Vacuum Technology
Room: Southwest Exhibit Hall - Session VT-TuP

Vacuum Technology Poster Session and Student Posters

VT-TuP1 Vacuum Pressure Simulation for the Hard X-Ray Insertion Device Beamline 17A at NSLS, ***J.-P. Hu***, Brookhaven National Laboratory

Built in the 1980's, the insertion device beamline-17 at the X-ray storage ring of the Brookhaven Lab's National Synchrotron Light Source (NSLS) has been using superconducting-wiggler generated hard X-rays to facilitate cutting edge research. By sharing the wiggler's horizontal beam fan, three inline and one adjacent beamlines (17B1-B3 and 17C) have been designed to perform material stress-strain mapping, mineral phase transition under high-pressure, laser heating, and diffraction crystallography. To meet present-day high demand of hard X-rays for nano-structure probing via surface and interface scattering experiments and for large-volume high-press studies, a new beamline dubbed 17A, which also shares the wiggler's beam fan, has been constructed at immediately downstream to the common monochromator for all the branch beamlines at 17. For the purpose of improving beam quality, user safety and system vacuum, the degraded monochromator was replaced during the 17A construction by a custom-made monolithic unit to accommodate (1) a Si-crystal for the white beam bending (7.6-deg) into the 17A line, (2) a water-cooled white-beam filter followed by a collimated aperture for beam steering, (3) a Hevi-Met alloy of tungsten for bremsstrahlung shielding, (4) an ASME-certified burst disk for high pressure release, and (5) a sputter ion pump for outgas removal and high vacuum upkeep. Flanged to the beam exit port at the SS monochromator chamber is a round SS spool piece and a copper-brazed Be-window, installed to separate the beamline-17A vacuum from its upstream beamline-17 vacuum. At 1.4-meter downstream of the Si-crystal in monochromator is a 6-way cross, set to install a phosphor screen and a CCTV for the beam image viewing and profile recording. Along the beam path of 2.6-meter from the 6-port optical enclosure, a 200 L/s sputter ion pump is hooked and sealed beneath the round beam pipe to remove desorbed gases from photon-stimulated scattering amid two Be-windows. For beam size confinement, residual gas analysis, synchrotron radiation blockage and shock wave monitoring, a tungsten slit, a tee-port, a tantalum-plated safety shutter and a Be-window are respectively installed at 0.7-, 1.5-, 1.8- and 2.5-meter off the ion pump. Prediction of pressure profile along the 17A was performed using the Monte-Carlo based Molflow code for gas conductance estimate and the finite-difference based Vaccalc code for pressure distribution calculations. Details of beamline vacuum versus pre-cleaned and pre-baked assemblies encompassing the segmented beampipe will be presented. (Work performed under auspices of the US DOE, under contract DE-AC02-98CH10886)

VT-TuP2 Yttria/ Rhenium Alloy Emission Filaments for Analytical Instrumentation, ***J. Manura***, *R. Shomo, C. Baker*, Scientific Instrument Services

VT-TuP3 Calibration of Ultra-High Vacuum Gauge from 10^{-9} Pa to 10^{-5} Pa by Two-Stage Flow-Dividing System, ***H. Yoshida***, *K. Arai, M. Hirata, H. Akimichi*, National Institute of Advanced Industrial Science and Technology (AIST), Japan

A new two-stage flow dividing system has been developed for the calibration of ultrahigh vacuum gauges from 10^{-9} Pa to 10^{-5} Pa for N_2, Ar, and H_2. This system is designed based on the techniques of the calibration system in high vacuum region from 10^{-7} Pa to 10^{-2} Pa [1].

The system consists of four chambers: an initial chamber V_0, a flow divider V_1, a calibration chamber V_2, and an evacuation chamber V_3. Chambers between V_0 and V_1 and chambers between V_1 and V_2 are connected to each other with a capillary and a sintered filter, respectively. The chamber V_2 is evacuated by a turbo molecular pump (1100 L/s for N_2) through an orifice of 30 mm in diameter. The flow divider V_1 is evacuated by a subsidiary turbo molecular pump (220 L/s for N_2). The pressure P_0 in the initial chamber is changed in 12 steps using a pressure controller in the range from 10^2 Pa to 10^5 Pa. The time interval for each step is 600 seconds. Following the change in the P_0, the pressure P_1 in the flow divider and the pressure P_2 in the calibration chamber similarly change from 10^{-4} Pa to 10 Pa and from 10^{-9} Pa to 10^{-5} Pa, respectively. The pressure P_2 is determined from the pressure P_1 using a pressure ratio of P_2 to P_1. The ratio is pressure independent because the conductances of sintered filter C_1 and the effective pumping speed of the turbo molecular pump though the orifice C_{main} are pressure independent at molecular flow region.

The modifications of this system from the previous one are listed below. (1) TiN coated stainless steel vacuum chambers are used as V_2 and V_3 to decrease outgassing from the chambers [2]. (2) The conductance of the sintered filter is 1000 times smaller than that of previous system to control the pressure in the range from 10^{-9} Pa to 10^{-5} Pa. (3) The ratio P_2/P_1 is measured using a calibrated ionization gauge and a calibrated spinning rotor gauge. The ratio for N_2, Ar, and H_2 is obtained to be 6.41 $x10^{-7}$, 6.26 $x10^{-7}$, and 8.36 $x10^{-7}$, respectively.

The pressure P_2 is measured by an Extractor gauge (EXG) and an Axial-Symmetric Transmission gauge (ATG). The typical background pressure was (2-4)$x10^{-9}$ Pa. These gauges were calibrated from 10^{-9} to 10^{-5} Pa for N_2, Ar, and H_2 with an uncertainty of about 5% with the confidence level of 95% (k=2). The linearities of these gauges were within ±2%. The fluctuations of pressure indications were within ±2% for 1 hour.

[1] H. Yoshida, K. Arai, H. Akimichi, M.Hirata, J. Vac. Sci. Technol. A 26 128 (2008)

[2] H. Akimichi, M Hirata, Metrologia 42 S184 (2005)

VT-TuP4 Simultaneous Measurement of Pressure and Viscosity with a Resonant Sensor in a Viscous Flowing Gas, ***A. Kurokawa***, AIST, Japan, *H. Hojo, T. Kobayashi*, VPI Co., Japan

With a quartz tuning-folk resonator vibrating at the resonant frequcny in the viscuos flowing gas, we found that the measurement of the resonator's Δf and ΔZ enabled to derive the pressure and the viscosity of the viscous flowing gas simultaneously. The parameter of Δf is the frequency change from its vibrating frequency in high vacuum. Another parameter of ΔZ is the impedance change from the resonator impedance in high vacuum. Also the ΔZ is related to the pressure and the viscosity of the gas. We focused on the pressure dependence of Δf and of ΔZ to derive the pressure and the viscosity.

In this experiment, to achieve the precise measurements of Δf and ΔZ, we paid careful attention to the temperature control because Δf was very sensitive to the temperature. We used the constant-temperature chamber in which the resonator, the driving circuit for the resonator, mass flow controllers, and the absolute pressure gauge were installed. The temperature variation was ±0.1ºC during the experiment. In addition the driving circuit was stored in a thermostatic box which temperature was maintained at 30±0.02ºC to minimize the frequency drift. The driving circuit applied constant driving voltage(Vd) to the resonator and the driving current(Id) passing through the resonator was monitored. The impedance of the resonator (Z) was given by the ratio of Vd to Id. The resonator was a tuning-folk type quartz resonator and had a vibration frequcny of 32kHz. The measured gases were Ne, Ar, N_2, O_2, Kr. The gas was charged at 130 kPa initially, and was vacuumed at the rate of 20 Pa/sec. The pressure of the gas was measured with the capacitance manometer.

The results showed that P-ΔZ for every gas showed the same characteristics; the ΔZ has larger value for higher pressure. For the higher mass of the gas showed the larger ΔZ at atmospheric pressure except for Ne. The every P-ΔZ curve did not across each other except for Ne.

The P-Δf graph showed also the same tendency. The Δf has larger value for higher pressure, however, for the higher mass of the gas showed the larger Δf at atmospheric pressure including Ne. The every P-ΔZ curve did not intersect one another except for Ne. Then showed close but not the same characteristics.

The ΔZ-Δf plot revealed the difference between the P-ΔZ and P-Δf. The ΔZ-Δf curves did not intersect one another above 1 kPa and that the ΔZ-Δf curves were arranged in order of the viscosity of the gas. Then the pressure and the viscosity of the gas can be derived simultaneously from ΔZ-Δf curve.

VT-TuP5 Study on Calibration Methods of Discharge Coefficient of Sonic Nozzles using Constant Volume Flow Meter, ***W.S. Cheung***, *J.H. Shin, S.B. Kang, K.A. Park, J.Y. Lim*, KRISS, Republic of Korea

This paper address technical issues in calibrating discharge coefficients of sonic nozzles used to measure the volume flow rate of low vacuum dry pumps. The first challenging issue comes from the technical limit that their calibration results available from the flow measurement standard laboratories do not fully cover the low vacuum measurement range of 10^{-3} ~ 10^2 mbar although the use of sonic nozzles for precision measurement of gas flow has been well established in national metrology institutes. The second one is to make an ultra low flow sonic nozzle sufficient to measure the throughput range of 10^{-2} mbar-l/s. Those small-sized sonic nozzles 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 down stream pressures for the measurement of the volume flow rate of

vacuum pumps. These distinctive properties of sonic nozzles are exploited to measure the pumping speed of low vacuum dry pumps widely used in the vacuum-related academic and industrial sectors.

Sonic nozzles have been standard devices for measurement of steady state gas flow, as recommended in ISO 9300. This paper introduces two small-sized sonic nozzles of diameter 0.03 mm and 0.2 mm precisely machined according to ISO 9300. The constant volume flow meter (CVFM) readily set up in the Vacuum center of KRISS was used to calibrate the discharge coefficients of the machined nozzles. The calibration results were shown to determine them within the 3 % measurement uncertainty. Calibrated sonic nozzles were found to be applicable for precision measurement of steady state gas flow in the vacuum process in the ranges of 0.6 ~ 2,050 cc/min. Those flow conditions are equivalent to the very fine gas flow with Reynolds numbers of 26 ~ 8,500. Those encouraging results may confirm that calibrated sonic nozzles enable precision measurement of extremely low gas flow encountered very often in the low vacuum processes. Both calibrated sonic nozzles are demonstrated to provide the precision measurement of the volume flow rate of the dry vacuum pump within one percent difference in reference to CVFM. Calibrated sonic nozzles are applied to a new 'in-situ and in-field' equipment designed to measure the volume flow rate of low vacuum dry pumps in the semiconductor and flat display processes.

VT-TuP6 High-k Gate Dielectric and Electrical and Surface Studies of Al_2O_3, HfO_2, La_2O_3, $Al_xHf_yO_z$, and ZrO_2/HfO_2 on Silicon via Atomic Layer Deposition, *G. Hernandez, R. Candler, S. Franz,* ***Y.S. Lin****, UCLA

VT-TuP7 Overview of Anharmonic Resonant Ion Trap Mass Spectrometry Technology, ***P. Acomb****, G. Brucker, K. Van Antwerp, M.N. Schott*, Brooks Automation, Inc.

The poster will present the basics of an economical and commercially available mass spectrometer based upon Anharmonic Resonant Ion Trap Technology for mass selection. The mass separation method using electrostatic fields for ion trapping and the property of Autoresonance for mass selection will be shown. The key elements of gauge biasing, gas ionization, low-power RF-based mass separation and ion detection will be highlighted. Key performance characteristics of the anharmonic resonant ion trap will be summarized.

VT-TuP8 Elements of Vacuum Quality Measurement using an Anharmonic Resonant Ion Trap Mass Spectrometry Technology, ***L. Landman***, Brooks Automation, Inc.

The poster will present the basics of a Vacuum Quality Measurement System using the inputs from commercially available mass spectrometer based upon Anharmonic Resonant Ion Trap Technology for mass selection, a total pressure gauge, external signals and a scripting tool to transform complex measurements into a single valued output.

VT-TuP9 A Computationally Simple, Wafer-to-Feature-Level Model of Etch Rate Variation in Deep Reactive Ion Etching, ***J.O. Diaz****, H.K. Taylor,* Massachusetts Institute of Technology, *R.J. Shul, R.L. Jarecki, T.M. Bauer,* Sandia National Laboratories, *D.S. Boning,* Massachusetts Institute of Technology, *D.L. Hetherington*, Sandia National Laboratories

Modeling etch rate variation in Deep Reactive Ion Etching (DRIE) helps to identify possible defects in MEMS and IC devices arising from sub-optimal etching depths and times. Besides tool-specific properties, such as the chamber design, another cause for the observed non-uniformity effects is the particular wafer pattern employed. At the wafer scale, previous studies have shown that wafers with a large percentage of open (exposed Si) area, or pattern density, exhibit a radial center-low etch-rate distribution, while those with low pattern density achieve radial center-high etch rates. At the die scale, it is widely known that etch rate decreases as local pattern density increases. Furthermore, at the feature scale, the microloading effect describes how adjacent features tend to compete for radical species, thus decreasing overall etch rates within individual features.

We present a model to capture these pattern-dependencies by tracking the spatial and temporal distribution of the ion and radical species within the DRIE chamber. The model implementation uses a time-stepped algorithm with three levels – corresponding to the three different length scales – and a coarse-grain approach where multiple features in a given region are characterized by a particular shape, size and density. The local radical species concentration distribution above the wafer is determined at each time step using current feature geometries to compute their Knudsen transport coefficient which is linked to the radical transport mechanisms within other areas in the chamber. At the end of each time step, etch rate estimates based on this radical concentration distribution and current feature geometries are used to update feature depth information for the next time interval. At the wafer scale, our modeling results achieve a success comparable to that of previously-developed wafer-level models with an etch rate RMS error percentage between 2.1% and 8.2%. The results also show that feature-level etch evolution substantially impacts the wafer-level fluorine concentration and thereby modifies the wafer and die etch rate uniformity. We expect a similar model could be incorporated into CAD software tools to evaluate masks and correct potential design issues before they are made. Our results also shed light on possible tool and process modifications to allow users the capability of altering across-wafer etch rate variability. Sandia National Laboratories is a multi program 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.

VT-TuP10 Design, Simulation, and Implementation of Plasma Enhanced Atomic Layer Deposition in a Laminar Flow Reactor, ***K. Kellogg****, P. Falvo,* University of South Florida, *S. Lee,* University of South Florida, *T. Wright, J. Wang*, University of South Florida

A plasma enhanced atomic layer deposition reactor (PE-ALD) was built for the purpose of growing thin films on wafers up to 2.5" in diameter. Internationally, papers have been published describing characteristics of both homebuilt [1,2,3] and commercially available ALD reactors [4]. The construction of this reactor was strategically designed using these descriptions, within an allowable project time and budget. Design characteristics include an inert carrier gas, millisecond speed precursor valves, a remotely generated inductively coupled plasma, and a chamber with a high volume to surface ratio geometry. The reactor will act to complement and increase the current application repertoire versus our commercially available reactor located in the University's thin films laboratory. In this regard, the chamber must be optimized to accommodate unique recipe applications currently unattainable with the in-house system. The functionality of this reactor will include three separate modes of operation: a thermal reaction mode (thermal ALD) for use with general recipe applications, an isolated chamber mode necessary for high aspect ratio substrates, and a plasma enhanced mode (plasma enhanced ALD) for greater process recipe versatility such as metals and nitrides. ALD allows for a precision unattainable with other deposition processes. Unlike CVD, ALD is not dependent upon precursor flux upon the substrate surface, instead relying upon step-wise A + B = P synthesis. Reactor characteristics such as laminar gas flow and plasma ion locality concentration and intensity will be modeled with COMSOL finite element simulations. ALD deposition cycle times are optimized according to ALD chemical reactions and by in-situ monitoring of sample growth rates by means of fiber optic spectroscopy. Important considerations included an optimized pumping rate and a minimization of unavoidable deposition upon all surfaces other than the process wafer. Process optimization was also pursued by means of vacuum gauge feedback and automation of precursor valve cycle sequence by means of a Lab View enabled PC. Other automated controllable growth parameters include substrate heater temperatures, reactor wall temperatures and the energies of plasma ion bombardment upon the substrate surface species. Safety concerns have also been addressed by ensuring suitable gas exhaust, pump maintenance, hard-wired safety valve shut-off programming and gas cylinder and hazardous materials safety training of individual users. The chamber design, multitude of process optimizations, and comparisons with existing designs and models allow for substantial research parameters to be explored and discussed.

References: [1] J. W. Elam, M. D. Groner, and S. M. George, "Viscous Flow Reactor with Quartz Crystal Microbalance for Thin Film Growth by Atomic Layer Deposition," Review of Scientific Instruments, Vol. 73 No. 8, Aug. 2002, pp. 2981-2987 [2] H. C. M. Knoops, L. Baggetto, E. Langereis, M. C. M. van de Sanden, J. H. Klootwijk, F. Roozeboom, R. A. H. Niessen, P. H. L. Notten, and W. M. M. Kessels, "Deposition of TiN and TaN By Remote Plasma ALD for Cu and Li Diffusion Barrier Applications," Journal of the Electrochemical Society, Vol. 155, No. 12, Oct 2008, pp. G287-G294 [3] G. A. Ten Eyck, J. J. Senkevich, F. Tang, D. Liu, S. Pimanpang, T. Karaback, G. Wang, T. Lu, C. Jezewski, and W. A. Lanford, "Plasma-Assisted Atomic Layer Deposition of Palladium," Chemical Vapor Deposition, Vol 11, No. 1, 2005, pp. 60-66. [4] S. B. S. Heil, J. L. van Hemmen, C. J. Hodson, N. Singh, J. H. Klootwijk, F. Roozeboom, M. C. M. van de Sanden, and W. M. M. Kessels, "Deposition of TiN and HfO2 in a Commercial 200mm Remote Plasma Atomic Layer Deposition Reactor," Journal of Vacuum Science and Technology A, Vol. 25, No. 5, Sept/Oct 2007, pp. 1357-1366.

VT-TuP11 A Cryogenic Vacuum Chamber for Low Temperature Thermophotovoltaic Testing, ***D. DeMeo****, T. Vandervelde*, Tufts University

Thermophotovoltaics (TPV) are devices capable of converting infrared electromagnetic radiation into electricity. Strained Layer Superlattices allow

***** VT Student-Built Vacuum Systems Poster Competition

TPV devices to operate at longer wavelengths. In order to determine the performance of these devices, a unique test apparatus was designed and constructed. As the devices become sensitive to longer wavelengths (lower temperatures) in the infrared, the need to control the sample's ambient temperature becomes paramount. Here, we present a custom, cryogenic vacuum chamber specifically designed to test long wavelength TPV cells. The tester utilizes two copper heat shields cooled via conduction with two liquid nitrogen reservoirs to block outside thermal radiation. A blackbody source illuminates a temperature controlled sample at high vacuum, ~10^{-6} Torr. The chamber is also connected to multiple thermocouples and a source-meter for measurement and testing purposes. This test apparatus will enable future research into low temperature TPV and other optoelectronic devices.

VT-TuP12 Experimental Approach to Equalizing the Orifice Method with the Throughput One for the Measurement of TMP Pumping Speed, ***J.Y. Lim***, *S.B. Kang, J.H. Shin,* Korea Research Institute of Standards and Sciences, Republic of Korea, *D.J. Cha,* Kunsan National University, Republic of Korea, *D.Y. Koh,* Korea Institute of Machinery and Materials, Republic of Korea, *W.S. Cheung*, Korea Research Institute of Standards and Sciences, Republic of Korea

Methods of the characteristics evaluation of turbo-molecular pumps (TMP) are well-defined in the international measurement standards such as ISO, PNEUROP, DIN, JIS, and AVS. The Vacuum Center in the Korea Research Institute of Standards and Science (KRISS) has recently designed, constructed, and established the integrated characteristics evaluation system of TMPs based on the international documents by continuously pursuing and acquiring the reliable international credibility through measurement perfection.

The measurement of TMP pumping speed is normally performed with the throughput and orifice methods dependent on the mass flow regions. However, in the UHV range of the molecular flow region, the high uncertainties of the gauges, mass flow rates, and conductance are too critical to precisely accumulate reliable data. With UHV gauges of uncertainties less than 15% and a calculated conductance of the orifice, about 35% of pumping speed uncertainties are experimentally derived in the pressure range of less than 10^{-6} mbar. In order to solve the uncertainty problems of pumping speeds in the UHV range, we introduced an SRG with 1% accuracy and a constant volume flow meter (CVFM) to measure the finite mass flow rates down to 10^{-3} mbar-L/s with 3% uncertainty for the throughput method. In this way we have performed the measurement of pumping speed down to less than 10^{-6} mbar with an uncertainty of 6% for a 1000 L/s TMP. In this article we suggest that the CVFM has an ability to measure the conductance of the orifice experimentally with flowing the known mass through the orifice chambers, so that we may overcome the discontinuity problem encountering during introducing two measurement methods in one pumping speed evaluation sequence.

VT-TuP13 Implementation of a Lambertson Magnet in an Ultrahigh Vacuum Electron Storage Ring, *V. Anferov, J. Doskow, G. East, S.Y. Lee, T. Rinckel,* ***C. Romel****, T. Sloan, P. Sokol*, Indiana University

The Advanced Electron-Photon Facility (ALPHA), built at Indiana University, is a multipurpose electron accelerator to be used for DoD radiation effects testing as well as IU's interest in a compact high-brightness x-ray source. ALPHA consists of a 50 MeV linear accelerator source and 20 m storage ring which operates at 1x10^{-11} Torr. A Lambertson magnet, used to inject/extract the electron beam into and out of the ring, has been uniquely designed for optimal vacuum behavior and septum straightness while maintaining magnetic field quality. The design minimizes the ultrasonically-tested, 1018 steel pole tip exposure to UHV via a nickel plated surface and an exterior stainless steel vacuum body, welded to the pole tip. The magnet assembly yielded positive results in magnetic field and vacuum testing and is currently being commissioned in the ring.

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