ashing hydrocarbons. The rate of carbon decontamination has been shown to be dependent on a number of factors: RF power level, chamber pressure and geometry, distance between radical source and contamination, speed of the pumping system, and type of oxygen containing gas used. Decontamination rates can be accurately estimated if chemical models of both the oxygen radical reactions within the chamber and on the contaminant surface can be developed. These models are validated by physical data from two experiments varying the parameters listed above.

Data is presented from two experiments with oxygen radicals. Both experiments use a quartz crystal microbalance (QCM). In the first, a silver-coated QCM is placed in the vacuum chamber and subjected to the plasma cleaning process. Oxygen radicals will incorporate themselves into the QCM and increase its mass. The flux of oxygen radicals impinging on the QCM surface can be calculated using the Deal-Grove model of surface oxidation. By locating the silver-coated QCM in different locations of a vacuum chamber, a map of oxygen radical concentrations as a function of distance from the plasma can be made. In the second, a gold-coated QCM is contaminated with hydrocarbons. Test contamination is achieved by heating a small amount of hydrocarbon in a vacuum chamber and allowing the evaporation to recondense on the gold-coated QCM. The cleaning process is then initiated and an experimental trace showing mass loss from the gold-coated QCM as a function of cleaning time is obtained.

A chemical box model which assumes that once the plasma is lit there is a steady-state oxygen radical concentration within each box can be compared to the data from the silver-coated QCM experiments. The chemistry within each box is obtained by using a standard database of gas phase reaction rates. The second model focuses on the gas surface chemistry of decontamination. The results of the second model are compared with the data from the mass loss traces of the gold-coated QCMs. The combination of both models will provide a means to estimate rates of downstream plasma cleaning for any contaminated vacuum system.

9:20am **VT-MoM4 Methods for Measuring Outgassing for Qualification of Materials, Components and Systems**, ***N.B. Koster***, *R. Koops, E. van Zeijl*, TNO Science and Industry, Netherlands

Presently cleanliness requirements for vacuum systems in use for Extreme Ultra Violet Lithography (EUVL) are beyond what with standard procedures can be achieved. Especially the constraint that the system cannot be baked after assembly, whilst cleanliness better than UHV is needed, requires special measures with respect to manufacturing and qualification. Because of the constraint of not being able to bake the system we refer to this type of vacuum as Ultra Clean Vacuum (UCV). This presentation will focus on outgassing measurement methods for qualification of materials and components. Traditionally only the total outgassing is measured and reported, as can be found in many vacuum handbooks. In the case of EUVL, or other systems with high energetic particles, we distinguish several species of interest, like water and hydrocarbons and provide numbers for outgassing of these species as measured with a RGA. These measurements enable engineers to calculate total pressure and cleanliness of a system under design. Results of these measurements will be shown including a way of representing the data in a clear format. We also will show results of a new method for measuring hydrocarbon outgassing with the aid of a RGA when the outgassing levels are at the lower detection limit of the RGA.

9:40am **VT-MoM5 Outgassing Characterization of Elastomeric Seals Used in Semiconductor Wafer Processing**, ***M. Heller***, *S. Sogo, J. Chen, J. Legare*, DuPont Performance Elastomers L.L.C.

Many integrated circuit manufacturing processes operate in high or ultra high vacuum (UHV) environments. It is important that vacuum levels are maintained within specified limits to insure optimum process efficiency. While specification of an appropriate size vacuum pump for the system can insure that overall vacuum levels are maintained, outgassing from sealing materials can interfere in the process by changing the composition and morphology of the deposited layer. For instance, outgassing contaminants absorbed by the exposed substrate during the initial steps of the deposition process can induce undesired interactions at the interface level and consequently affect the grown film as well as the overall process. Therefore, it is important to understand the outgassing characteristics of elastomeric seal materials in order to select the appropriate material for a given application.

A methodology has been developed using a residual gas analyzer to measure the outgassing properties of elastomers. Results indicate that outgassing typically takes place in two stages. With some minor exceptions, the first stage involves the evolution of atmospheric gasses and absorbed moisture (i.e. nitrogen, water, oxygen, and carbon dioxide). The second stage and possibly of greater interest involves the evolution of gasses related to the thermal stability and decomposition of the material in question.

This paper compares the outgassing characteristics of three different types of elastomeric seals (perfluoroelastomers, fluorelastomers and silicones) typically used in semiconductor wafer processing. Data on outgassing rate as a function of time and temperature, and classification of gas species evolved for products in each material class are presented. While perfluoroelastomers offer the lowest outgassing rate at elevated temperatures, there can be some performance variation within this material class. The relationship between outgassing performance and elastomer formulation will also be discussed.

10:00am **VT-MoM6 Permeation Through Elastomers: Comparison of Viton® and Chemraz® 653 O-rings under Controlled Compression and Temperature**, ***N.T. Peacock***, MKS Instruments, HPS Products

Many types of elastomers are available and used for demountable seals in vacuum service. One important consideration in the selection of the elastomer material is the permeation rate. The permeation rate for gasses like helium can differ by orders of magnitudes for different seal materials. In this study, the gas load through a single O-ring due to permeation was compared for Viton® E and for Chemraz®653. The procedure was to use a MSLD (mass spectrometer leak detector) with helium and log the leak signal at intervals often a few seconds apart as a controlled flow of helium was applied to the seal. This was done both at room temperature and at elevated temperatures up to 140o C. The test O-ring was located in a specially constructed fixture that allowed an O-ring to be compressed to five different values ranging from 15% to 27% compression. Leak signals due to permeation through the 2-227 sized O-ring (nominal 0.139 inch cross section) were found to vary by orders of magnitudes. For instance at 22% compression and room temperature, the peak leak signal from the Viton® seal was approximately 1x10-10 mbar-l/sec while for the Chemraz®653 seal it was approximately 2x10-8 mbar-l/sec. When the seals were at 140o C with the same compression, the leak signals became approximately 1x10-8 mbar-l/sec for the Viton® and approximately 8x10-7 mbar-l/sec for the Chemraz®653 seal.

Leak signals due to permeation of these magnitudes are very important when troubleshooting or qualifying equipment since leak rate specifications on equipment are often lower. The same set up was also used to help find ways to distinguish a response on the leak detector due to a leak from a signal due to permeation. Using the rapid data recording and graphical display of the leak signal, it was found that permeation responses had a characteristic shape. With a response due to permeation, there is a short time before the response starts, a ramp up time, and then a slow decay. By contrast, signals from known leaks were shown to have a very rapid response time, and a quick decay or 'clean up' when the probe gas was removed. Using a graphing display, and comparing the response to known examples, operators can distinguish the two situations.

10:40am **VT-MoM8 Controlled Formation of Condensed Frost Layers in Cryogenic High Vacuum Pumps***, **S.E. Syssoev**, A.J. Bartlett, M.J. Eacobacci*, Brooks Automation Inc.

Cryogenic high vacuum pumps are used on a wide variety of vacuum substrate processing equipment, space simulation systems, and analytical instruments. They produce high pumping speeds for all gases and work over a wide range of pressures. Pumping residual gases occurs by cooling them to the point that they condense on the appropriate cryogenic surface. Thus, the pumping speed of the cryopump can be converted into deposition rate of the pumped gases onto cold surfaces inside the pump. The thickness of the deposited layer is uneven due to geometry of the cryopanels inside the pump. The majority of the trapped gas forms thick and comparable stable amorphous structures, while a significantly smaller amount of the pumped gas is participating in low rate deposition on those zones inside the pump that are less exposed to the gas flow. This low rate deposition leads to formation of polycrystalline films with complicated crystallographic structure even for the simple binary gas mixture widely used in the most applications in semiconductor industry. As with any thin film, this type of polycrystalline frost can be subject to appreciable residual stress due to structural defects. The concentration of such defects depend on operating conditions such as pumped gas composition, pressure, rate of deposition, and condensation temperature. For the stressed film there is always a certain film thickness (critical thickness, [1]) after which the film can exhibit one of the possible cracking pattern – surface crack, channeling, or debond. Defects in the condensed solid gas films grown inside the cryopump can lead to spontaneous delamination resulting in frost flakes being ejected from the array surface with subsequent sublimation on the warmer surfaces of the pump. Sporadic sublimation of delaminated flakes lead to unwanted pressure variations, or bursts, inside the vacuum system. This report discusses the types of film formations found in a typical cryopumping array structure and summarizes the development of a new cryopump with increased capacity and elimination of sporadic pressure bursts occurring during the cryopumping of type II gases. The pump employs the GM refrigeration cycle and is a further modification of the Brooks Automation On-Board IS 8F cryopump [2]. The test results showing pressure bursts free operation and 50% higher capacity for type II gas achieved with no changes to cryopump external geometry are presented and discussed.

[1]. J.Hutchinson et al. *Mixed mode cracking in layered material.* Advances in applied mechanics, 29, 63 (1992).

[2]. A.J.Bartlett et al. *Pressure burst free high capacity cryopump.* United States Patent Application 20080168778, (2008).

11:00am **VT-MoM9 Combination of Compact NEG and Small Ion Pumps for UHV Systems***, **P. Manini**,* SAES Getters, Italy*, C.D. Park, S.M. Chung*, Pohang Accelerator Laboratory, South Korea

Achieving a better base pressure and reducing bake-out time are the two important practices for an UHV system. Use of a sputter ion pump (SIP) in combination with non-evaporable getter (NEG) is one of the good solutions for this. Although many efforts have been made showing results of the pumping performances of NEG-SIP combination, the SIPs used were relatively large. Furthermore there is a demand for high performance, compact combination pumps that can be installed in a tight space in a storage ring of the proposed PLS-II project. Thus we tested the characteristics of a compact NEG-SIP combination pump (CNP) to see if the CNP can meet the above mentioned desires.

A compact getter cartridge mounted on CF40 flange (Capacitorr D 400-2) was used in combination with small SIPs, having speeds ranging from 10 to 60 l/s. The CNP was attached to a stainless steel chamber that has five CF40 flanges with a total inner surface area of 3,000 cm^2.

Base pressures (BPs) of the CNP-UHV system, in a wide range of situations, with/without NEG and with/without baking were measured. Significantly lower pressures and faster pumping could be achieved using the CNP. Base pressures of low 10^{-11} mbar could be obtained with a compact NEG for 10 l/s and 60 l/s SIPs after a 48-h bakeout.

The results also show that the compact CNP can provide high pumping speed and reach 10^{-11} mbar after a very short (few hours) bakeout. The BP was $1x10^{-10}$ mbar with 60-l/s SIP alone after a 48-h bakeout, whereas it was $7.9x10^{-11}$ mbar with the CNP; a better result after only 2-h bakeout. This is quite a remarkable decrease in the bakeout time of a UHV system.

It is worthwhile to note that UHV could also be achieved with the CNP even in a fully unbaked system: A pressure of $3.9x10^{-10}$ mbar with the CNP was reached, while it was $8x10^{-9}$ mbar with the SIP alone. The other interesting result of the CNP-UHV system is that the pressure increase is much less and slower when the SIP is switched off. This is also a good characteristic, required for portable vacuum devices.

All these characteristics are particularly useful for the design and operation of the vacuum system of a storage ring. It may also be beneficial for the miniaturization of vacuum equipments and mobile applications which require smaller pumping systems.

11:20am **VT-MoM10 Water Vapor Cryopumping: Refrigerant Phaseout Compliance***, **K. Flynn**, C. Rebecchi*, Brooks Automation Polycold Systems

Water vapor cryopumps, which use mixed gas refrigeration technology, rely on mixtures containing four or more refrigerants, each with widely spaced boiling points. Historically, these mixtures contained two or more chlorinated refrigerants such as chlorofluorocarbons (CFC's) or hydrochlorofluorocarbons (HCFC's). Both classes of compounds contribute to depletion of the stratospheric ozone layer and are subject to legislative action to phase out these compounds. CFC refrigerants were banned in the US and other developed countries in 1995. HCFC refrigerants are currently in use, but are targeted for phase out. Mixed gas refrigerant water vapor cryopumps have relied on HCFC refrigerants, including HCFC R-22 since the early 1990's when CFC refrigerants were phased out. Although water vapor cryopumps experience much lower leakage rates than commercial refrigeration systems, they are subject to the same laws as all other refrigeration equipment. Effective January 1, 2010, the use of R-22 will be banned on new equipment in the US. R-22 is a key refrigerant in water vapor cryopumps due to its excellent refrigeration capacity and its relatively low freezing point (-160 °C). The phase out of R-22 has required extensive development of alternative refrigerants. It has been accomplished for three important sizes of water vapor cryopumps. The resulting products provide water vapor cryopumping at the same speeds and water vapor partial pressures as the previous mixtures with R-22. This paper reviews the development approach, and compares system and pumping performance for these green products. Experimental data from commercial vacuum systems is presented for the old and new product.

11:40am **VT-MoM11 Vacuum Processing for the 21st Century***, **S. Ormrod**, N. Schofield*, Edwards Ltd, UK

On the 90th anniversary of the foundation of Edwards by FD Edwards, the origins of industrial vacuum processing are examined. They are then compared with progress at the time of FD Edwards' death in 1966 and finally, possible developments are examined in the light of vacuum processing technology in 2009.

Proliferation of vacuum processes are shown to drive the evolution from mercury based vacuum technology through oil sealed pumping to dry pumping in the primary and secondary pumping pressure region resulting in a significant market for vacuum processing equipment.

Looking ahead, likely commercial influences are identified, such as electronic, environmental, and safety applications.

To meet that demand, trends and limitations in vacuum engineering are highlighted, particularly capacity, power and rotational speed. The benefits of applying electronics to vacuum processing become apparent - the very products vacuum processing equipment has helped to manufacture so successfully.

Vacuum Technology
Room: C1 - Session VT-MoA

Pressure, Partial Pressure, and Flow Measurement
Moderator: J. Setina, IMT

2:00pm **VT-MoA1 Investigations on the Dynamic Response of Pirani Gauges**, ***M. Wüest***, *B. Andreaus, R. Stocker*, INFICON, Liechtenstein

For over 100 years the Pirani sensors measure vacuum pressure from ~$5x10^{-5}$ mbar to atmosphere. Pirani sensors are based on heat conduction through gas. Due to this measurement principle the accuracy of Pirani sensors is reduced near atmospheric pressure. Yet many industrial processes use the low cost Pirani sensors for venting applications and the trend is to faster cycle times. Depending on the construction Pirani sensors can display various inaccuracies during rapid pressure changes. This is because the wall temperature measurement used for temperature compensation lags the pressure change. Here we present an investigation to optimize Pirani sensor design for rapid pressure venting applications.

2:20pm **VT-MoA2 Portable Gas Sampling Instrument Capable of Measuring Leak Rates, Volumes, and Pressures without A/C Power**, ***S. Thornberg***, *J. Brown,* Sandia National Laboratories, *L. Miller, J. Ithaca*, B&W Pantex

Certain operations (e.g., volume measurement, gas sampling, and leak rate determination) commonly employed in the field of vacuum technology typically require A/C-powered equipment (vacuum pumps, electrometers, computers, etc.) to perform the measurement or operation. However, some hazardous applications require the cessation of A/C-powered operations when certain conditions exist like the presence of a thunderstorm that can generate dangerous voltage spikes from nearby lightning strikes. To alleviate this problem, a new instrument designed and prototyped at Sandia National Laboratories is capable of performing leak tests (greater than 5 x 10^{-4} atm cc/s air), measuring the internal volumes of complex manifolds (up to liters in volume), making absolute pressure measurements, and performing gas sampling, all without the use of A/C power. The system is designed to be very easy to use with many pneumatic valves behind the instrument panel that are controlled by simple control valves specifically designed/invented for this application. Other functions this instrument can perform are the generation of a modest vacuum (approximately 10 Torr) and backfilling the system with a user-supplied gas. The system has been prototyped, and production models have been fabricated and are in use on production lines. This presentation will highlight the design and features that enable these operations to be performed without A/C power in an operator-friendly package that is not much larger than a thick briefcase. Extensive qualification testing has been performed using these instruments, and the results will be presented to show the performance and NIST traceability. (Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.)

2:40pm **VT-MoA3 Mass Spectrometer Sampling of Transient Gas Compositions in Processes**, ***R.E. Ellefson***, Consultant

Many modern vacuum processes involve transient gas densities and compositions. Analysis of the composition of process gas requires the transport of a sample from near the process point of interest to the gas analyzer. The transport time and surface conditioning time of the sampling apparatus needs to be much shorter than the cycle times of the process to give useful composition-versus-time profiles. Many processes for CVD or ALD deposition involve metal organic precursor gases that adsorb on surfaces conformally as part of the deposition process. These gases also adsorb on the sampling system internal surfaces. Management of the surface coverage dynamics for each process is an important factor for good sampling. In this paper, the time constants for species diffusion within the process, sample gas transport and surface coverage times for adsorption and desorption as the composition changes are defined and calculated for typical applications. Strategies for accelerating the stabilization of the sampling system surface composition by controlling surface temperature in relation to the process temperature are discussed. Designs and results for sampling systems and component measurements are presented for four representative processes: Hot He degas of wafers, high-density (fluorocarbon) plasma etch, and monitoring atomic layer deposition and various CVD processes.

3:00pm **VT-MoA4 A Novel Electrostatic Ion Trap Mass Spectrometer**, *A.V. Ermakov,* ***B.J. Hinch***, Rutgers University

We have developed, built and tested a novel mass spectrometer which uses purely electrostatic fields for confinement of in-situ ionized residual gases within a linear trap. An anharmonic trapping potential well focuses the ion trajectories of all ion masses, and of a wide range of ion energies, such that their lifetimes are long enough to allow for systematic sequential ejection of the ion mass/charge ratios. Ions are generated within the ion trap by electron impact of residual gases. Mass selective ejection is achieved through a novel autoresonant pumping process. The mass spectrometer has an unlimited mass range, is capable of achieving high sensitivity at high and ultrahigh vacuum levels, and has demonstrated much faster scan rates than the widely used (larger size and) more complicated quadrupole or magnetic sector mass spectrometers. In addition, the new mass spectrometer is very compact (less than 2" long), and requires very low power (in the mW range, excluding ionizer) as it uses only static bias potentials and a very small RF voltage (in the 100mV range). The principles of autoresonant ejection of ions are presented, along with a detailed analysis of the design and operational parameters affecting mass spectral resolution, detection limit, and dynamic range.

3:40pm **VT-MoA6 A Practical Electrostatic Ion-Trap Sensor**, ***G.A. Brucker***, *J. Rathbone, S. Blouch, M. Schott, K. Van Antwerp*, Brooks Automation, Inc.

We have expanded upon the work of A.V. Ermakov and B.J. Hinch from Rutgers University to further develop a novel electrostatic ion trap sensor that is based upon the principles of autoresonant ion-ejection and detection for use in low mass range mass spectrometry applications. The improved sensor is approximately 15 cm in length, with a 2.5 cm ion-trap component capable of scanning a mass range of 1-300amu with a mass resolving power of >130x. A symmetric RF pumping scheme combined with a custom RF frequency sweep profile provide simplified electrical design along with optimal ion ejection efficiency across the entire mass range. A novel dual-filament, off-axis ionization scheme provides both pressure range and detection limit enhancements. The entire structure that includes the ionizer, mass analyzer and detector were integrated into a pre-existing Stabil-Ion® gauge total pressure ionization sensor envelope. The improved sensor retained many of the benefits of the original concept sensor such as a rapid sensor scanning speed approximately 70ms for 1-100amu scans and a mW RF ion-trap drive requirement that allows for a remote gauge cable connection to the controller electronics. The simple structure and intelligent electronics were implemented to allow for self- calibration of partial pressure measurements and automated recalibration of the electron multiplier detector. A novel dual-filament ionization source design was incorporated into the ion trap to allow fast and easy field replacement of filaments.

4:00pm **VT-MoA7 Total Pressure Measurement Integrated into a Ratiometric Partial Pressure Electrostatic Ion Trap Sensor**, ***P.C. Arnold***, *G.A. Brucker*, Brooks Automation, Inc.

A method of total pressure measurement concomitant with partial pressure analysis in a partial pressure analyzer ion trap will be presented along with representative construction geometries and data of the measurements. This combination of total pressure and partial pressures into a single sensor allows a more complete evaluation of the gas content of a vacuum chamber as well as its changing composition and absolute pressure. This method includes one ionization gauge structure which measures the pump-down progress to evaluate correct time of trap turn-on. Another ionization gauge structure is included that provides total pressure at high vacuum intermittently with the partial pressure scans. Ion traps are ratiometric devices that have an upper limit in the ion density that can be stored in their ionization trapping volumes. This limits the total number of ions measurable so that as pressure increases, no further absolute increase is observed in the sum of the amplitudes of individual gas species peaks, even though the differentiation in the various relative mass peaks continues to be readily seen.

4:20pm **VT-MoA8 Instrument Design for an Integrated Total and Partial Pressure High Speed Vacuum Quality Monitor Sensor**, ***M. Schott***, *J. Rathbone, P. Sandt, K. Van Antwerp*, Brooks Automation Inc.

Design details and performance test results of an integrated total and partial pressure high speed vacuum quality monitor instrument will be presented. A single-sensor, high-speed total pressure and partial pressure instrument has been developed with a 1-100amu, 100ms update rate. The complex sensor is comprised of a hot-filament ion source, electrostatic ion-trap mass separator, Shulz-Phelps based total pressure detector, and an electron

multiplier ion detector that is shared for both UHV total pressure and ratiometric partial pressure measurements. A dual board electronics instrument package has been designed to control, drive and process complex sensory data, and output the processed data into a usable form within the cycle time of the measurement update rate. High speed data processing and real time sensor control was achieved by dividing the sensory control and measurement function from the data reduction and host input/output functions. The mass spectrometer interface (MSI) electronics board utilizes a local uC, which directly controls and provides system status on the following sensory functions: multiple ion-trap bias voltages, filament power & emission current, ion-trap mass analyzer RF drive amplitude & frequency and ion current electrometers. The MSI local processor accepts serial high-level commands from the host input/output (HIO) board processor, which predetermines the sensory "scan" control parameters. The HIO board performs data reduction and user input/output. HIO data reduction algorithms process the raw sensory data into usable total and partial pressure [amu, amplitude] matrix data. All resulting in hard-coded and/or custom user outputs, which may produce a number of real-time and non-real-time datum.

4:40pm **VT-MoA9 NIST Traceable Vacuum Standard Based upon MEMS Resonant Silicon Gauge Technology**, ***J. Hendricks***, *T. Gooding, D.A. Olson*, National Institute of Standards and Technology

In the mid 1990's the development and use of micro electro mechanical systems (MEMS) enabled pressure sensor technology to make significant advances in both precision and accuracy. Resonant Silicon Gauges (RSGs) are MEMS sensors that are manufactured by micromachining silicon to produce silicon diaphragms nominally a few millimeters square by a fraction of a millimeter thick. Over the past decade, NIST has calibrated these gauges and has found them to be very stable, rugged, and ideally suited as core technology for a high-stability precision pressure standard that can be calibrated against the NIST primary pressure standards [1].

The RSGs use two single-crystal silicon resonators encapsulated in a vacuum microcavity. Changes in pressure on the diaphragm are determined by measuring strain-induced changes in the two resonant frequencies [2]. Since each resonant element is encapsulated in a vacuum, the most critical part of the sensor is never in direct contact with the calibration gas which makes the pressure sensor gas species independent. The RSG sensors are commercially available and NIST has performance data dating back over 9 years on one sensor that has been calibrated 18 times, and has a demonstrated average calibration shift of only 0.008% [3].

NIST has developed and built a Resonant Silicon Gauge Transfer Standard Package (RSG-TSP) with a range of 100 Pa to 130 kPa. NIST scientists recently completed a long-term stability study of this transfer standard, demonstrating that the uncertainty due to stability is only a few ppm at 130 kPa, increasing to 0.01 % at 100 Pa (k=1). This standard is expected to find applications in national "round robin" and international key comparisons of pressure standards, and is ideally suited for use as a "high end" precision pressure standard for secondary calibration laboratories.

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

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

[3] NIST internal calibration report NC212.

5:00pm **VT-MoA10 A New Approach to Gas Flow Calibration**, ***P.D. Levine***, Zero K Designs

Gas flow calibration is typically accomplished by measuring the rate at which volume is displaced by gas flowing at constant pressure. The measurement relies upon the accurate determination of the first order change in position of the object displacing the gas. Through active control of gas pressure and displacement, higher order effects are minimized to enhance measurement precision. These systems are mechanical in nature and require substantial sophistication in their manufacture and utilization to achieve primary standards levels of uncertainty. An alternative method which generates volumetric flow-rates by non-mechanical means is described. The method takes advantage of a natural physical process inherently linear to first order within practical measurement intervals.

By allowing gas to leak from a fixed volume through a throttling valve, leak-down can be controlled such that first order effects dominate for measurement times sufficient for high precision data to be obtained. The volumetric flow-rate is directly proportional to the rate of pressure drop within the fixed volume during the measurement interval. Thus accurate measurements of the fixed volume and the rate of pressure drop can yield high precison results. This method takes full advantage of the resolution and sensitivity offered by state of the art Capacitance Diaphragm Gages (CDG) as used in national standards laboratories. As such, it should be possible to achieve uncertainty levels approaching those of primary references. Indeed, previous work has proven this method as effective as displacement based standards for orifice flow calibration systems[i] . The basic concept lends itself to many realizations making it capable of covering a wide range of flow rates.

One such realization, which can be readily assembled from off the shelf components and some custom fabrication of flow manifolds, is described. It would be capable of providing calibration to 1000 SCCM (Standard Cubic Centimeters per Minute) with a minimum estimated k=2 uncertainty of 0.60%.

The Precision Gas Flow Calibrator described here represents a new and simplified approach to gas flow calibration. The achievable measurement precision offers the potential of a stable and reproducible reference with great utility for the calibration of a wide variety of gas flow measuring devices.

iP.D. Levine, J.R. Sweda, "A Precision Gas Flowmeter For Vacuum Calibration", J. Vac. Sci. and Technol. A 15(3) May/June 1997; pp 747-752.

Vacuum Technology
Room: Hall 3 - Session VT-TuP

Vacuum Technology Posters and Student-Built Vacuum Systems Poster Competition

VT-TuP1 New Developments at ISIS – The Worlds Leading Pulsed Neutron and Muon Source, ***S. Patel***, STFC Rutherford Lab, UK

Over the past 12 months there have been major advances at the above research facility operated by STFC, which is based at the Rutherford Appleton Laboratory, Oxford, England. In addition to the Second Target Station (TS2) becoming operational with a suite of seven new instruments, there have also been developments to improve the performance and reliability of existing instruments on Target Station One. Some of the key vacuum challenges faced during the last year will be outlined here, together with details of the challenges that lie ahead.

VT-TuP2 Vacuum Pressure Simulation for the Insertion Device Beamline at X-Ray Ring of NSLS, ***J.-P. Hu***, Brookhaven National Laboratory

Beamline 9 at the X-ray storage ring of the Brookhaven Lab's National Synchrotron Light Source has been upgraded from a conventional bending magnet beamline to an insertion device beamline, with installation of a mini gap undulator (MGU) between the two RF cavities at upstream of dipole magnet. The new water-cooled undulator, which is made of neodymium-iron-boron magnet and vanadium-permandur poles, was tested to generate a high-brightness coherent photon beam through the X-9 front-end to the experimental end-station enclosure, where sampling of nano materials will be conducted by small-angle X-ray scattering (SAXS). To meet required ultra-high vacuum (UHV) for beam transport under minimum scattering and aberration, the X-9 front-end was also upgraded, with installation of following provisions: fixed-aperture photon mask for beam filtering, high-density safety shutter for *bremsstrahlung* shielding, water-cooled collimator for ray focusing, windowless differential ion pump for shockwave throttling and spectrum broadening (2-20 keV), and pneumatically closed and sealed gate valve for the front-end vacuum and beamline vacuum separation. At downstream of the front-end gate valve, the 6-meter long X-9 is constructed of UHV-compatible SS spool pieces, welded bellows, optical chambers, fast shutter and angle valves. To maintain the intensity and quality of undulator beam for high-resolution sampling of nano materials, the conductance-limited beamline is equipped with multiple high-capacity ion pumps, respectively mounted at cryo-ready monochromator container (dual 300 l/s pumps), XZ-staged mirror tank (one 500 l/s) and exit-slit housing (one 300 l/s). For vacuum pressure minimization, the Monte-Carlo based Molflow code was used to simulate inline assemblies and pumping units encompassing the beam chamber, and the finite-difference based Vaccalc program was used to calculate pressure distribution along the beam trajectory, starting from the photon source MGU down to the beamline end valve next to the enclosure wall. Details of calculated pressure profile versus pumping setup will be presented. (Work performed under auspices of the United States Department of Energy, under contract DE-AC02-98CH10886)

VT-TuP4 A Vacuum Quality Monitor Sensor using an Integrated Total and Partial Pressure Measurement Design, ***B.G. Olsen***, *G.A. Brucker, J. Rathbone, S. Blouch, M. Schott, K. Van Antwerp*, Brooks Automation, Inc.

We have refined and built upon the work of A.V. Ermakov and B.J. Hinch from Rutgers University to further develop a novel electrostatic ion trap sensor that is based upon the principles of autoresonant ion-ejection and detection for use in low mass range mass spectrometry applications. In addition, we have developed a practical method of integrating a total pressure measurement capability into the same sensor envelope. This highly integrated Vacuum Quality Measurement (VQM) sensor is comprised of a hot-filament ion source, electrostatic ion-trap mass separator, Shulz-Phelps based pressure sensor, and an electron multiplier ion detector that is shared for both UHV total pressure and ratiometric partial pressure detection. The VQM ion-trap sensor is capable of a 1-100amu scan rate within 70ms and has been coupled with a total pressure and partial pressure measurement update rate of 100ms. A set of sensor electronics has been developed to control, drive and process complex sensory data, and output the processed data into a usable form within the cycle time of the measurement update rate. Finally, a novel dual-filament ionization source design was incorporated into VQM sensor design to allow fast and easy field replacement of filaments.

VT-TuP5 A Compact RHEED-TRAXS Chamber Modification Design for Real Time, In-Situ Stoichiometry Analysis during MBE, ***B. Sun***, *T.L. Goodrich, K.S. Ziemer*, Northeastern University

Real-time control of MBE film growth using Reflection High Energy Electron Diffraction (RHEED) oscillations allows precise layer-by-layer growth using real-time surface structure information. Many complex functional oxides of device importance, however, require tight stoichiometry control. RHEED- Total Reflection Angle X-ray Spectroscopy (RHEED-TRAXS) can provide real-time chemical information and thus has the potential to achieve real time stoichiometry control. When incident RHEED electrons with energy in the range of 12-20 keV graze the sample surface at approximately a 2° angle, characteristic x-rays which are representative of the film surface stoichiometry are emitted. By measuring the x-rays at or close to their total reflection angle, RHEED-TRAXS is reported to probe only the top 20Å of group V elements [1].

The goal of the RHEED-TRAXS chamber modification design is to incorporate a non-UHV compatible x-ray detector into the chamber, and ensure highly accurate detector positioning within 0.01° through a 4° angle range. For real time operation, a shielding strategy that is transparent to x-rays must be developed to protect the detector from fouling during MBE processing. As a high volume of x-rays are excited by the RHEED electrons, collimation is necessary to control the incoming x-ray flux and avoid detector overload.

Our system uses a Nor-Cal PMXY-600-400-2 ±1 inch X-Y stage to achieve 0° to 4.65° angular positioning of the detector. Differential pumping with a Leybold TURBOVAC 50 L/s turbo molecular pump is used to achieve UHV compatibility. Due to limited chamber space, off-the-shelf shielding options such as shutters would cut down the detector movement and thus reduce the maximum detection angle by 50%. To avoid this, we combined detector fouling protection and collimation by mounting the detector with a custom made half-nipple covered with a removable aperture cap which provides both collimation and beryllium foil shielding support. The ability to remove the aperture cap allows the Be foil to be replaced when needed and also allows the flexibility control net x-ray flux by changing the aperture size. The system has been used for real-time study of thin film deposition by MBE, and the results will be presented.

References:

1. Braun, W. and K.H. Ploog, Real-time surface composition and roughness analysis in MBE using RHEED-induced X-ray fluorescence. Journal of Crystal Growth, 2003. 251(1-4): p. 68-72.

VT-TuP6 Method of Measuring the Volume Flow Rate of Vacuum Pumps Using CFVN, ***W.S. Cheung***, *K.A. Park, S.W. Kang, S.S. Hong, J.Y. Lim*, KRISS, Republic of Korea

Critical flow Venturi nozzles (CFVN) have been widely used in most of national metrology institutes for the precision measurement and calibration of pressurised gas flow. They enable the relaisation of the critical flow speed equal to the speed of sound at the throat of the Venturi nozzle. The critical flow is exploited in this study not only to achieve the noble stability and repeatability of gas flow but also to minimize effects of the fluctuation of upstream and down stream pressures for the measurement of the volume flow rate of vacuum pumps. These singular properties of CFVN has not fully utilized to measure the pumping speed widely used in the vacuum-related academic and industrial sectors. On the onset of this work, it became apparent that the use of CFVN unfolds new findings for precision measurement of the volume flow rate.

One of the most technical challenges in measuring the volume flow rate was to design a set of Venturi nozzles that can cover the five decades of inlet pressures from 1 bar to 0.001 mbar. Preliminary tests were carried out to examine the practical range of upstream pressure Venturi nozzles can be used within the desired measurement uncertainty of 0.2 %. They revealed that Venturi nozzles were well calibrated in the three and half decades without loss of measurement uncertainty. This observation is very significant since two different sized nozzles are sufficient to cover the desired inlet pressure test range of vacuum pumps, specifically from 100 mbar to 0.001 mbar. This point has encouraged authors to develop a new CFVN-based measurement system targeted for the measurement of the volume flow rate of vacuum pumps. This paper will introduce the details of the developed measurement system, including the configuration of mechanical parts and measurement instruments. Test results obtained from the CFVN-based measurement system are compared to those from the conventional throughput method. The pros and cons of both measurement methods are also discussed. Finally, potential applications of developed CFVN-based volume flow rate measurement technologies for vacuum pumps are briefly pointed out for instance the MFC market for gas flow

control and the on-site performance analyzer of dry vacuum pumps in the semiconductor and flat display production lines.

VT-TuP7 Vacuum System for a Low Temperature Dynamic Force Microscope, ***L. Tröger***, *M. Reichling*, University of Osnabrück, Germany

We present a complete ultra-high vacuum system designated for the operation of a home built dynamic scanning force microscope for use at cryogenic temperatures. The vacuum system was designed for maximum flexibility and consists of a measurement chamber with the cryostat and two separate chambers for sample transfer and preparation.

The cryostat was modified to implement leverage for the scan head for optimum thermal coupling and vibration decoupling by eddy current damping. Thermal anchors for all electrical supply lines were installed. An in vacuo reservoir for the glass fibre for the interferometric detection system of the force microscope ensures protection from vibrations and stores spare fibre for repair. The measurement chamber was designed for best handling and optimised use of space under several technical constraints. Due to the attached cryostat functioning as cryo-pump the chamber reaches lowest pressure regimes providing best conditions not only during experiments but also for storing force microscopy tips and samples in a magazine. The preparation chamber is based on several planes with distinct focus points for preparation instruments along the main axis. The load lock is conceived for maximum exchange efficiency enabling the transfer of up to eight tips or sample at a time. This is achieved by taking advantage of the rotational degree of freedom of the transfer rod that carries a revolving magazine.

VT-TuP9 Magnetron Sputter Coater Construction and Experiments, ***A. Mezzacappa***, Vassar College

Magnetron sputter coating is a method of physical vapor deposition which occurs in vacuum with an inert gas. Production of quality coatings necessitates a rigorous approach to vacuum science. Over the course of the 2008 – 2009 academic year with support from the University of Collaboration and private donors we constructed a sputter coater modeled on a General Atomics sputter coater. The vacuum vessel is eight inches in diameter and stands approximately two feet high. It has thirteen different ports ranging in size from one and one quarter inches to eight inches. The ports accommodate a turbo pump backed by a small diaphragm pump providing 30 liter per second pumping speed, vacuum gauging, Argon and Nitrogen in-gassing, electrical feed-throughs for biasing, viewing windows, and a double tip Langmuir probe on a linear bellows. The magnetron is a two inch US Gunn capable of height adjustment. It is water cooled and powered by a MDX Advanced Energy Power Supply. The sum total of these parts is a research quality machine with immediate applications for Vassar faculty and students. Since construction of the system, we have performed the following experiments: arc discharge, copper sputter coating, spectroscopy, and spatially resolved double tip Langmuir probe scans. We have determined plasma parameters such as electron density and electron temperature. Future experiments will include coating analysis using ultrafast acoustic thin film measurements techniques. In future years, the machine will become an advanced laboratory experiment maintained by Vassar College faculty for plasma physics education and research at Vassar College .

VT-TuP10 Design, Development and Assembly of a Modified PHI 5400 XPS System for XPS/UPS Surface Analysis, ***R. Davies***, *B. Gila*, *C. Abernathy*, University of Florida

A surface analysis system consisting of a vacuum chamber intended for 1-inch samples was redesigned and reconfigured to accommodate 3-inch samples due to laboratory equipment limitations and financial constraints. The surface analysis system is mainly comprised of a PHI 5400 XPS system with additional functionality provided by a SPECS UVS 10/35 UV source (UPS) and a PHI 77-067 sputter ion gun (surface analysis with depth profiling). Due to budgetary considerations, a previously used PHI 5400 XPS system was purchased. The redesign of the main vacuum chamber was necessitated by the requirement of joining this system with a 3-inch sample size Varian Gen II MBE system. The redesign of the vacuum chamber intended for surface studies involved utilizing the chamber in a horizontal orientation instead of the vertical orientation typically associated with XPS systems. Due to this reconfiguration, the vacuum chamber could both integrate with the current MBE system and accommodate 3-inch samples. The reconfiguration also introduced the need to design a sample manipulation system from square one. Working with Thermionics, a manipulation system was designed that provides for 3-inch sample transport along the x, y and z axis of the Cartesian coordinate system in addition to polar and azimuthal sample rotation. This manipulation system also includes a sample heater for surface adsorption studies up to 1200°C. The customization of the sample manipulation system provided numerous capabilities for surface analysis experimentation after being attached to the reconfigured vacuum chamber. In addition, a 56-inch long vacuum chamber, which acts as a buffer extension between the surface analysis system and both the MBE system and a vacuum briefcase, was designed and assembled. All of the vacuum plumbing necessary for the differential pumping of the sputter ion gun and UV source was designed to readily combine with the reconfigured main vacuum chamber and then assembled. A vacuum briefcase has been diagrammed to provide for sample transport from a Riber MBE 2300 system to the XPS/UPS surface analysis system under vacuum.

VT-TuP11 Reconstruction of a Veeco 776 Ion Beam Deposition System With Digital Sensing and Logging Modifications, ***J. Vanderford***, *A.P. Genis*, Northern Illinois University

The purpose of this project was to document the efforts of restoring a thirty-five year old Veeco 776 vacuum deposition system equipped with a 3 inch ion beam milli-tron which was destroyed in a laboratory fire. This was a system used for the deposition of Indium Tin Oxide (ITO) used for the fabrication of ITO / P-Silicon solar cells. The fire destroyed all electronics for powering the ion source, the gas delivery system for the ion source, vacuum measurement and valve control systems, the substrate chuck heat controller, and considerable damage to the vacuum pump stack and valves Due to the age of the system, direct replacement of these components were not available. The goal of this project was not only to rebuild the vacuum system but also to incorporate a data acquisition and logging system for monitoring and recording critical process parameters associated with the operation of the system in a real time graphic interface environment. The design and engineering which was required to complete this project, as well as the re-engineering of specialized components to achieve these goals will be presented.

VT-TuP12 Ultra-Clean Magnetron Sputtering System for Materials Research and Education, ***H. V Nampoori***, *G.J. Mankey*, University of Alabama

Construction and implementation of a multi-target magnetron sputtering system with substrate carousel is reported in this poster. The system has four magnetrons arranged on a circle and facing up, to enable deposition of multilayers for applications such as magnetic media, tunnel junctions and MRAM devices.

Up to twelve substrates can be loaded into the system on a rotating carousel. In addition, a lifter assembly can be used to move samples between positions on the carousel fitted with shadow masks. The bottom up sputtering is achieved in stainless-steel, bell-jar chamber with a rotary vane pump and Cryotorr 8 combination. With internal bake-out heaters using two 600 W halogen bulbs, a base pressure of 2×10^{-8} Torr is achieved. Argon pressure during sputtering is controlled using a MKS flow controller and Adaptorr butterfly valve with a Baratron gauge. Each magnetron has a shutter controlled by a Durant programmable timer. Substrate heating during deposition could be achieved using a 150 W halogen projector lamp located above each magnetron source. A quartz crystal microbalance thickness monitor can be used to determine the deposition rate for each gun. In addition, the carousel has integrated permanent magnets designed to grow magnetic thin films with induced uniaxial anisotropy.

This poster will describe the motivation and design of the system and present some preliminary results. The results will highlight the uniqueness of the system design for a manually-operated, simple and user-friendly machine.

This work was supported in part by the National Science Foundation MRSEC Grant DMR-0213985.

VT-TuP13 Outgassing Measurement of Ion and Getter Pumps at UHV Regime, ***G.Y. Hsiung***, *C.M. Cheng,* NSRRC, Taiwan, *J.R. Chen*, NSRRC and NTHU, Taiwan

The combination of ion pumps and getter pumps have been used for the advanced pumping at UHV regime of a pressure below 10 nPa. The effective pumping speed of ion and getter pumps is limited at UHV pressure due to the outgas of the materials inside the pumps such as H_2 and CO or that evolved from the surface reactions during or after pumping such as CH_4. Besides, the outgas of the noble gas such as He or Ar buried inside the cells of ion pumps as well as the Kr or Ar from the coated film of getter pumps is regarded as one of promising limit of pumping speed. The measurement of outgas of ion and getter pumps is performed by pressure build up method. The cleaning process for reduction of the outgas of the ion and getter pumps are evaluated.

VT-TuP14 Study of Secondary Electron Yield for KEKB Positron Ring, ***S. Kato***, *M. Nishiwaki*, KEK, Japan

In order to mitigate electron cloud instability in high-intensity positron and proton accelerators, material surface with a low secondary electron yield (SEY) for the beam ducts is highly desired. In-situ SEY measuring system

in the straight section of the KEKB positron ring was reported where one can measure SEYs of sample coupons exposed to electron cloud during the KEKB operation. In this study we aim to develop a mobile UHV system for sample coupon transfer from an arc section of the positron ring to a load lock chamber of XPS at our laboratory in order to carry out SEY measurements and surface analyses without exposing coupons to the air. There are two sample ports with a size of 8x8 mm^2 at the side and the bottom of the positron beam duct for comparison. While both of samples are exposed to electron cloud caused by strong synchrotron light from a bending magnet of the ring, the light directly hits only the sample positioned at the side port. Sample coupons exposed to electron cloud can be transferred to UHV suitcases 1 and 2 through isolation gave valves installed between the beam duct and the suitcases. An amount of electron cloud is measured with the electron monitor. The UHV suitcase consists of a gate valve, linear and rotary motion drives to transfer the coupons, an ion pump with its power supply and drive batteries. The total weight is about 10kg. Two suitcases are almost identical. These suitcases are moved and connected to the second load lock chamber where the coupons up to 12 can be kept in UHV before the measurement. In this paper, the detail of the SEY measuring system is mentioned with its experimental results after a long time exposure of the coupons to the electron cloud during the KEKB operation.

VT-TuP15 Energy Consumption Characteristics of Low Vacuum Dry Pumps in Semiconductor Manufacturing, ***J.Y. Lim***, KRISS, Korea, *H.Y. CHoi*, LOTVacuum, Korea, *W.S. Cheung, J.H. Shin, S.B. Kang, Y.-H. Shin*, KRISS, Korea

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. The evaluation system exploits the constant volume flowmeter to measure the mass flow rate real-timely in standard level, and facilitates the evaluation of spatially averaged sound power levels using a reverberation chamber. 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.

VT-TuP16 Development of a Pulse Motor Driven All Metal Valve for a Static Expansion System, ***K. Arai***, *T. Tomita, H. Akimichi, M. Hirata*, NMIJ/AIST, Japan

A static expansion system generates standard pressures for the calibration of a spinning rotor gauge and a capacitance diaphragm gauge. Valves are important parts for the system. All metal pneumatic valves are used for an automatic operation. However, the pneumatic valve closes so rapidly (<1 s) that the undesirable differential pressure between both sides of the valve is seemed to be induced by pushing gas. In order to clarify it, a test system consists of 45 m chamber and 3000ml chamber connected by the pneumatic valve was set up. The 13 Pa of differential pressure at the 100 kPa of line pressure was generated by closing the valve. The pressure decreased to 1.5 Pa by elongating the valve closing time, 150 s, by the control of the flow rate of the pneumatic line. However, the repeatability of the valve closing was not sufficient.

Pulse motor driven all metal valve was developed: (1) The motor drive part is attached to a commercial available valve, (2) A valve stem is driven by the pulse motor via a torque-limiter, springs, and a valve shaft, (3) The valve shaft position at closing the valve is always same by using the position sensor, (4) Springs are used to close the valve with the same torque, (5) To avoid the increase of the temperature of the valve body, the motor is operated only for the valve operation and 50 cm away from the body, (6) The torque-limiter is put between the motor and the shaft not to break the valve by the over torque.

The stem speed was controlled ranging from 0.1 to 0.008 mm/s (closing time: 25 ~ 300 s). The differential pressure could not be eliminated by slowing the stem speed. The smallest pressure was 1.4 Pa at the 100 kPa of the line pressure. Taking into account the pressure and the test chamber volume, 1.4 Pa is corresponding to the 0.0006 ml volume change of the valve. The mechanism of the undesirable differential pressure during the valve closing can be analyzed by measuring the detailed pressure change as a function of the time and the position of the stem.

VT-TuP17 A Novel Reactor Setup for Surface and Gas-Phase Diagnostics during Atomic and Molecular Layer Deposition, ***B. Jariwala***, *V. Rai, C.V. Ciobanu, S. Agarwal*, Colorado School of Mines

In this presentation, the authors will describe the design of a versatile reactor setup with multiple in situ diagnostics to study the surface reaction mechanisms during atomic and molecular layer deposition. The setup consists of two vacuum chambers: the first chamber is equipped with real-time attenuated total reflection Fourier-transform infrared (ATR-FTIR) spectroscopy and quadrupole mass spectrometry, while the second chamber is equipped with a quartz crystal microbalance. Both chambers are connected to multiple in-house-built bubblers to supply different precursors. In addition, each chamber is equipped with an inductively-coupled, radio-frequency plasma source that is in line of sight with the substrate for plasma-assisted atomic layer deposition (ALD). The precursor delivery into the chamber is controlled through solenoid valves operated via Labview. The infrared analysis chamber is ideal for observing the surface species and the gas phase products during each half-reaction cycle. However, due to the multiple diagnostics, which require several ports, the chamber volume is large resulting in long precursor exposure and purge cycles. On the other hand, the second process chamber is a hot-wall tubular reactor with a small volume, which allows shorter reaction cycles enabling the deposition of films that are several 10s of nm in thickness: these thicknesses are required to obtain enough sensitivity for ex situ IR and x-ray diffraction analysis. We will specifically present results for the thermal and plasma-assisted ALD of TiO_2 that will demonstrate the synergistic utilization of each diagnostic tool to unravel the specific surface reactions during film growth.

VT-TuP18 A Method of Transfering Parts Rapidly Into and Out of a High Vacuum Environment, ***E. Trillwood***, CEO Electron Beam Engineering

The novel device uses a piston and a cylinder, both with seals to penetrate the wall of a high vacuum processing chamber. The piston is hollowed out for a portion of its length and the component to be processed in the chamber is placed in this cavity, or breach. The piston, as it moves into the chamber, passes over a pre pumping station which is fitted with a two stage mechanical pump to pre evacuate the breach. Since the volume closely fits the component the evacuation time is usually one second or less. When the component enters the chamber "volume sharing" occurs and the resulting pressure rise is very small and rapid as the chamber high vacuum pumps the differential pressure between the breach and the chamber.

The seals are placed in such a manner as to isolate the atmosphere, the pre pumping and the chamber vacuums from each other at all times in the cycle.

On completion of the process the piston is withdrawn from the chamber and the breach returned to atmosphere.

Apart from the speed of operation the system has the advantage of being self valving and if a second breach or dummy piston is added to the opposite side of the chamber the forces on the piston due to atmospheric pressure are equalized and the force required to transfer the piston is greatly reduced.

This system has been used successfully in production Electron Beam Welding but has many other potential uses where ease and speed of loading and unloading relatively small parts into a vacuum chamber is requied.

Vacuum Technology
Room: J1 - Session VT-WeM

Partical and Theoretical Aspects of Gas Dynamics
Moderator: R.E. Ellefson, Consultant

8:00am **VT-WeM1 Gas Dynamics Aspects of Atomic Layer Deposition**, ***S.M. George***, University of Colorado at Boulder **INVITED**

Atomic layer deposition (ALD) is a thin film growth method based on sequential, self-limiting surface reactions. ALD can produce extremely conformal and atomic layer controlled film growth. The rate of ALD film growth is dependent on surface reaction efficiencies and gas dynamics. This talk will review the design of various ALD reactors with emphasis on the role of gas dynamics. The optimum pressure in viscous flow ALD reactors will be shown to be a trade-off between gas entrainment and gas interdiffusion. The most rapid rates of ALD film growth will be achieved using "synchronous modulation of flow and draw" where the reactant exposures occur under near static conditions and viscous flow is only operative during reactant purging. The talk will conclude with a review of new ALD reactors operating at atmospheric pressure.

8:40am **VT-WeM3 Collimated Gas Beam Analysis for Atomic Layer Epitaxy of Cracked Disilane**, *M.P. Nadesalingam,* University of Texas at Dallas, *M. Kanouff,* Sandia National Laboratories, *J. Randall,* Zyvex Labs, *R.M. Wallace,* ***W.P. Kirk***, University of Texas at Dallas

The application of collimated gas beams has enjoyed a central role in many atomic and molecular beam experiments of the past, and is again proving to be important for the development of tip based nanofabrication of new devices such as quantum dots, qubits, NEMS oscillators and biomedical devices. We report the analysis of the molecular flux from micro-capillary array dosers for atomic layer epitaxy experiments of cracked disilane. The spatial distribution as well as the total flux can be important parameters for experiments and fabrication processes. Both analytic and numeric analyses have been performed and show values that differ in some aspects from the early results of Winkler and Yates.1 At high acceptance angles where the target is closer to the source, the flux is found to be greater than the previous results by approximately 10 to 15% for various ratios of source to target diameters. The consequences of our results for atomically precise manufacturing of nanometer scale structures will be discussed.2

References

1. A. Winkler and J. T. Yates, Jr., J. Vac. Sci. Technol. **A 6** (5), 2929 (1988).

2. This material is based upon work supported by the Defense Advanced Research Project Agency (DARPA) and Space and Naval Warfare Center, San Diego (SPAWARSYSCEN-SD) under contract N66001-08-C-2040. It is also supported by a grant from the Emerging Technology Fund of the State of Texas to the Atomically Precise Manufacturing Consortium.

9:00am **VT-WeM4 Decomposition Characteristic of Metal-organic Gases**, ***S. Yamashita***, Tohoku University, Japan, *M. Nagase, K. Ikeda,* Fujikin Inc., Japan, *M. Kitano, Y. Shirai, T. Ohmi*, Tohoku University, Japan

The Film formation process by using Metal-Organic (MO) CVD method is used for various applications such as interlayer dielectric of silicon semiconductor devices, ferroelectric substance film formations and transparent electrode formation. MO gases that are used in MOCVD processes are either in the liquid state or the solid state at room temperature and the vapor pressure of these gases is very low. In order to supply MO gases to the process chamber effectively, MO gases are heated to increase the vapor pressure and are supplied by using various means including the bubbling method. But many MO gases have high reactivity. So there is a possibility that MO gases may decompose during use. Due to this problem, there is the issue that byproduct of MO gas decomposition tend to be deposited in the gas supply system. So we evaluated the thermal decomposition property and the oxidation property of three kinds of MO gases [Tetraethoxysilane (TEOS), Trimethylphosphite (TMP) and Trimethylborate (TMB)] by using the FT-IR method to examine the cause of decomposition in MO gases. When MO gases are heated at an inert gas atmosphere, MO gases can be stably supplied without decomposition occurring until 400℃. This result shows that these gases have high stability regarding heat levels. However, when MO gases are heated at an atmosphere including 50 percent oxygen, decomposition temperature of each gas was significantly reduced and carbon dioxide was produced with the decomposition of MO gases. This result shows that the oxidative decomposition of MO gases occurs during heating in an atmosphere including oxygen. Next, MO gases were heated with a resin material used for the valve seat of the gas supply system. We used polyimide (PI) and Perfluoro-Alkoxy (PFA) as a resin material that can be used for the seat of the valve until 150℃. Firstly, TEOS could be stably supplied through tubing containing resin samples. When TMP and TMB flow through the tubing containing the PI test piece, the TMP and TMB could not be stably supplied even at 50℃ and these gases decomposed. And when we raised the heat temperature, decomposition of these gases furthered the progress. When TMP and TMB flow through the tubing containing PFA test piece, the TMB could be supplied stably at 50℃. Afterwards TMP decomposed and could not stably supplied at 50℃. But when TMP continued to flow for a designated duration of time, TMP could be stably supplied. In this case, when we raised the heat temperature, the decomposition of these gases did not occur. This phenomenon was caused by moisture evaporated from resin materials.

9:20am **VT-WeM5 Numerical Simulation of Rarefied Gas Flows through Short Tubes Driven by a Pressure Drop**, *F. Sharipov,* Unuversidade Federal do Parana, Brazil, ***S. Varoutis***, *D. Valougeorgis*, University of Thessaly, Greece

Rarefied gas flows through short tubes are investigated numerically by the Direct Simulation Monte Carlo method. The flow rate and flow field were calculated as a function of the gas rarefaction, length-to-radius ratio and pressure drop. The gas rarefaction, which is inversely proportional to the Knudsen number, is varied from 0 to 2000, i.e. the free-molecular, transitional and hydrodynamic regimes are embraced. A wide range of the length-to-radius ratio, namely from 0 corresponding to the orifice up to 10 representing a sufficiently long tube, are considered. Several values of the pressure ratio between 0 and 0.7 are regarded. This pressure range covers both gas flow into vacuum and into a back ground gas. It has been found that the rarefaction parameter has the most significant effect on the flowfield characteristics, followed by the pressure drop, while the length-to-radius ratio has a rather modest impact. The effect of gas rarefaction on the choked flow and on the Mach discs at large pressure drops is discussed. A comparison of the present numerical results with available experimental data has shown a good agreement.

9:40am **VT-WeM6 Modelling a 25 Stage Turbomolecular Pump with 6 Orders of Compression with DSMC**, ***R. Versluis***, *R. Dorsman*, TNO Science and Industry, The Netherlands

Last year we presented a new method to model moving surfaces in DSMC. The method was validated by modelling a single rotor of a turbomolecular pump and comparison with experimental results. We have now applied the method to model the gas dynamics inside a 25 stage turbomolecular pump (13 rotors and 12 stators) under various discharge pressures and for various gases and gas mixtures. The turbo pump consists of two sections with different number of blades and different angles. The compression of the turbopump is about 6 orders of magnitude and the flow regime insode the pump goes from free molecular conditions at the inlet side to transitional flow on the discharge side. Interesting phenomena inside the pump are shown, such as a non-linear pressure profile inside he pump, with the non-linearity taking place at a position that would not be expected based on the geometry. Details of the gas flow inside the turbopump are visualized such as the concentration profile of gas mixtures inside the pump, temperature effects and the pressure contours inside the pump. All of these things can also be visualized as a function of time showing the pressure increase at the blade edges ahen a rotor passes a stator and the pressure decrease when the rotor has passed the stator, followed by the backflow of molecules in the wake of the blade.

The method allows a completely new look inside the turbopump and offers possibilities for simulation of new prototypes, optimisation of blade geometry, spacing etc. The current algorithm that calculates the interactions between molecules and rotors is limited to linear blade motions. The rotational motion of the blade is therefore linearized to a straight motion, but the method itself is general. The algorithm can easily be replaced for non-linear velocities although the calculation of collisions between blade and molecules becomes more tedious.

By running the calculations a large cluster of dedicated computers (up to 100 parallel nodes) the calculation time for discharge pressures around 1 Pa is still reasonably small (around 1 day).

The attached document shows an example of the results of a calculation for nitrogen.

10:40am **VT-WeM9 New Spiral Molecular Drag Stage Design for High Compression Ratio, Compact Turbo-Drag Pumps**, ***S. Giors***, *L. Campagna, E. Emelli*, Varian S.p.A, Italy

The current turbo-drag pumps commercially available for high vacuum systems are based on either Gaede or Holweck molecular drag stages technology, used in series downstream axial bladed stages to extend the maximum compression ratio up to the 10 mbar foreline pressure range.

Modern Gaede molecular drag stages use a disk shaped impeller, allowing a very compact design, but their maximum compression ratio is limited by the leakage effect to about 10 per stage.

Holweck stages use a less compact drum-shaped impeller, but are able to supply a higher compression ratio per stage and can easily be designed to supply a higher pumping speed thanks to the presence of many channels in parallel.

In this paper a new spiral molecular drag stage design is presented, with the advantages of both high compression ratio and pumping speed per stage and very compact design: a stage occupying the very tiny axial room of a Gaede, can compress as much as two or three Gaede stages in series, and supply the same compression ratio and pumping speed of a Holweck stage of the same diameter and peripheral speed, in a much smaller axial room.

The new spiral drag stage allows the design of very compact, high compression ratio turbo-drag pumps. The comparison of new design turbo-drag pump in the size of 700 l/s with existing Gaede and Holweck based products of the same size is presented, showing the technology advantages of the new design.

11:00am **VT-WeM10 Numerical Analysis of the Rarefied Gas Flow through a Short Channel into a Vacuum**, ***O. Sazhin***, Ural State University, Russia

A rarefied gas flow through a short channel into a vacuum presents a complex task due to significant non-equilibrium. Therefore, it is possible to find a good number of empirical formulas in open literature for calculating flow rate in this case. Correct approach to solving this problem should be based on the Boltzmann equation [1]. The difficulties of numerical solutions for this equation, caused by a large number of independent variables and a complex structure of a non-linear collision integral, are well-known. In our opinion, direct simulation Monte Carlo (DSMC) method [2], which is customarily viewed as a stochastic solution for Boltzmann equation, is preferable for use in tasks with strong non-equilibrium. DSMC method is an effective tool to solve problems of rarefied gas dynamics from free molecular to viscous regimes. An approach based on using DSMC method allows to take into account several factors, such as strong non-equilibrium, as well as to use various models of the gas-surface scattering and the gas molecule-molecule interactions. Therefore, it is appropriate to use DSMC method to study the rarefied gas flow through a short channel into a vacuum.

Practical application of the results of such research can be in the development and creation of such devices as micro- and nanoseparators, micropumps, microshutters, microgyroscopes, micro- and nanosatellites, and other micro- and nanoelectromechanical systems (MEMS/NEMS) [3]. The flow of gas in MEMS/NEMS, depending on device size and gas pressure, can be viscous, transitional or free molecular.

In this study, the mass flow rate through the channel into a vacuum is calculated over the wide range of gas rarefaction as function of channel's length. To study the gas molecule–molecule interaction influence, we used the variable hard sphere and variable soft sphere models defined for inverse–power–law potential and also the generalized hard sphere model defined for the Lennard–Jones potential. Maxwell, Cercignani–Lampis and Epstein models were used to simulate the gas–surface scattering. This study demonstrates that the gas molecule–molecule interaction and the gas–surface scattering can have a significant influence on the rarefied gas flow through a short channel into a vacuum. The analysis of the flow field, both within the channel as well as in upstream and downstream containers, is presented.

REFERENCES

1. C. Cercignani, *The Boltzmann Equation and its Application*, Springer, New York (1988).

2. G.A. Bird, Molecular Gas Dynamics and the Direct Simulation of Gas Flow, Oxford University Press, Oxford (1994).

3. *Encyclopedia of Microfluidics and Nanofluidics*, ed. by Dongqing Li, Springer, New York (2008).

11:20am **VT-WeM11 Effect of Surface Material and Roughness on Conductance of Channel between Parallel Disks at Molecular Flow**, ***H. Yoshida***, *M. Shiro, K. Arai, M. Hirata, H. Akimichi*, National Metrology Institute of Japan / AIST, Japan

For precise calculations of conductance and pressure distribution in vacuum chamber at molecular flow, it is important to know a degree of realization of diffuse reflection (also called cosine law) at surface. The conductance of an experimental channel changing the surface material and roughness was measured and compared with the results using Monte Carlo calculation assuming diffuse reflection.

The experimental channel consisted of two parallel disks was equipped with the vacuum chamber with an inner volume of 8.42x10-2 m3.The lower disk made from polished stainless steel (SS) has a diameter of 40 mm and a hole of 10 mm in diamter at the center. The upper disk with 51 mm in diameter is located as facing parallel to the lower one. The space between the upper and the lower disks was determined from 0.3 mm to 0.7 mm using gauge blocks as a spacer. After the vacuum chamber was filled with N2, Ar, or He gas at approximately 100 Pa, it was evacuated from the hole of lower disk by turbo molecular pump (0.22 m3/s) through the space between two parallel disks. The conductance of the channel was obtained from the pressure decrease rate in the vacuum chamber.

Eleven upper disks with different material and surface were prepared: polished SS, unpolished SS, quartz, Ti, Cu, Al, alumina with smooth surface, alumina with rough surface, SS with Au coating, SS with Pt coating, and SS with DLC coating. The effect of surface material and roughness on conductance was estimated from the measurement of the conductance of the channel by replacing the upper disk.

The conductance for N2 using polished SS with 0.5 mm in space was 3.68x10-4 m3/s (±2.7%), which was comparable to the calculated value of 3.67x10-4 m3/s (±1.3%). Similarly, the experimental values for N2 and Ar using polished SS, quartz and SS with DLC coating showed good agreement with the calculated ones within the measurement uncertainty. On the other hand, the conductance using SS with Pt coating was about 7% smaller than the calculated one. Their surfaces morphologies were analyzed by optical microscope and atomic force microscope (AFM). The microscopic surfaces of polished SS, quartz and SS with DLC coating were very smooth with the roughness less than 1 nm and the specific area less than 1.01. In the case of SS with Pt coating, however, the microscopic surface was rough with the specific area of 1.10. Judging from the results of all disks, the conductance seemed to be influenced by surface roughness rather than surface material. In the case of He, the experimental value was about 4% larger than the calculated one. This reason should be the influence of the specular reflection and/or the lobular scattering.

Vacuum Technology
Room: J1 - Session VT-WeA

Modeling and Accelerators
Moderator: M. Stutzman, Jefferson Lab

2:00pm **VT-WeA1 Slit Flow Simulation using Non-Linear BGK and ES-Models**, ***I.A. Graur***, *A. Polikarpov*, Provence University, France

The flow through a two-dimensional slit is simulated using non-linear model kinetic equations (BGK, ES-model) in the large Knudsen number range. The discrete velocity method is implemented to determine the flow parameters. Several different (finite and infinite) tank pressure ratios are considered and are compared with the results of DSMC simulations and some experimental data.

2:20pm **VT-WeA2 Background Reduction Strategies for Angular Profile Measurements of Gas Injected in Ultra-High Vacuum**, ***L.J. Isnard***, *R.M. Arès*, Université de Sherbrooke, Canada

Ultra-high vacuum (UHV) based deposition techniques, such as molecular beam epitaxy (MBE) and chemical beam epitaxy (CBE), have stringent requirements on layer thickness and composition uniformity. Concurrently, the source use efficiency is usually very low and needs to be improved while maintaining the same level of uniformity. There is therefore a need for a precise and reliable simulation platform to predict the angular distribution of gas molecules injected in vacuum through a nozzle of a given geometry. Several calculation techniques have already been proposed for MBE [1-6] and CBE [7].

However, the validity of such models needs to be established through a systematic experimental study that clearly isolates the contributions of each parameter. For this purpose, a test platform dedicated to the measurement of molecular beam angular profiles produced by a nozzle in UHV was designed and built. Its main features are discussed, especially regarding its ability to produce precise and reproducible data. For profiles being measured far away from the injector, the unwanted contribution from the molecules that reach the sensor after being scattered by the chamber walls (i.e. background level) is fairly large. In order to reduce it, several design strategies are considered and evaluated on the basis of the theory of rarefied gas dynamics. In particular, an innovative approach based on an angular selection tube is presented with a quantitative evaluation of its effect on the signal to background ratio. Finally a rule of thumb is proposed for the choice of the tube's dimensions allowing a maximum background reduction while keeping the impact on the signal as small as possible.

[1] J. A. Curless, J. Vac. Sci. Technol. B 3, 531 (1985).

[2] Z. R. Wasilewski, G. C. Aers, A. J. SpringThorpe, and C. J. Miner, J. Vac. Sci. Technol. B 9, 120 (1991).

[3] K. T. Shiralagi, A. M. Kriman, and G. N. Maracas, J. Vac. Sci. Technol. A 9, 65 (1991).

[4] Yu. N. Grigor'ev, M. Sh. Shavalev, and V. P. Shapeev, Tech. Phys. 39, 759 (1994).

[5] E. V. Ozolova, I. V. Igrat'ev, and A. P. Abramov, Tech. Phys. 39, 957 (1994).

[6] S. Kincal and O. D. Crisalle, Proc. Am. Control. Conf. 6, 4001 (2000).

[7] L. Isnard and R. Arès, J. Crystal Growth 311, 1640 (2009).

2:40pm **VT-WeA3 Investigation of Vacuum Flows in Fusion Reactors**, ***S. Varoutis***, *V. Hauer*, *C. Day*, Forschungszentrum Karlsruhe (FZK), Germany

Vacuum flows are strongly connected to several subsidiary systems of fusion reactors. In particular, there are high vacuum pumping systems for evacuation and maintenance of the needed low pressure levels in the torus, in the cryostat and in the neutral beam injectors. Each vacuum system consists of networks of various channels with different lengths and cross sections. The flow in such channels varies from the free molecular regime up to the hydrodynamic limit. In the present work, an experimental setup for measuring the mass flow rate of gases is proposed. Its principle is based on the predefined conductance through the duct and the measurement of the corresponding pressure difference. Experimental data for channels with various lengths and cross sections are presented and compared with corresponding numerical results based on the linearized kinetic BGK equation and the direct simulation Monte Carlo method (DSMC). It is noted that in all cases a very good agreement between experimental and numerical approaches, is observed.

3:00pm **VT-WeA4 Accurate Measurements of Low Permeation Flows of Hydrogen**, ***V. Nemanic***, *B. Zajec*, *M. Zumer*, Jozef Stefan Institute, Slovenia

Permeation of hydrogen isotopes from the upstream pressure through a membrane into high vacuum at elevated temperatures is a challenging task for vacuum technology when very low flows must be determined. The detection limit and accuracy of results depend on several experimental details. Geometrical and mechanical constraints set an engineering issue since the ultimate tightness of seals at high temperature must be preserved. On the other hand, measurements of the steady permeation flux and its transients require high sensitivity and stability of the gauges. It is also essential that the background represents only a fraction of the signal. We present recent improvements applied on a permeation cell design that results in efficient background suppression. When implemented in an all-metal UHV system, low permeation fluxes down to 10^{-11} mbar L/(cm^2 s) could be measured. We also present an innovative technique to perform measurements at a low upstream pressure capable of detecting changes corresponding to a permeation flux as low as 10^{-14} mbar L/(cm^2 s). The interpretation of data is presented by the surface rate constants rather than by diffusivity and solubility since the permeation regime at low pressures is known to be limited by surface reactions. Better experimental capability is needed today in the hydrogen storage technology and also in the field of nuclear fusion reactors to study the efficiency of permeation barriers and to predict tritium retention in the walls.

4:00pm **VT-WeA7 Vacuum R&D at Cornell Towards to Cornell Electron Storage Ring Test Accelerator for ILC Damping Ring and the ERL-based Light Sources**, ***Y. Li***, Cornell University **INVITED**

Many research and development efforts in the vacuum technology front in supporting two major research programs at the Cornell Laboratory for Accelerator Based-Sciences and Education (CLASSE). Over the past 3 years, a prototype DC photo-cathode injector was designed and constructed at CLASSE, as a key initial step towards to the Energy Recover Linac (ERL) based light sources at Cornell. The prototype injector includes a DC photo-cathode electron gun, a 10-cell superconducting radio-frequency cavity cryo-module, electron beam transporting beamlines equipped with a suit of beam instrumentation and electron beam dumps. Among various challenges, achieve and maintain extreme high vacuum in the DC photo-cathode electron gun is essential to the success of the prototype injector project. In the past year, we have also successfully re-configured the Cornell Electron Storage Ring (CESR) vacuum system to convert it into a test accelerator (thus CesrTA), as a part of the Globe Design Efforts (GDE) of the International Liner Collider Damping Ring. One of the goals is to understand electron cloud growth in vacuum chambers with many in-vacuum instruments of unique low-profile design, and to explore various eletron cloud suppression methods, including coatings of interior surfaces of vacuum beampipes. In this talk, highlights of the vacuum R&D efforts related to the two research programs are discussed.

4:40pm **VT-WeA9 Amorphous Carbon Films for the Eradication of Electron Cloud Effects in Modern Particle Accelerators**, ***P. Chiggiato***, CERN, Switzerland

High-intensity and high-energy positively charged beams could engender high density electron clouds in vacuum chambers. As a result, several detrimental effects could arise, such as beam instability, pressure increase and, at cryogenic temperatures, excessive thermal load. Among the crucial factors, the secondary electron yield (SEY) of the beam pipe material plays an important role: only when it is higher than a well defined threshold, the electron cloud build-up is possible. As an example, a value of 1.3 has been calculated for the Large Hadron Collider (LHC) nominal beam. Coating the whole vacuum chamber with a low SEY material is an attractive solution to this accelerator performance limitation.

Low maximum SEY have been reported for Ti-Zr-V non-evaporable getter films following in-situ heating. However, heating is not always possible. To cope with this constraint, sputtered amorphous carbon thin films have been studied for the unbakeable vacuum system of the Super Proton Synchroton (SPS), namely the largest LHC injector. After exposure to air for a few hours, the produced coatings show maximum SEY of about 1. In general, the yield increases for a longer exposure to air, but it can be kept lower than the threshold providing the coating parameters are suitably selected. UHV compatibility has been also studied and the relationship between outgassing rate and coating parameters has been highlighted.

The encouraging results obtained for small samples and a few vacuum chambers installed in the SPS vacuum system have triggered a programme possibly leading to the implementation of a-C films in the whole SPS (about

7 Km which amount to roughly 600 vacuum chambers); such a large scale application will be presented and the production strategy depicted.

5:00pm **VT-WeA10 Update on Pressure Simulation of Vacuum System at NSLS-II Storage Ring**, ***M.J. Ferreira***, *H.C. Hseuh, J.-P. Hu*, Brookhaven National Laboratory

National Synchrotron Light Source II (NSLS-II) will be a 3-GeV, 792-meter circumference, 3rd generation synchrotron radiation facility, with ultra low emittance electron beams and extremely high brightness X-ray beams. The storage ring vacuum system has a simulated average operating pressure of less than 1x10-9 mbar. A summary of the updated vacuum system design will be presented, based on outcome from pressure simulation using window-version Monte-Carlo based MOLFLOW+ code. The versatile PC-compatible code provides increasing details in pressure distribution of residual gases in the vacuum system, particularly for those active species scattering at innards of high-power and small-gap insertion devices. Since low emittance for electron beam is expected to achieve when proposed damping wigglers are installed at storage ring, a fine segmentation of code input at such critical sections will be processed to evaluate details from calculated pressure profile.

*Work performed under auspices of the United States Department of Energy, under contract DE-AC02-98CH10886

5:20pm **VT-WeA11 Fabrication of NSLS-II Storage Ring Vacuum Chambers**, ***H.C. Hseuh***, *L. Doom, M.J. Ferreira, C. Longo, P. Settepani, K. Wilson*, Brookhaven National Laboratory

National Synchrotron Light Source II (NSLS-II), being constructed at Brookhaven, is a 3-GeV, 500 mA, 3rd generation synchrotron radiation facility with ultra low emittance electron beams. The storage ring vacuum system has a circumference of 792 m and consists of over 250 vacuum chambers ranging from 1 m to 6 m in length, and an average operating pressure of less than $1x10^{-9}$ mbar to minimize beam-residual gas interactions. Most vacuum chambers are made of aluminum and stainless steel, with different cross sections either fitted into the bending magnets or surrounded by multipole magnets. The layout of the storage ring vacuum systems will be presented. The detailed design of the vacuum chambers, the pumps and the photon absorbers will be described. The aluminum chambers are extruded, curved with 25 m radii in the case of the bending chambers, precision machined and welded to bi-metal Conflat flanges using robotic welding machines. The fabrication and evaluation of these aluminum chambers will be presented.

*Work performed under auspices of the United States Department of Energy, under contract DE-AC02-98CH10886

5:40pm **VT-WeA12 The Vacuum System of the 3 GeV Taiwan Photon Source**, ***J.R. Chen***, NSRRC and NTHU, Taiwan, *G.Y. Hsiung, C.C. Chang, C.L. Chen, C.K. Chan, H.P. Hsueh, C.M. Cheng, C.Y. Yang*, National Synchrotron Radiation Research Center, Taiwan

A design and prototype of the vacuum system of a low-emittance 3 GeV synchrotron light source, the Taiwan Photon Source (TPS, with a circumference of 518.4m), is described. The TPS vacuum system has low-outgas aluminum beam ducts, low impedance structure, oil-less pumping system and oil-less fabrication process. Little dust, a stable mechanical structure and high reliability components are also equipped in the vacuum system. A 14 m long prototype of the TPS vacuum system was fabricated. Two 4 m long bending-magnet chambers were made by the CNC machining process, lubricated with ethyl alcohol to protect the aluminum surface from oil contamination. Ozonated water cleaning process was applied to reduce the photo-desorption rate from the chamber surface. The design considerations, the critical factors in fabrication and the test results of the vacuum system prototype are presented.

Authors Index

Bold page numbers indicate the presenter

— A —

Abernathy, C.: VT-TuP10, 6
Agarwal, S.: VT-TuP17, 7
Akimichi, H.: VT-TuP16, 7; VT-WeM11, 9
Andreaus, B.: VT-MoA1, 3
Arai, K.: VT-TuP16, **7**; VT-WeM11, 9
Arès, R.M.: VT-WeA2, 10
Arnold, P.C.: VT-MoA7, **3**

— B —

Bartlett, A.J.: VT-MoM8, 2
Blouch, S.: VT-MoA6, 3; VT-TuP4, 5
Brown, J.: VT-MoA2, 3
Brucker, G.A.: VT-MoA6, **3**; VT-MoA7, 3; VT-TuP4, 5

— C —

Campagna, L.: VT-WeM9, 9
Chan, C.K.: VT-WeA12, 11
Chang, C.C.: VT-WeA12, 11
Chen, C.L.: VT-WeA12, 11
Chen, J.: VT-MoM5, 1
Chen, J.R.: VT-TuP13, 6; VT-WeA12, **11**
Cheng, C.M.: VT-TuP13, 6; VT-WeA12, 11
Cheung, W.S.: VT-TuP15, 7; VT-TuP6, **5**
Chiggiato, P.: VT-WeA9, **10**
CHoi, H.Y.: VT-TuP15, 7
Chung, S.M.: VT-MoM9, 2
Ciobanu, C.V.: VT-TuP17, 7

— D —

Davies, R.: VT-TuP10, **6**
Day, C.: VT-WeA3, 10
Doom, L.: VT-WeA11, 11
Dorsman, R.: VT-WeM6, 8

— E —

Eacobacci, M.J.: VT-MoM8, 2
Ellefson, R.E.: VT-MoA3, **3**
Emelli, E.: VT-WeM9, 9
Ermakov, A.V.: VT-MoA4, 3

— F —

Ferreira, M.J.: VT-WeA10, **11**; VT-WeA11, 11
Flynn, K.: VT-MoM10, **2**

— G —

Genis, A.P.: VT-TuP11, 6
George, S.M.: VT-WeM1, **8**
Gila, B.: VT-TuP10, 6
Giors, S.: VT-WeM9, **9**
Gooding, T.: VT-MoA9, 4
Goodrich, T.L.: VT-TuP5, 5
Graur, I.A.: VT-WeA1, **10**

— H —

Hauer, V.: VT-WeA3, 10
Heller, M.: VT-MoM5, **1**
Hendricks, J.: VT-MoA9, **4**
Hinch, B.J.: VT-MoA4, **3**
Hirata, M.: VT-TuP16, 7; VT-WeM11, 9
Hong, S.S.: VT-TuP6, 5
Hseuh, H.C.: VT-WeA10, 11; VT-WeA11, **11**
Hsiung, G.Y.: VT-TuP13, **6**; VT-WeA12, 11
Hsueh, H.P.: VT-WeA12, 11
Hu, J.-P.: VT-TuP2, **5**; VT-WeA10, 11

— I —

Ikeda, K.: VT-WeM4, 8
Isnard, L.J.: VT-WeA2, **10**
Ithaca, J.: VT-MoA2, 3

— J —

Jariwala, B.: VT-TuP17, **7**

— K —

Kang, S.B.: VT-TuP15, 7
Kang, S.W.: VT-TuP6, 5
Kanouff, M.: VT-WeM3, 8
Kato, S.: VT-TuP14, **6**
Kendall, B.R.F.: VT-MoM1, 1
Kirk, W.P.: VT-WeM3, **8**
Kitano, M.: VT-WeM4, 8
Koops, R.: VT-MoM4, 1
Koster, N.B.: VT-MoM4, **1**

— L —

Legare, J.: VT-MoM5, 1
Levine, P.D.: VT-MoA10, **4**
Li, Y.: VT-WeA7, **10**
Lim, J.Y.: VT-TuP15, **7**; VT-TuP6, 5
Longo, C.: VT-WeA11, 11

— M —

Manini, P.: VT-MoM9, **2**
Mankey, G.J.: VT-TuP12, 6
Mezzacappa, A.: VT-TuP9, **6**
Miller, L.: VT-MoA2, 3
Morgan, C.G.: VT-MoM3, **1**

— N —

Nadesalingam, M.P.: VT-WeM3, 8
Nagase, M.: VT-WeM4, 8
Nemanic, V.: VT-WeA4, **10**
Nishiwaki, M.: VT-TuP14, 6

— O —

Ohmi, T.: VT-WeM4, 8
Olsen, B.G.: VT-TuP4, **5**
Olson, D.A.: VT-MoA9, 4
Ormrod, S.: VT-MoM11, **2**

— P —

Park, C.D.: VT-MoM9, 2
Park, K.A.: VT-TuP6, 5
Patel, S.: VT-TuP1, **5**
Peacock, N.T.: VT-MoM6, **1**
Polikarpov, A.: VT-WeA1, 10

— R —

Rai, V.: VT-TuP17, 7
Randall, J.: VT-WeM3, 8
Rathbone, J.: VT-MoA6, 3; VT-MoA8, 3; VT-TuP4, 5
Rebecchi, C.: VT-MoM10, 2
Reichling, M.: VT-TuP7, 6

— S —

Sandt, P.: VT-MoA8, 3
Sazhin, O.: VT-WeM10, **9**
Schofield, N.: VT-MoM11, 2
Schott, M.: VT-MoA6, 3; VT-MoA8, **3**; VT-TuP4, 5
Settepani, P.: VT-WeA11, 11
Sharipov, F.: VT-WeM5, 8
Shin, J.H.: VT-TuP15, 7
Shin, Y.-H.: VT-TuP15, 7
Shirai, Y.: VT-WeM4, 8
Shiro, M.: VT-WeM11, 9
Smith, D.A.: VT-MoM1, **1**
Sogo, S.: VT-MoM5, 1
Stocker, R.: VT-MoA1, 3
Sun, B.: VT-TuP5, **5**
Syssoev, S.E.: VT-MoM8, **2**

— T —

Thornberg, S.: VT-MoA2, **3**
Tomita, T.: VT-TuP16, 7
Trillwood, E.: VT-TuP18, **7**
Tröger, L.: VT-TuP7, **6**

— V —

V Nampoori, H.: VT-TuP12, **6**
Valougeorgis, D.: VT-WeM5, 8
Van Antwerp, K.: VT-MoA6, 3; VT-MoA8, 3; VT-TuP4, 5
van Zeijl, E.: VT-MoM4, 1
Vanderford, J.: VT-TuP11, **6**
Vane, R.: VT-MoM3, 1
Varoutis, S.: VT-WeA3, **10**; VT-WeM5, **8**
Versluis, R.: VT-WeM6, **8**

— W —

Wallace, R.M.: VT-WeM3, 8
Wilson, K.: VT-WeA11, 11
Wüest, M.: VT-MoA1, **3**

— Y —

Yamashita, S.: VT-WeM4, **8**
Yang, C.Y.: VT-WeA12, 11
Yoshida, H.: VT-WeM11, **9**

— Z —

Zajec, B.: VT-WeA4, 10
Ziemer, K.S.: VT-TuP5, 5
Zumer, M.: VT-WeA4, 10