Vacuum Technology Division
Room A213 - Session VT-MoM

Pumping, Outgassing, leaks, and Vacuum Pressure Measurement

Moderators: Scott Heinbuch, MKS Granville-Phillips Division, Longmont, Giulia Lanza, SLAC National Accelerator Laboratory

8:20am **VT-MoM-1 Operational Experiences of Compact Non-Evaporable Getter Pumps in CHESS-U and CBETA***, **Yulin Li**, Y Lushtak, L Ying,* Cornell University

In two recently commissioned accelerator projects at Cornell Laboratory of Accelerator-based Sciences and Education (CLASSE), a large number of high pumping capacity, compact non-evaporable getter (NEG) pumps were implemented to fulfill the required vacuum performances with very tight space constraint. In the Cornell Brookhaven ERL Test Accelerator (CBETA), NEGs are the only installed pumps. At a maximum electron beam energy of 150-MeV, no beam-induced gas load is expected in normal beam operations. We have demonstrated that adequate level of vacuum ($P<10^{-8}$ torr) can be achieved quickly after a ultra-dry nitrogen venting without in situ bakeout, which provide required flexibility in the CBETA vacuum system for various beam test configurations. In contrast, very high dynamic gas-load due to synchrotron radiation induced desorption (SRID) is expected in the vacuum system for the CHESS-U Upgrade, a major upgrade project for the Cornell High Energy Synchrotron Source (CHESS). During the commissioning phase of the CHESS-U, an extremely high SRID gas load may not only cause rapid NEG saturation (thus requiring frequent NEG re-activations), but also may potentially damage the small sputtering ion pumps (SIPs) of the NexTorr® (a NEG-SIP combination pump from SAES Getters). Protective control program is developed to prevent the potential damage to these SIPs, while keeping monitoring. In this paper, we will present our operational experiences of these compact NEGs in both CBETA and CHESS-U projects.

8:40am **VT-MoM-2 Al_2O_3 Coated Stainless Steel Vacuum Chamber and Parts***, **Martin Wüest**, Y Kuzminykh, G Mata Osoro, W Fuchs, J Gabathuler, L Ospelt,* INFICON Ltd., Liechtenstein

We built a vacuum system for calibration of total pressure sensors in the conventional way. We made initial performance measurements such as pumpdown times and achieved base pressure. This system was then taken apart and the stainless steel parts (chamber and fittings) were then coated with an Al_2O_3 layer using an ALD process. To do this we cleaned the parts with ozone, heated them to 300 °C and then finally coated them with an Al_2O_3 ALD process. We rebuilt the vacuum system using those coated parts and performed the performance test again. The result is that we can achieve a lower base pressure in shorter time. The achieved base pressure is approximately a factor 3 lower in the coated version compared to the uncoated version.

9:00am **VT-MoM-3 Comparative Outgassing Study of Identical Vacuum Chambers***, **James Fedchak**,* National Institute of Sandards and Technology (NIST)

We have measured and compared the H_2 and water outgassing rates for 7 identical vacuum chambers constructed of common vacuum materials and heat treatments: 304L, 316L, 316LN-ESR (electro-slag remelt), titanium, aluminum vacuum-fired 316L, and vacuum-fired 316LN-ESR. These chambers are of identical geometry and are from the same manufacturer. Comparison studies of outgassing from a large selection of chambers has the advantage over those of single samples or chambers in that the influence of chamber geometry in minimized. Much of the motivation for NIST to conduct this study is to identify ultralow outgassing materials for UHV and XHV vacuum systems, common candidate materials include aluminum, titanium, and vacuum-fired 316L or 316LN-ESR stainless steel. Obtaining these low pressures usually requires vacuum chambers with outgassing rates much less than 10^{-9} Pa L s^{-1} cm^{-2}. In addition, vacuum chambers constructed from materials with ultra-low outgassing rates can help reduce the cost of large vacuum systems by requiring fewer pumps (with the associated cost of operation and maintenance) to obtain the desired ultimate pressure. Other considerations in the selection of vacuum materials include the material cost, strength, machinability, weldability, and chemical resistance. One of our aims of this study is to put outgassing rates into the engineering tool kit. In addition to the above materials, we intend to present data on post process of some of the chambers, including electropolishing and a light air-bake, and on mild steel chambers.

9:20am **VT-MoM-4 The NIST VAcuum LEaks System (VALES): a new system for the primary and comparison calibration of small gas flows.***, **Julia Scherschligt**, J Fedchak, R Vest,* National Institute of Sandards and Technology (NIST)

Helium leak standards for low molecular flow rates are critical to the calibration of leak detectors, gas analyzers, and other equipment used in vacuum, aerospace, and space industries. Since 1984, the National Institute of Standards and Technology (NIST) has provided calibration services for the calibration of vacuum leak standards using two independent systems: The Primary Leak System (PLS), which calibrates leak artifacts against a flow meter, and the Leak Comparison Standard (LCS) which compares a customer leak to a NIST owned leak artifact as a function of temperature. The PLS system has recently been upgraded with a new mass-sensitive detector (a quadupole mass analyzer or QMA). The LCS has been retired from service but its functionality has been efficiently replicated on PLS. In this talk, we will describe the new calibration system, VALES, present recent results on the characterization of the new PLS detector and discus the on-going upgrade and automation of the entire calibration system

9:40am **VT-MoM-5 Creating a Controlled Gas Environment for Lifetime Testing of EUV Optics***, **Timo Huijser**, M van Putten, M van der Lans,* TNO, Netherlands

Optics used in Extreme ultra-violet (EUV) lithography typically operate in an environment of 0.01 to 0.1 mbar hydrogen. Since EUV machines cannot receive a bake out after installation it is difficult to reduce background outgassing such as for water, oxygen, nitrogen and hydrocarbons. Although the partial pressures of these contaminants are orders of magnitude lower, their presence in combination with EUV irradiation induces oxidation, etching, deposition and other processes that affect the lifetime of EUV optics.

At TNO these processes are studied using an EUV beam line facility (EBL2). To enable this type of research a method was developed to create a well-controlled environment of multiple gases with defined and stable partial pressures.

The gas environment typically consists of hydrogen (10^{-2} to 10^{-1} mbar) with added oxygen, water, nitrogen and/or hydrocarbons (10^{-8} to 10^{-4} mbar). The strategy for controlling the gas environment is to start by setting the pressures of the additives prior to adding hydrogen. For accuracy, the pressure values are chosen such that the pump speed drop after adding hydrogen is taken into account. In order to do this, the pump speed of all gases needs to be known for both (ultra) high vacuum conditions as well as medium vacuum conditions (after addition of hydrogen). The procedure for setting the gas environment comprises 4 steps:

1. Determine the pump speed at HV conditions of relevant additives such as oxygen, water, nitrogen and/or hydrocarbons
2. Calibrate the differentially pumped RGA system with a gas mixture of hydrogen with defined, small fractions of additives.
3. Inject this mixture in the exposure chamber at nominal operating conditions. Using the RGA calibration data, the individual pump speed of each species in hydrogen is now calculated.
4. Set the partial pressures of additives prior to adding hydrogen, taking into account the calculated drop of pump speed.

Once step 1 to 3 have been carried out for all additives the resulting pump speed values can be applied for each exposure as long as the vacuum system and its geometry are not altered. As a result the partial pressures can be set quickly using common ion gauges.

The method developed to create a well-controlled environment of multiple gases along with its corresponding procedures and results will be presented.

10:00am **VT-MoM-6 Sampling System Design to Predict Mixture Composition at a Quadrupole Mass Spectrometer Ion Source***, **Robert Ellefson**,* REVac Consulting

The use of gas mixtures to measure the sensitivity and fragmentation ratios for calibration of a quadrupole mass spectrometer (QMS) simplifies the process and enables *insitu* calibrations. A necessary factor in a mixture calibration method is knowledge of the composition present in the QMS ion source and at the reference ion gauge. Under the conditions of molecular flow of the mixture into the ion source and molecular pumping of the outlet flow, the composition at the ion source is equal to the stated values of the mixture. This knowledge enables a composition-weighted correction of the ion gauge reading to get the true ion source pressure due to different gauge sensitivities of each species. The partial pressures of components in the ion source are calculated using the mole fraction of the mixture's species times the corrected ion gauge pressure. The sensitivity for a specific gas species is the ratio of the ion current representing the species to the calculated partial pressure at a common time.

The gas dynamics of very low flow rate gas into the ion source from an end crimped capillary or small pore size frit from a high-pressure mixture is presented. The low flow rate produces molecular effusion and the stated mixture composition is established in the ion source. Another model for low pressure (< 10 Torr) gas introduction through an orifice predicts molecular flow into the ion source and a (correctable) species dependence of the mixture composition as a function of time as the species deplete from the sample volume. Results of QMS calibrations using these gas sources and methods are presented together with composition analyses of unknown gas samples.

10:40am **VT-MoM-8 Quantum Pressure Standard in the range 200 Pa to 20 kPa using Superconducting Microwave Cavity***, **Laurent Pitre,*** LNE Cnam-LCM, France*; P Gambette,* LNE-Cnam LCM, France*; R Gavioso, D Ripa,* INRiM, Italy*; M Plimmer,* LNE-Cnam LCM, France **INVITED**

An LNE-INRiM collaboration is conducting proof-of-principle tests of a primary pressure standard operating at pressures 200 Pa< p < 20 kPa at temperatures 4.6 K < T < 5.8 K. The proposed standard is based on precise measurements of the microwave resonance frequencies of a quasi-spherical, helium-filled, superconducting cavity maintained at cryogenic temperatures. Ultimately, the accuracy of this standard will be competitive with the present standard at LNE over the whole pressure range. The proposed standard exploits 4 theoretical and technological advances: (1) recent *ab-initio* calculations of the microwave-frequency refractive index of helium $n(p, T)$ near 6 K with an uncertainty corresponding to a relative pressure uncertainty $u_r(p) < 1.10^{-5}$ (at a 68% confidence level); (2) the commercial availability of cryogen-free, low-cost, pulsed-tube refrigerators, (3) the ability to manufacture superconducting microwave cavities with resonance quality factors on the order of 5 million (4) and the impending change of the SI that fixes the value of the Boltzmann constant, thereby reducing the uncertainty of thermodynamic temperature determinations in the cryogenic range. A crucial requirement for microwave pressure standards is maintaining the purity of the ^4He sample under test. For the proposed standard, this is facilitated by cryogenic cold traps that effectively remove all impurities except ^3He.

The first experimental result will be present with a 2.5 cm radius and with Nobium coated quasi sphere. A particular focus on the hydrostatic head correction and the thermomolecular effect will be presented during the presentation.

11:20am **VT-MoM-10 Progress Toward Primary Pressure Measurements based on Refractive Index***, **Kevin Douglass**, J Ricker, J Hendricks,* National Institute of Standards and Technology (NIST)

Towards the goal of quantum-based traceability of the Pascal, NIST has developed an optical pressure measurement system where traceability is achieved through accurate quantum mechanical calculations of the refractivity virial coefficients. Extremely accurate measurements of refractive index are possible; however, traceability is currently through the mercury manometer. Primary traceability for the NIST Fixed Length Optical Cavity (FLOC) will require an independent approach, relying solely on refractive index type measurements. A critical step in achieving primary traceability for the FLOC is determining the pressure dependent distortion terms. This is a major challenge because the pressure and the distortion term need to be determined simultaneously. A dual-wavelength approach can provide two measurements in-order to solve for the two unknown variables. The operational wavelengths for this measurement are at 633 nm and 1542 nm. The dual-wavelength approach and current results will be presented.

11:40am **VT-MoM-11 Application of Porous Conductance Element for High Vacuum Gauge Calibration***, **Martin-Viktor Johansson,*** Aix Marseille University, France*; M Wüest,* INFICON Ltd., Liechtenstein*; P Perrier,* Aix Marseille University, France*; I Graur,* Aix-Marseille University, France

It is well known that the sensitivity of high vacuum gauges, such as ionization gauges (IG), drift in time [1] and need to be periodically recalibrated. Removal of the sensors from in-situ is time-consuming, and calibration by direct comparison with calibrated IGs has limited accuracy.

The permeability and conductance of the micro sintered stainless-steel membranes with pores varying from 0.2 µm to 0.5 µm was investigated for a wide range of pressure and several gases, from continuum to free molecular regime using a previously developed method [2]. The conductance of this kind of membranes was found constant for low pressures. This property makes the studied membranes particularly suitable as a leak element, by taking advantage of the constancy of conductance in the free molecular regime.

Effective pumping speed of a turbo molecular pump and the conductance of the fabricated microporous conductance element tend to a constant value as the pressure decreases [3], which is still in the measurement range of a 10 mTorr CDG. With the measured constant value, we can use a CDG and the sintered porous stainless steel to calibrate high vacuum sensors. The proposed configuration can be put on the user's high vacuum system for calibration on site. This calibration method is based on absolute pressure sensors and was found to be robust and easy to use.

References:

[1] H.Yoshida, K.Arai, H. Akimichi, M. Hirata, Stability tests of ionization gauges using two-stage flow-dividing system, Vacuum, 84, 705-708, 2009

[2] M.V. Johansson, F. Testa, I. Zaier, P. Perrier, J.P. Bonnet, P. Moulin, I. Graur, Mass flow rate and permeability measurements in microporous media, Vacuum, 158, 75-85, 2018

[3] H. Yoshida, K. Arai, M. Hirata, H.Akimichi, New leak element using sintered stainless steel filter for in-situ calibration of ionization gauges and quadrupole mass spectrometers, Vacuum, 86, 838-842, 2012

Materials and Processes for Quantum Information, Computing and Science Focus Topic
Room B231-232 - Session QS+EM+MN+NS+VT-MoA

Systems and Devices for Quantum Computing

Moderators: Jonas Bylander, Chalmers University of Technology, Sweden, Ruichen Zhao, National Institute of Standards and Technology (NIST)

1:40pm **QS+EM+MN+NS+VT-MoA-1 DEMUXYZ Gate Using Single Microwave Drive Line for Multiple Qubits***, **Matteo Mariantoni**,* University of Waterloo, Canada*; C Earnest,* University atof Waterloo, Canada*; J Béjanin,* University of Waterloo, Canada

Superconducting qubits have the potential to lead to large-scale quantum computers with 10^5 or more qubits in 2D arrays. As the number of qubits increases, finding methods to connect all the necessary control lines to each qubit can become a serious challenge. In this talk, we introduce a new demultiplexed one-qubit gate: DEMUXYZ. This gate makes it possible to decrease the number of microwave control lines from N^2 to 1 by allowing multiple qubits to share a single microwave line. The shared line carries a continuous wave (CW) microwave tone, which is initially detuned from the qubits' idle frequency. When a qubit must undergo an arbitrary rotation on the Bloch sphere, the qubit is tuned on resonance with the CW tone and allowed to interact with the drive for the duration required to achieve the desired rotation. The rotation phase is tuned by detuning the qubit frequency away from the drive and idle frequency for the required time length. We demonstrate a first proof of concept for this gate performing experiments on Xmon transmon qubits. We characterize the gate ON/OFF ratio and perform quantum state tomography.

Funding Acknowledgement: This research was undertaken thanks in part to funding from the Canada First Research Excellence Fund (CFREF) and the Discovery and Research Tools and Instruments Grant Programs of the Natural Sciences and Engineering Research Council of Canada (NSERC).

2:00pm **QS+EM+MN+NS+VT-MoA-2 Structural and Electronic Characterization of a Novel Si/SiGe Heterostructure for Quantum Computing***, **Thomas McJunkin**, E MacQuarrie, S Neyens, B Thorgrimsson, J Corrigan, J Dodson, D Savage, M Lagally, R Joynt, M Friesen, S Coppersmith, M Eriksson,* University of Wisconsin - Madison

In recent years, silicon-based quantum dots have been shown to be a promising avenue for quantum computing. However, dots formed in silicon quantum wells exhibit a near-degeneracy of the two low-lying valley states. Motivated by a desire to increase the magnitude and tunability of this valley splitting, we report the characterization of a novel Si/SiGe heterostructure grown with a thin layer of SiGe embedded within the Si quantum well, near the top of the well. The Si/SiGe heterostructure is grown via UHV-CVD on a linearly graded SiGe alloy with a final Ge concentration of 29%. STEM measurements reveal the quantum well structure to consist of a ~10 nm Si layer, followed by a thin ~1 nm SiGe layer, and subsequent ~2 nm layer of pure Si. Above this quantum well, a ~35 nm layer of SiGe with 29% Ge is grown to separate the quantum well from the surface. The intent of this ~1 nm layer of SiGe, positioned just below the upper interface of the quantum well, is to modify the valley splitting of electrons in a 2-dimensional electron gas (2DEG) that reside near this interface. By modifying an external vertical electric field, the electron wavefunction can be moved on and off this spike in germanium concentration.

We report electronic measurements of both Hall bars and quantum dot devices that are fabricated on this heterostructure. Shubnikov-de Haas (SdH) and quantum Hall (QH) measurements reveal a peak transport mobility in excess of 100,000 $cm^2/(V\ s)$ at $6 \times 10^{11}\ cm^{-2}$ carrier density . We report SdH and QH measurements over a wide range of carrier density and magnetic field in the form of a fan diagram. Valley splitting values are measured in the quantum dot device by magnetospectroscopy, in which a few-electron dot transition is measured as the in-plane magnetic field is swept. Measuring at the second, third, and fourth electron transition in the quantum dot, we find valley splittings of 29, 48, and 65 ueV, respectively. To measure tunability of valley splitting, nearby gate voltages are changed to vary the vertical electric field at constant charge occupation. We find that both the lowest lying valley splitting and the valley splitting in the first excited orbital can be tuned over a factor of 2 by means of such changes in gate voltage.

2:20pm **QS+EM+MN+NS+VT-MoA-3 Efficient Quantum Computation using Problem-specific Quantum Hardware and Algorithms***, **Stefan Filipp**,* IBM Research - Zurich, Switzerland **INVITED**

In recent years we have observed a rapid development of quantum technologies for the realization of quantum computers that promise to outperform conventional computers in certain types of problems. This includes problems in optimization, machine learning, finite element calculations, and in the computation of complex molecules. A key requirement to perform computations on current and near-term quantum processors is the design of quantum algorithms with short circuit depth that finish within the coherence time of the qubits. To this end, it is essential to implement a set of quantum gates that are tailored to the problem at hand and that can be directly implemented in hardware. To efficiently compute the ground and excited states of molecular hydrogen we utilize a parametrically driven tunable coupler to realize exchange-type gates that are configurable in amplitude and phase on two fixed-frequency superconducting qubits. Such gates are particularly well suited for quantum chemistry applications because they preserve the number of qubit excitations corresponding to the fixed number of electrons in the molecule. With gate fidelities around 95% we compute the eigenstates within an accuracy of 50 mHartree on average, an good starting point for the simulation of larger molecular systems.

3:00pm **QS+EM+MN+NS+VT-MoA-5 Reconfigurable Magnetic Textures for Quantum Information Applications***, **Alex Matos-Abiague**,* Wayne State University **INVITED**

Spintronic devices such as spin valves have extensively been used for non-volatile memory applications. The magnetic fringe fields generated by spin valves strongly depend on the magnetic state of the device. Thus, an array of electrically switchable spin valves allows for the generation of reconfigurable magnetic textures whose specific form and properties can be controlled on the nanometer scale. When combined with materials with large g-factor, such magnetic textures can have sizable effects not only on the spin but also on the localization, exchange, and transport properties of carriers. We show how the local control of the fringe-field-generated magnetic texture provides a unique tool for creating effective reconfigurable nanostructures and how it can be used for various quantum information applications. In particular, we focus on the use of reconfigurable magnetic textures as a new path to the realization of fault-tolerant topological quantum computing by enabling the generation and manipulation of Majorana bound states (MBSs) in superconductor/semiconductor heterostructures [1-4]. MBSs are emergent quasiparticles that obey non-Abelian statistics and can store quantum information that is immune against smooth local perturbations. Magnetic textures can provide not only synthetic spin-orbit and Zeeman fields -two important ingredients for the creation of MBSs- but also spatial confinement by creating closed domains in the form of effective topological wires. The effective wires can be re-shaped and re-oriented by properly changing the magnetic texture, allowing for the transportation of the MBSs [1,3] and the realization of quantum gates through braiding operations [2]. Other platforms combining the use of reconfigurable magnetic textures and Josephson junctions, as well as the main experimental challenges regarding materials, scalability, and detection are also discussed.

ACKNOWLEDGMENTS: This work is supported by DARPA Grant No.DP18AP900007 and US ONR Grant No. N000141712793

[1] G. L. Fatin, A. Matos-Abiague, B. Scharf, I Žutić, Phys. Rev. Lett. **117**, 077002 (2016).

[2] A. Matos-Abiague, J. Shabani, A. D. Kent, G. L. Fatin, B. Scharf, I. Žutić, Solid State Commun. **262**, 1 (2017).

[3] T. Zhou, N. Mohanta, J. E. Han, A. Matos-Abiague, and I. Žutić, Phys. Rev. B **99**, 134505 (2019).

[4] N. Mohanta, T. Zhou, J. Xu, J. E. Han, A. D. Kent, J. Shabani, I. Žutić, and A. Matos-Abiague, arXiv:1903.07834

4:00pm **QS+EM+MN+NS+VT-MoA-8 Coaxial Multilayer Superconducting Circuits for Quantum Computing***, **Peter Leek**,* University of Oxford, UK **INVITED**

Superconducting circuits are one of the leading candidates for the realization of quantum computers, in particular for near-term applications which may already be reached with circuits consisting of a few hundred qubits, provided they are operated at high fidelity. Until recently, the topology of superconducting circuits has typically been constrained to two dimensions, which becomes difficult to scale as the number of qubits increases and control and measurement wiring is needed for qubits in the middle of large arrays. It is natural to explore new circuit topologies that incorporate wiring in the third dimension to solve this problem. In this talk I will present an overview of an approach that builds on a coaxially-symmetric circuit QED unit cell with out-of-plane wiring [1] that provides a simple route to scaling to grids of many qubits. In this approach, arrays of qubits and resonators can be fabricated on opposing sides of a substrate and capacitively coupled, while control and readout are achieved via off-chip coaxial wires which run perpendicular to the chip plane and are built into a precision micro-machined enclosure that provides a high-quality microwave environment for the circuit.

[1] Rahamim et al., Applied Physics Letters **110**, 222602 (2017)

4:40pm **QS+EM+MN+NS+VT-MoA-10 Josephson Parametric Amplifiers based on Micron Scale Overlap Junctions (O-JPA)***, **Mustafa Bal**, J Long, R Zhao, H Wang,* National Institute of Standards and Technology (NIST)*; C McRae,* National Institute of Standards and Technology (NIST) and University of Colorado Boulder*; R Lake, X Wu, H Ku, D Pappas,* National Institute of Standards and Technology (NIST)

Quantum limited amplifiers have become indispensable tools in superconducting quantum circuits. In recent years, quantum limited amplification has been demonstrated in parametric amplifiers based on high kinetic inductance superconductors as well as Josephson junctions. Previously, we have demonstrated submicron scale overlap Josephson junction fab process for qubits with long coherence times [1]. Here, we extend the overlap junction fab process to micron scale junctions to enable the realization of other superconducting quantum devices such as overlap junction-based Josephson parametric amplifiers (O-JPA). Our fab scheme yield frequency tunable O-JPAs with negligible insertion loss. We readily observe over 25 dB gain. Compared to other competing processes, overlap junction process for micron scale junctions allows the fabrication of O-JPAs with high yield and good device performance at a much lower infrastructure requirements. The fabrication details of overlap junction process as well as the results of O-JPA characterization will be presented. The metrology of overlap Josephson junctions will also be presented in this this symposium [2].

[1] X. Wu, J. L. Long, H. S. Ku, R. E. Lake, M. Bal, and D. P. Pappas, “Overlap junctions for high coherence superconducting qubits”, Appl. Phys. Lett. **111**, 032602 (2017).

[2] R. Zhao *et al*., “Josephson Junction metrology for superconducting quantum device design”, also presented at AVS 66th International Symposium & Exhibition.

5:00pm **QS+EM+MN+NS+VT-MoA-11 Development and Characterization of a Flux-pumped Josephson Parametric Amplifier***, **Martina Esposito**,* University of Oxford, UK

Josephson parametric amplification is a tool of paramount importance in circuit quantum electrodynamics (circuit-QED), especially for the quantum-noise-limited single-shot readout of superconducting qubits. Here we present the development and characterization of a flux-pumped Josephson parametric amplifier (JPA) based on a lumped-element LC resonator, in which the inductance L is composed by a geometric inductance and an array of superconducting quantum interference devices (SQUIDs) [1]. In addition, we show preliminary experiments where the JPA is used as the first stage of amplification for the readout of a superconducting qubit based on a coaxial architecture recently developed in our lab in Oxford [2]. Finally, we will introduce future scientific direction based on using JPAs for generation and control of non-classical states in microwave photons.

[1] M. Esposito et al. EPJ Web of Conferences 198, 00008 (2019)

[2] J. Rahamim et al. Applied Physics Letters 110, 222602 (2017)

Vacuum Technology Division
Room A213 - Session VT-MoA

Gas Dynamics, Surface Science for Accelerators, and Ultra-Clean Vacuum Systems

Moderators: Jason Carter, Argonne National Laboratory, James Fedchak, National Institute of Standards and Technology

1:40pm **VT-MoA-1 Advancement in Transient Flow Simulations: Applications to Channel and Porous Media Conductance Modeling***, **Irina Graur Martin**,* Aix Marseille University, France **INVITED**

The gas flow through long channels of various and variable cross-sections is a practical problem in the MEMS and vacuum technology applications. As examples of such kind of flows the leakage through compressor valves and the flows in the micro bearing may be given. Among these applications, the gas flows through the low permeable membranes, which are also the flows at microscale, present also a great interest, especially in vacuum technology for filtering, separation process, protection and flow control. Recently some advancement in the transient flow simulation, based on the gas kinetic theory, was proposed in [1], [2]. Using this approach, the determination of the micro tube conductance is realized in [3]. The very similar approach is also proposed recently to characterize the permeability of the porous media like the low porous membranes [4]. Different examples of application of the proposed methodology will be shown for various type of porous media et different gases under isothermal and non-isothermal conditions.

References:

[1] F.Sharipov, I.Graur, General approach to transient flows of rarefied gases through long capillaries, Vacuum, v100, pp.22-25, 2014

[2] Graur, M.T. Ho, Rarefied gas flow through a long rectangular channel of variable cross-section, Vacuum, 101, 328-332, 2014.

[3] M. Rojas-Cardenas, E. Silva, M.-T. Ho, C. J. Deschamps, I. Graur, Time-dependent methodology for non-stationary mass flow rate measurements in a long micro-tube: Experimental and numerical analysis at arbitrary rarefaction conditions, I. Microfluid Nanofluid (2017) 21: 86.

[4] M.V. Johansson, F. Testa, I. Zaier, P. Perrier, J.P. Bonnet, P. Moulin, I. Graur, Mass flow rate and permeability measurements in microporous media, v 158, Vacuum, 2018, pp. 75-85

2:20pm **VT-MoA-3 A Multiphysics Simulation Tool for Storage Ring Vacuum System Design and Optimization***, **Nicholas Goldring**, Z Wu, D Bruhwiler, B Nash,* RadiaSoft LLC*; J Carter, J Lerch, K Suthar,* Argonne National Laboratory*; R Nagler,* RadiaSoft LLC*; P Den Hartog,* Argonne National Laboratory

Fourth generation storage ring light sources are creating orders-of-magnitude brighter x-rays by reducing horizontal emittance via multi-bend achromats. This requires the bending magnet pole tips to be closer to the electron beam axis, which in turn requires smaller vacuum chambers. The resultant design challenges are dictated by complex and coupled physical phenomena including electromagnetic wake fields, high thermal stresses and photon stimulated desorption. To better analyze and optimize next-generation vacuum systems, the authors are developing and benchmarking a suite of COMSOL Multiphysics models, which include the production, propagation, and surface interactions of synchrotron x-rays, as well as the resulting physical phenomena specified above. These coupled physics models are benchmarked against the open source codes SynRad and MolFlow. Finally, the models are embedded within a browser-based GUI, enabling scientists and engineers to execute simulations in the cloud.

2:40pm **VT-MoA-4 Vacuum System Design and Modeling for the Jefferson Lab Electron Ion Collider Interaction Region***, **Marcy Stutzman**,* Jefferson Lab

Jefferson Lab and Brookhaven National Lab are both pursuing designs to build an electron ion collider in the United States following the 2015 US Nuclear Science Advisory Committee recommendations for such a facility. The design of the Jefferson Lab Electron Ion Collider (JLEIC) interaction region (IR) requires vacuum in the UHV regime to reduce background rates sufficiently in the detectors. Additionally, though the final bending magnets are far upstream from the IR in the electron line, the interaction between residual gas and the electron beam will produce synchrotron radiation and subsequent elevated gas load in the interaction region. Preliminary designs of the vacuum system for the JLEIC interaction region and the cryogenic final focusing quadrupoles will be presented using the Molflow+ software. Synchrotron radiation due to the finite beam envelope traveling through the quadrupoles will be also modelled using Molflow's complementary program SynRad. However, since the primary synchrotron radiation in this system may be from the beam-gas interactions in the long straight section upstream of the IR, synchrotron radiation distributions and their effect on the gas load will also be studied using an existing 2D radiation prediction code and GEANT4 beam-gas interaction cross section calculations.

3:00pm **VT-MoA-5 Photocathode Growth and Diagnostic Systems for LCLS-II**, ***Xianghong Liu****, T Vecchione, B Dunham,* SLAC National Accelerator Laboratory

We have designed and manufactured a multisource physical vapor deposition system for producing photocathodes to be used in the LCLS-II, a hard X-ray free electron laser accelerator facility at SLAC. The photocathodes currently produced are thin film Cs_2Te, but the system has the capability to integrate up to four independent sources permitting the future growth of ternary and quaternary compounds. The deposition system has a load-lock which permits photocathodes to be transferred into and out of the system without breaking vacuum. The geometry of the photocathode substrate is adopted from INFN, so photocathodes can be exchanged between systems and institutions that share the same design using a vacuum suitcase. We have also designed a diagnostic system for characterizing photocathode performance and are in the process of manufacturing this system. The system is capable of measuring the quantum efficiency and transverse momentum distributions of photoemitted electrons. The wavelength dependence of these measurements can be recorded as a function of temperature down to below 10 K. We will present the designs of these systems and report on their operational status and early results.

3:20pm **VT-MoA-6 Characterization of NbTiN Thin Film Structures**, ***David Beverstock****, A Valente-Feliciano,* Jefferson Lab*; V Smolyaninova,* Towson University*; M Kelley,* The College of William and Mary

Approaching the bulk Nb material RF performance limits has urged development of alternative superconducting materials for superconducting radio frequency (SRF) accelerator cavities for further performance enhancement. A promising theory has predicted that thin film structures of superconductor-insulator-superconductor (SIS) [1] can delay magnetic flux penetration in accelerator cavities to higher fields. A candidate superconductor for the SIS structures is NbTiN. A few key aspects of SIS structures development are high quality individual layers, sharp interfaces and optimum thickness for first flux penetration (H_{fp}) delay. High quality monocrystalline NbTiN films are deposited by reactive DC magnetron sputtering. In a parallel development, interface quality was assessed by depositing bilayers of 3 nm NbTiN with ~1 nm AlN repeated up to 16 times with no increase in roughness of the structure. The stacked layers form a metamaterial, which could exhibit T_c greater than bulk NbTiN [2]. This contribution presents the characterization of the surface, material and superconductivity of NbTiN with concentration on the H_{fp} enhancement for 200 to 5 nm films and multilayer nanostructures.

References:

[1] Gurevich, Alex. "Maximum screening fields of superconducting multilayer structures." *AIP Advances 5.1* (2015): 017112.

[2] Smolyaninova, Vera N., et al. "Enhanced superconductivity in aluminum-based hyperbolic metamaterials." *Scientific reports 6* (2016): 34140.

Acknowledgements:

*Work supported by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177 and by DARPA grant W911NF1710348.

4:00pm **VT-MoA-8 Future Laser Interferometer Gravitational Wave Observatories and their Vacuum Requirements**, ***Chandra Romel,*** California Institute of Technology*; R Weiss,* Massachusetts Institute of Technology*; M Zucker,* California Institute of Technology*; H Dylla,* American Institute of Physics **INVITED**

The Laser Interferometer Gravitational Wave Observatory (LIGO) comprises a pair of large facility observatories in Washington and Louisiana dedicated to gravitational wave (GW) astronomy and astrophysics, funded by the U.S. National Science Foundation. A century after Einstein predicted the existence of gravitational waves, LIGO detected these ripples in the fabric of spacetime resulting from two massive binary black holes colliding almost 1.3 billion years away, birthing a new era of GW astronomy. For this achievement LIGO founders were awarded the 2017 Nobel Prize in Physics. Since the first detection in 2015, over a dozen black hole mergers have been recorded, in addition to neutron star collisions, marking a significant breakthrough for multi-messenger astronomy. Concepts of third generation GW instruments are undergoing research and development, with the promise to expand humanity's ability to listen to the cosmic symphony of gravitational waves out to the very edge of the universe.

An NSF workshop was held at the LIGO Livingston site in January to explore potential novel vacuum system solutions for 3G observatories. Cost effective solutions are required for the design, construction and operation of these large vacuum systems, proposed to be a factor of ten larger than the current systems in the U.S. (LIGO), Europe (Virgo) and Japan (KAGRA). Technologies developed and employed in the existing GW observatories have been shown to meet stringent requirements of vacuum integrity, low hydrogen and heavy molecule outgassing, minimal particulate generation, low vibration, and stray light optical absorbance for successful operation. However, extrapolating costs from current lengths to 40km/arm of vacuum beamtube indicates the need to investigate a wide range of technologies and materials that could significantly lower the final cost of 3G observatories such as the Cosmic Explorer in the U.S. and the Einstein Telescope in the E.U. Two classes of solutions for the vacuum enclosures were examined: 1) the first design concept is an extrapolation of the single-wall vacuum pipe in the present generation of detectors; 2) the second design concept involves double-walled or nested vacuum pipes that would separate the atmospheric load from the stringent UHV properties needed for the inner wall. Pumping solutions and surface treatments were examined for both concept designs with an emphasis on potential hardware and treatments that could lower total costs but still meet the stringent vacuum requirements.

4:40pm **VT-MoA-10 Status Update on the New Space Calibration Facility at TNO**, ***Freek Molkenboer****, R Jansen, F Driessen, T Luijkx,* TNO, The Netherlands

In 2018 TNO started with the conceptual design of a new Space calibration facility, called CSI. The CSI will be used for the performance verification and calibration of optical earth observation instruments on satellites. At the end of 2018, Angelantoni Test Technologies (ATT) from Italy was awarded a contract after completion of the European tendering procedure as the supplier of the Thermal Vacuum Chamber (TVC) and in January 2019 Symétrie, located in France was awarded a contract after completion of the European tendering procedure as the supplier for the hexapod on a rotation table that will be placed inside the vacuum chamber.

The TVC will be a vertically placed stainless steel cylinder with a diameter of 2.75 meter and a height of 2.5 meter. The chamber and thermal shrouds are sliced diagonally, resulting in a wedge shaped bottom half and top half, this reduces the total height (room and top half of the chamber) required for opening the chamber and loading a space instrument.

The thermal shroud of the TVC will be able to create an environment between 193K and 353K. Two thermal plates will be present to cool part(s) of the instrument down to 100K if required. The vacuum system consists of two turbomolecular pumps and two cryopumps to reach the ultimate pressure of 10e-7 mbar. The vacuum conditions in the TVC will be monitored with an RGA (Residual Gas Analyser) and a QCM (Quarts Cristal Microbalance).

During the calibration of a Space instrument, its position relative to the calibration light sources (Optical Ground Support Equipment or OGSE) has to be changed with an extremely high accuracy and reproducibility. To achieve this, TNO has selected a vacuum compatible hexapod on a rotation table that meets the stringent accuracy and stability requirements. Additionally TNO has designed an active thermal system around the hexapod in order to locally create a thermal stable environment.

During this talk I will discuss the design and current manufacturing status of both the thermal vacuum chamber, including the vacuum lay-out and thermal lay-out, and the design of the hexapod on rotation table including the protective measures we have taken to keep the hexapod at stable temperature.

5:00pm **VT-MoA-11 Advancements in Monitoring and Operating Thermal Vacuum Environmental Test Chambers for Next-Generation Space Exploration Hardware**, ***Maxwell Martin****, A Wong, W Hoey, J Alred, P Boeder, C Soares,* Jet Propulsion Laboratory, California Institute of Technology

As space exploration missions continue to develop and implement increasingly sensitive instruments and incorporate advanced detection capabilities for organics, contamination control protocols have necessarily evolved in their sophistication and stringency. Monitoring spacecraft hardware as it undergoes environmental testing requires high-precision measurements in thermal vacuum chambers. With increased sensitivity of instruments and missions, the traditional use of witness plates and solvent swabs is insufficient to characterize both chamber background, and the induced environment of the system being tested and the associated ground-support equipment. Quartz crystal microbalances (QCMs) are required to conduct *in situ* monitoring of hardware outgassing rates. QCMs are sensitive to thermal and mechanical perturbations; therefore, within an environmental testing facility, as-collected QCM data requires post-processing for signal noise due to instrumentation sensitivity, and uncertainties in data analysis. Insertion and removal of hardware into chambers introduces ambient atmosphere to the vacuum systems, providing additional sources of measurement uncertainty, particularly as relates to the collection and interpretation of pre-test chamber backgrounds. In an effort to support the next generation of space exploration, the Contamination Control team at JPL is implementing upgrades in systematic data analysis, thermal vacuum chamber operations, and instrumentation selection for use in spacecraft hardware environmental testing. These advancements in environmental test chamber monitoring support JPL's current portfolio of space exploration missions, and challenging mission science objectives.

Energy Transition Focus Topic
Room A212 - Session TL+MS+VT-TuM

Implications of Implementation: Making Energy Transition a Reality (ALL INVITED SESSION)

Moderators: Margaret Fitzgerald, Colorado School of Mines, Natalie Seitzman, Colorado School of Mines

8:00am **TL+MS+VT-TuM-1 The Energy Transition: Science and Technology Development Aspects*, Richard M.C.M. van de Sanden,*** DIFFER, Eindhoven University, The Netherlands, Netherlands **INVITED**

The Paris climate agreement requires a decarbonization of our energy infrastructure leading to a CO_2 neutrality by 2050. Therefore renewable energy generation by means of wind or from solar radiation through photovoltaics or concentrated solar power will continue to increase its share in the energy mix. Intermittency (due to e.g. day/night cycle), the regional variation of these energy sources, and penetration of renewable energy into other sectors than electricity (e.g. the chemical industry) requires means to store, transport and convert energy on a large scale. A promising option is the synthesis of chemicals and synthetic fuels (easily deployable within the present fossil fuels infrastructure) from raw feedstock using renewable energy. A truly circular economy requires that the raw materials are the thermodynamically most stable molecules such as water (H_2O), carbondioxide (CO_2) and nitrogen (N_2) to produce base chemical feedstock, such as e.g. hydrogen, hydrocarbons and ammonia. In this talk I will discuss the opportunities this transformation of the chemical industry provides. Furthermore, I will highlight the science and technology challenges, the catalytic materials, processes and systems developments needed that can provide compatibility of renewable energy driven chemistry with e.g. intermittency and localized production.

8:40am **TL+MS+VT-TuM-3 Electrochemical CO2 Reduction Across Scales: From Fundamental Mechanisms to Practical Applications*, Wilson Smith,*** Delft University of Technology The Netherlands, The Netherlands **INVITED**

Electrocatalytic CO_2 reduction has the dual-promise of neutralizing carbon emissions in the near future, while providing a long-term pathway to create energy-dense chemicals and fuels from atmospheric CO_2. The field has advanced immensely in recent years, taking significant strides towards commercial realization. While catalyst innovations have played a pivotal role in increasing the product selectivity and activity of both C1 and C2 products, slowing advancements indicate that electrocatalytic performance may be approaching a hard cap. Meanwhile, innovations at the systems level have resulted in the intensification of CO_2 reduction processes to industrially–relevant current densities by using pressurized electrolytes, gas-diffusion electrodes and membrane-electrode assemblies to provide ample CO_2 to the catalyst. The immediate gains in performance metrics offered by operating under excess CO_2 conditions goes beyond a reduction of system losses and high current densities, however, with even simple catalysts outperforming many of their H-cell counterparts. Using recent literature as a guidepost, this talk will focus on some of the underlying reasons for the observed changes in catalytic activity, and proposes that further advances can be made by shifting additional efforts in catalyst discovery and fundamental studies to system-integrated testing platforms.

9:20am **TL+MS+VT-TuM-5 Perspectives on the Research and Development of Nanomaterials for Hydrogen Production*, Marcelo Carmo,*** Forschungszentrum Jülich, Germany **INVITED**

Hydrogen is often considered the best means by which to store energy coming from renewable and intermittent power sources. With the growing capacity of localized renewable energy sources surpassing the gigawatt range, a storage system of equal magnitude is required, such as the production of electrolytic hydrogen by water electrolysis. Despite of more than 100 years of experience in alkaline electrolysis systems, and thousands of plants installed all over the world, only a few systems or industries remain, providing the state-of-the-art of this technology today. This is due to the fact that the cost of electrical energy has always remained as an uncomfortable barrier, with electrolytic hydrogen costs not being able to compete with the costs for the production of hydrogen by conventional steam reforming of fossil fuels. Nevertheless, today, increased interest can be observed for PEM water electrolysis technology, and over the past 20 years, new companies and projects have appeared, with new leaders being consequently established in this growing niche. The reason is that PEM electrolysis provides a sustainable solution for the production of hydrogen, and is well suited to couple with energy sources such as wind and solar. The advantages of PEM electrolysis over alkaline electrolysis together with novel R&D approaches can potentially reduce the investment costs of PEM electrolysers. We expect that in the following years, frontier advancements on PEM electrolysis systems will appear, demonstrating a true capacity to ultimately establish hydrogen as a key player in the energy market, and contribute to a future hydrogen economy.

11:00am **TL+MS+VT-TuM-10 Impacts and Adaptation Strategies in Ethiopia*, Aschale Dagnachew Siyoum,*** Xavier University of Louisiana

This paper highlights climate change and variability and its impact and adaptation strategies in Ethiopia. Due to low adaptive capacity and high sensitivity of socio economic systems, climate vulnerability is worsening over the last few decades in Ethiopia. Available evidences showed that since 1960, the mean annual temperature of the country has risen by about 1.3°C with an average rate of 0.28°C per decade imposing a significant challenge on food security, water availability, energy supply, poverty reduction and sustainable development efforts of the nation. Ethiopia has responded to the increasing impact of climate change and variability through developing relevant adaptation strategies, plans and policies largely focused on decreasing vulnerability in many different sectors including agriculture and food security, water resources, forestry, and health. To tackle the impact of climate change, the government has approved the National Adaptation Program of Action (NAPA) in 2007 which includes projects that focused on promoting drought insurance program, strengthening drought and flood early warning systems, developing small-scale irrigation and water harvesting schemes in arid, semi-arid, and dry sub-humid areas, and realizing food security through a multi-purpose large-scale water development project. Results, however, shows that although some progress has been made in addressing the impacts of climate change and variability, adaptation measures implemented over the last few decades were generally ineffective resulting in increasing losses as more and more people occupy vulnerable areas. This requires a sustained effort to further plan and implement the right mix of climate change adaptation strategies to address vulnerability to biodiversity and humanity to the increasing impacts of climate change. Addressing the impact of climate change requires a good understanding of the nexus between climate change adaptation measures and sustainable development as well as knowledge of climate change adaptation tools and techniques, which when used properly can minimize the total damage to life and property.

11:20am **TL+MS+VT-TuM-11 Developing and Scaling Up the Manufacturing of Thin Film Materials for the Future of Energy Production, Storage, and Reduction*, Ken Nauman,*** Von Ardenne North America **INVITED**

The world, and thus the economy, are clearly dependent on energy and in particular electricity. Production of electricity is ever increasing while the desire to create cleaner sources becomes a higher priority to reduce the environmental impact. The transition to electricity for mobility in transportation and communication relies on new technology to improve market penetration. Thus, the three key aspects of electricity in our modern society are: generation, storage, and saving. In order to make the energy transition a profitable reality, companies that develop technology will have to reduce the cost of energy production and storage while also considering how to lower energy usage. This talk will cover these key aspects from the perspective of an equipment and process technology company. Companies such as Von Ardenne that develop thin film materials have focused on these topics to reduce the CapEx and CoO for our customer's factories. This includes processes for Thin Film Photovoltaics and Crystalline Photovoltaics, along with emerging cell architectures, to reduce the cost of electricity generation while reducing overall CO2 production. Our company also works on leading material science in battery and fuel cell technology to increase storage capacity and cost of storing energy. Finally, other technology development is focused on saving energy with low-e coatings for glass and plastics. This presentation will review the history of the technological development as well as the latest trends, economics, and status of market leading performance in manufacturing products related to generating, storing, and saving electricity.

Vacuum Technology Division
Room A213 - Session VT-TuM

Accelerators and Large Vacuum Systems

Moderators: Yulin Li, Cornell University, Marcy Stutzman, Jefferson Lab

8:00am **VT-TuM-1 Vacuum Operation and Future Upgrade of the LHC Accelerator Complex***, **Giuseppe Bregliozzi**,* CERN, Switzerland **INVITED**

The LHC accelerator complex returned in operation in April 2015, after almost 2 years of long shutdown (LS1) for various upgrades and consolidation programs. During Run2 of operation (2015-2018), the entire accelerator complex has shown remarkable reliability and in particular, the LHC operated for more than 3600 fills reaching a total integrated luminosity of more than 150 fb−1.

In 2019, the entire LHC accelerator complex will stop again for 2 years (Long Shutdown 2 - LS2). This period will be dedicated to the LHC Injector Upgrade (LIU) and will prepare the CERN injector complex for the final upgrade of the LHC to High-Luminosity (HL-LHC) foresee during the LS3 (2024-2025).

This paper summarizes the vacuum related major issues happened during last 3 years of operation in the entire LHC accelerator complex and a summary of the most important vacuum observations along the LHC during the physics runs are presented. In addition, an overview of the planned activities during the LS2 will be presented and an outlook on the technical challenges for the HL-LHC upgrade is given.

8:40am **VT-TuM-3 Final Design into Production for the APS-Upgrade Storage Ring Vacuum System***, **Jason Carter**,* Argonne National Laboratory

The Advanced Photon Source Upgrade (APS-U) project is progressing from its final design phase into production for the future 6 GeV, 200 mA, multi-bend achromat upgrade of the existing APS and so too is the storage ring vacuum system design. The vacuum system will include over 2500 custom vacuum chambers ranging from 50 mm up to 2.5 meters in length and typically featuring APS-U's standard narrow 22 mm inner diameter aperture. The vacuum system must maintain UHV for the circulating electron beam while the water-cooled vacuum components intercept significant synchrotron radiation loads. The scope of NEG coatings was increased to 50% of the length of the vacuum system to ensure the vacuum system conditions quickly and pressure requirements can be met.

Vacuum chamber locations, lengths, and materials were settled in the preliminary design phase but significant effort was required to work through local and system level design challenges. Local challenges include detailing robust welds and brazes on the thin-walled vacuum chambers and performing detailed FEA thermal/stress analysis for vacuum components which intercept large synchrotron radiation heat loads. System level challenges include using CAD to design within the complex machine assembly, networking components to utilities, and planning for installation and alignment. This presentation will highlight the major design challenges and solutions for the storage ring vacuum system and also plans for production and installation.

9:00am **VT-TuM-4 The Design of the Advanced Photon Source Upgrade (APSU) Insertion Device (ID) Straight Section Vacuum Systems***, **Jason Lerch**, M Szubert, E Anliker, T Bender,* Argonne National Laboratory

There are 35 straight sections in the APS-U, requiring 30 planar vacuum chambers (IDVC) and 5 superconducting vacuum systems (SCU VC). These vacuum systems provide Ultra-High Vacuum (UHV) continuity between storage ring (SR) sectors. The IDVC, nominally 5.363 meters long, requires bake-out before operation and expands 10mm on both ends. The SCU vacuum chambers, nominally 5.383 meters long, are cooled cryogenically and contract 14 mm on both ends. The APS-U straight sections are identical around the SR but require bellows on both ends to accommodate the change in length of both systems. The aluminum planar vacuum chamber operates in UHV with a 600 thick wall over a length of 5050 mm and requires the use of 1 ion pump and 7 NEG cartridges for pumping down the system. The SCU is comprised of two copper "warm" vacuum systems, operating at room temperature outside the cryostat, and one aluminum "cold" vacuum system (4.8m long), operating at 20K inside the cryostat. The "warm" chambers have a minimum wall thickness of 1 mm and operate as photon absorbers at either end of the system, one protecting the cryogenically pumped chamber and one protecting downstream equipment. The "cold" chamber has a minimum wall thickness of 400 and operates at UHV at 20 Kelvin. The internal geometries of these various systems are optimized to reduce dissipated heat on the chamber walls where possible and allow for seamless transitions for various apertures. Both vacuum systems require the ability to align the apertures ±50 microns along their lengths.

9:20am **VT-TuM-5 The Vacuum Commissioning and Simulation of Non-Evaporable Getter Dominated Cornell High Energy Synchrotron Source Upgrade.***, **Yevgeniy Lushtak**, Y Li, X Liu,* Cornell University

The Cornell High Energy Synchrotron Source Upgrade (CHESS-U) converts the Cornell Electron Storage Ring (CESR) from dual-beam to single-beam operation while significantly reducing the beam emittance, increasing the beam energy to 6 GeV, and improving the facility's X-Ray beamline brightness.

The CHESS-U vacuum system was completed in the fall of 2018 and the initial beam current and energy targets were met in the spring of 2019. The majority of the CHESS-U vacuum system consists of narrow gap aluminum chambers. With pre-installation 150 C bake followed by in situ 95 C hot-water bake and relying on the high pumping speed of distributed and lumped Non-Evaporable Getters (NEGs), a low 10^{-9} Torr base pressure was quickly achieved.

Since the CHESS-U vacuum pumping system is NEG-dominated and NEGs are prone to surface saturation at high synchrotron radiation (SR) induced gas loads, the vacuum conditions during the CHESS-U accelerator commissioning were carefully monitored and periodical vacuum simulations using MolFlow were performed to ascertain the status of the NEGs. The SR-induced vacuum conditioning has proceeded very well, with the dynamic pressure holding in the low 10^{-9} range with 100 mA stored positron beam current, after an accumulated beam dose of 20 A-hr. With the moderate initial beam conditioning, a beam lifetime allowing X-ray beam operation to commence has already been achieved. Further gradual improvements in the dynamic pressure and beam lifetime are expected during the course of X-ray user operations.

In this paper, we describe the CHESS-U vacuum system, report on the SR-induced vacuum conditioning status, and detail the computational model developed to accurately simulate the vacuum conditions while taking into account the NEG saturation and the radiation-induced cleaning of the chambers.

9:40am **VT-TuM-6 Advanced Light Source Upgrade Vacuum Controls and Instrumentation Design***, **Sol Omolayo**,* Lawrence Berkeley Lab, University of California, Berkeley

A project is underway to upgrade the existing Advanced Light Source (ALS) synchrotron. The goal of the project is to lower the horizontal emmitance to <75pm resulting in a 2 orders of magnitude increase in soft x-ray brightness. The design features two new accelerators: the accumulator ring and the storage ring. Both rings are also connected by transfer lines. The preliminary design for the vacuum systems for these rings and transfer lines in underway. With over 400m long electron beam vacuum pipe, the control and instrumentation required for the vacuum system is complex. We present the design specification and solution the project has adopted.

11:00am **VT-TuM-10 Vacuum Electronics Community Pioneers Additive Manufacturing of Copper***, **Diana Gamzina**,* SLAC National Accelerator Laboratory*; T Horn, C Ledford,* North Carolina State University*; C Nantista,* SLAC National Accelerator Laboratory*; P Frigola,* Radiabeam **INVITED**

Even though there are many players in the world of additive manufacturing (AM), vacuum electronic devices (VED) community made a significant impact on AM of copper specifically, with recognition by industrial partners and government agencies. Copper is a challenging material to print because of its high reflectivity and high thermal conductivity; material purity is also hard to achieve due to the lack of high quality precursors. VED community has the most stringent requirements for copper. The successful implementation of copper AM for VEDs will support a wide range of applications, including thermal management, power electronics, and nuclear. Many critical to VED manufacture properties have been achieved (density, ultra-high vacuum compatibility, electrical and thermal properties), but few still remain to be challenging (reduction of oxygen content and surface roughness). A variety of components relevant to VED community have been manufactured; more interesting examples include: high efficiency klystron output cavity with micro cooling channels and weight reducing web support structure; one inch long sections of WR-10 waveguide demonstrating post-polishing techniques to reduce surface roughness to 2 microns in enclosed envelopes, coupled cavity travelling wave tube amplifier circuit structures demonstrating over 50% cost reduction capability. Most of the benefits that AM can offer still lie ahead to be explored: predesigning material properties local to specific design features while varying physical, electronic, or chemical properties locally.

11:40am **VT-TuM-12 Particle-Free Manufacturing and Installation for LCLS-II Vacuum Systems***, Arnela Gamzina,* SLAC National Accelerator Laboratory

SLAC National Accelerator Laboratory, a multipurpose laboratory for astrophysics, photon science, accelerator and particle physics, is currently building an upgrade to the World's First X-ray Free-Electron Laser (LCLS-II). In the past years, SLAC Vacuum Laboratory has prepared, tested, and assembled many of the beamline components and the activity is still in progress.

This presentation will go through the manufacturing and quality check processes, documentation and installation check lists that were developed to meet the LCLS-II UHV and Particle Free requirements. Especially, in order to meet Particle Free requirements new equipment and facilities were acquired. The vacuum group worked to establish new procedures and made sure that selected personnel developed the requested skills, best practices, and gained the experience necessary to complete a successful installation.

12:00pm **VT-TuM-13 Development of Remote Handleable Axially Decoupled Radiation Resistant Vacuum Seal***, Geoff Hodgson,* TRIUMF, Canada

Advanced Rare IsotopE Laboratory (ARIEL) facility is a major expansion of TRIUMF's rare isotope research program.

Aiming to triple the production of rare isotopes, ARIEL facility includes the new electron linac driver and

two target stations for electron and proton beams [1]. Particularities of ARIEL target stations design define the requirements for vacuum interfaces with both primary electron and proton beamlines and rare-isotope beamlines. None of the existing products fully met the requirements, driving the development of custom vacuum interfaces. The design of new vacuum seals is driven both by unique design specifications (limited amount of allowed axial forces, extreme radiation

resistance, remote handleability and high repeatability) as well as limitations of the proposed design of beamline nfrastructure in the target hall (limited available space and the choice of materials for certain components). This paper discusses preliminary results of the vacuum seal development and presents first results of prototype testing.

Vacuum Technology Division
Room A213 - Session VT-TuA

Advanced Applications of Vacuum Technology

Moderators: Julia Scherschligt, NIST, Alan Van Drie, TAE Technologies

2:20pm **VT-TuA-1 Single Atom and Single Electron Transistors for Quantum Technologies***, **Richard Silver**, X Wang, R Kashid, J Wyrick, P Namboodiri, K Liu, M Stewart, G Bryant,* National Institute of Standards and Technology (NIST) **INVITED**

Atomically precise fabrication has an important role to play in developing atom-based electronic devices for use in quantum information processing, quantum materials research and quantum sensing. Atom by atom fabrication has the potential to enable precise control over tunnel coupling, exchange coupling, on-site charging energies, and other key properties of basic devices needed for solid state quantum computing and analog quantum simulation. Using hydrogen-based scanning probe lithography we deterministically place individual dopant atoms with atomically aligned contacts and gates to build single electron transistors and single or few atom transistors.

We have developed robust lithography, device relocation, and contact processes that enable routine electrical measurement of atomically precise devices with an emphasis on minimizing process-induced dopant movement. Our low temperature palladium silicide contact process provides low-resistance ohmic contacts with yield better than 98%. Fabrication at the atomic scale requires exceptional vacuum and sample cleanliness. Our STM and sample preparation vacuum systems operate in the low $1x10^{-11}$ torr regime and we are implementing several hardware upgrades to achieve < 10^{-12} torr vacuum.

This presentation will cover the design, fabrication, and characterization of multiple STM patterned single electron transistors that demonstrate stable coulomb blockade oscillations. We will report measurements of the electronic properties and tunnel coupling in single electron transistors where the tunnel gap is varied at the dimer row scale. Shrinking single electron transistors to the atomic limit, we demonstrate single dopant atom and few dopant cluster devices - essential building blocks in silicon-based donor dot qubits and proposed solid state analog quantum simulators. This presentation will include spectroscopic transport measurements and modeling of atomically precise single and few atom transistors.

3:00pm **VT-TuA-3 Turbomolecular Pump for Achieving Ultra-high Vacuum in a High-power Proton Accelerator Vacuum System***, **Junichiro Kamiya**, M Kinsho,* Japan Atomic Energy Agency, Japan*; N Ogiwara,* KEK, Japan*; M Sakurai, T Mabuchi,* Osaka Vacuum, Ltd., Japan*; K Wada,* Tokyo Electronics Co., Ltd., Japan

Challenges for achieving an ultrahigh vacuum (UHV) region in J-PARC 3 GeV rapid cycling synchrotron (RCS), which produces proton beam with 1 MW power, come from the large static and dynamic outgassing. In the RCS vacuum system, turbomolecular pumps (TMP) have been used as main pump because it can evacuate such continuous and additional outgassing with a large pumping speed in the wide pressure range. TMP also has the advantage of not causing pressure instabilities like ion pumps. The more than 10 years operation of the RCS vacuum system showed that the UHV was rapidly obtained from the atmospheric pressure. It was also shown that the large additional outgassing during the high-power beam operation was promptly evacuated by the TMP due to its constant pumping speed in the wide pressure rage. The future operation with more high-beam power requires the vacuum system for the lower pressure region. The pumping speed and compression ratio of the standard TMP is limited by the rotational speed of the rotor. We have developed a TMP with the rotor of titanium alloy, which have much higher mechanical strength than aluminum alloy for the normal rotter. When the rotational speed increase by a factor of 1.3, the pumping speed and compression ratio increase by a factor of 1.3 and 12.5, respectively. The increase of the compression ratio is especially effective for hydrogen, which is the main outgas component in the UHV region. Challenges in the development comes from the difficulty of the machining performance and the weightiness of the titanium alloy comparing with the aluminum alloy. We report the signification and the status of the development of the TMP with titanium alloy.

3:20pm **VT-TuA-4 US Contributions to ITER Vacuum Auxiliary System***, **Charles Smith**,* Us Iter

This paper gives an overview of the ITER Tokamak Vacuum Auxiliary System (VAS) with a focus on the design challenges, solutions, and validation unique to a reactor-scale fusion vacuum system.

US ITER, the United States Domestic Agency for US contributions to the ITER project, is responsible for the final design, procurement, and acceptance testing for the Vacuum Auxiliary System (VAS) to be used in support of over 5000 clients of the ITER machine. The VAS system consists of more than six kilometers of pipework used in the vacuum roughing headers, more than 100 high-vacuum stations to support specific plant needs, and the Service Vacuum System (SVS) which is used to connect the roughing system to the end-use clients. VAS is a key element to the world's first vacuum system rated for a licensed nuclear fusion facility.

ITER received a nuclear construction authorization decree from the French Ministry of Environment in 2012, as its goal is to demonstrate the feasibility of fusion energy and produce a reactor-scale deuterium/tritium fueled plasma. ITER's VAS will utilize ASME B31.3 piping with a minimum schedule 10 wall thickness. In most large vacuum systems, commercially available vacuum fittings, flanges, and other standard components are designed around tubing. The requirement for schedule 10 piping and B31.3 design criteria has resulted in US ITER designing and certifying the components as opposed to procuring commercial off-the-shelf (COTS) items. These components must then be integrated into the overall VAS system in a way that meets all seismic and safety requirements needed to maintain tritium confinement. In addition to developing safety-critical double-gasket vacuum flanges, the certification of standard CF flanges to B31.3 has been required.

The VAS system's interfaces and location through the tokamak building have created another set of challenges to the use of standard vacuum equipment. The tokamak building will be subjected to radiation and high magnetic fields during plasma operations. The proximity of vacuum systems to high power RF systems and tritium containment are all design inputs for VAS design. The SVS portion of VAS, in addition to its role of interfacing between clients and the roughing header, acts as an integral part of plant safety systems. The interspaces between the gaskets on safety related flanges are actively monitored by SVS to detect any change in pressure which could indicate a leak. As an example, the SVS is used to verify the integrity of diamond vacuum windows used in high-powered RF plasma heating systems.

The work detailed in this paper, shall illustrate the progress being made to reach the first plasma milestone.

4:20pm **VT-TuA-7 Importance of Advanced Vacuum Technology to the Present Thin Film Photovoltaics Industry***, **Timothy Gessert**,* Gessert Consulting, LLC **INVITED**

World use of photovoltaic (PV) solar electricity has been increasing at an average annual exponential growth rate >35% since about 2000. Not surprisingly, during this same time, the percentage of US-consumed energy (~100 Quadrillion BTUs total) derived from PV has increased from ~0.003% in 2004, to >1% at the end of 2018. Indeed, if these trends continue, PV could produce >50% of all energy consumed in the US by as early as 2030. Combining this with the rapidly decreasing energy costs for large grid-tied PV systems (presently <2.5¢/kWh for long-term power purchase agreements) largely explains why PV-derived energy is – even now – a main source of *new* US and world energy. Although the majority of this PV-derived energy is presently generated by crystalline-based Si module technologies, because of combined efficiency, production, cost, and other advantages, an ever-increasing amount of PV energy is being produced from polycrystalline thin-film (TF) materials. These TF PV technologies owe much of their rapidly advancing success to improved understanding in related materials synthesis, while applying these advancements to industry, in turn, has relied on design innovations of related vacuum-process equipment. This talk will briefly overview the present state of TF PV technologies, taking into consideration both the present dominance of crystalline Si PV, and evolving trends in TF PV. Several examples where keen understanding of vacuum processes in laboratory-scale devices has fostered successful utilization of advanced vacuum technology in the commercial TF PV industry will be presented. The talk will also suggest some areas where further advancements in vacuum-process and equipment innovation could yield potentially even lower-cost TF PV technologies.

5:00pm **VT-TuA-9 Enabling Hydrogen as an Energy Carrier through Analytical Electron Microscopy*, David Cullen,* *K More,* Oak Ridge National Laboratory** **INVITED**

Hydrogen is an important energy carrier which can be produced from renewable or intermittent energy sources for use in markets ranging from metal refining to transportation. Polymer electrolyte membrane fuel cells (PEMFCs) are a key technology for converting the chemical potential energy of hydrogen in electrical energy and driving down the cost of these systems is important towards enabling a hydrogen economy. At the heart of the matter is the membrane electron assembly (MEA), which consists of an anode and cathode separated by a proton-conducting membrane. Pt-based catalysts are typically used to drive the sluggish oxygen reduction reaction (ORR) at the cathode and are responsible for much of the cost of the MEA. Near term approaches to reduce Pt loading and hence cost involve the development of Pt-alloy catalysts which show exceptionally high mass activity but require improvements in durability. Long-term solutions will require the development of stable platinum group metal-free (PGM-free) catalysts, with current best-in-class candidates being derived from transition metal doped metal organic frameworks (MOFs). In both approaches, accelerated materials discovery and development is required to keep pace with increasing market and performance demands.

To this end, scanning transmission electron microscopy (STEM) has been employed to study MEAs from the atomic to micron scale. The application of atomic-resolution spectroscopic techniques to assess the quality and durability of Pt-alloy and PGM-free electrocatalysts will be presented. At a wider scale, the impact of particle dispersion, hierarchal porosity and proton-conducting ionomer distribution will be linked to electrochemical performance limitations through quantitative STEM imaging and energy dispersive X-ray spectroscopy (EDS). Finally, the movement of dissolved species across the membrane and gaseous diffusion layer will be explored to explain durability losses during fuel cell cycling. The synergy between electron microscopy and other characterization techniques such as X-ray photoelectron spectroscopy, X-ray absorption spectroscopy, and Mossbauer spectroscopy will also be discussed

Research sponsored by the Fuel Cell Technologies Office, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy (DOE), as part of the FC-PAD and ElectroCat Consortia, which is part of the Energy Materials Network. Microscopy performed as part of a user project at ORNL's Center for Nanophase Materials Sciences (CNMS), which is a U.S. DOE Office of Science User Facility.

5:40pm **VT-TuA-11 Defect Manipulation to Control Energy Processes in Electronic Materials*, Leonard Brillson,* The Ohio State University** **INVITED**

The control of native point defects in advanced electronic materials and device architectures is critical to a wide array of energy intensive processes including generation, transport, storage, switching, and display. AVS research in electronic materials surfaces and interfaces at the nanoscale has played an important role in this arena. Defect control of transparent conducting oxides such as ZnO for smart windows and heads-up displays have revealed how to create homojunctions with high electron mobility 2-dimensional interfaces.[1] Surface/interface techniques enable identification and control of native defects in Ga_2O_3,[2] outlooked for RF power amplification and power switching. Defect control has enabled creation of 2-dimensional hole gases at $LaAlO_3/SrTiO_3$ interfaces, opening an avenue to new architectures for complex oxide electronics. Depth-resolved defect measurements in V_2O_5 battery electrode films reveal how lithiation introduces degenerate doping and secondary phase formation, integral to ion and charge transport inside next-generation nanoscale battery architectures.[3] Direct, localized optical, and electrical measurements of ZnO nanowires – envisioned for wearable electronics and displays - show that native point defects inside the nanowire bulk and created at metal-semiconductor interfaces are electrically active[4,5] and play a dominant role electronically, altering the doping, carrier density along the wire length, and the injection of charge into the wire.[6] Defects in all these materials can now be manipulated by ion beams, electric fields, remote oxygen plasmas, and nanoscale design, opening new avenues to control charge injection, transport, and storage.

1. G. M. Foster et al., "Direct Measurement of Defect and Dopant Abruptness at High Electron Mobility ZnO Homojunctions," Appl. Phys. Lett. **109**, 143506 (2016).

2. H. Gao et al., " Optical Signatures of Deep Level Defects in Ga_2O_3," Appl. Phys. Lett. **112**, 242102 (2018).

3. H. Lee et al., "Direct observation of a two-dimensional hole gas at oxide interfaces," Nature Materials **17**, 231-236 (2018).

4. W.T. Ruane et al., "Defect Segregation and Optical Emission In ZnO Nanowiresand Microwires," Nanoscale **8**, 7631-7637 (2016).

5. A. Jarjour et al., Single Metal Ohmic and Rectifying Contacts to ZnO Nanowires: A Defect Based Approach," Ann. Phys. (Berlin), **530**, 1700335 (2018).

6. J.W. Cox et al., "Defect Manipulation to Control ZnO Micro-/Nanowire-Metal Contacts," Nano Letters **18**, 6974 (2018). **DOI:** 10.1021/acs.nanolett.8b02892

Vacuum Technology Division
Room Union Station AB - Session VT-TuP
Vacuum Technology Poster Session

VT-TuP-1 Dynamic High Pressure Technique for Surface Analysis of Gas Sensors in Quasi-operating Condition*, **Taku Suzuki**, Y Adachi, I Sakaguchi,* National Institute for Materials Science (NIMS), Japan

One of the biggest problems in surface analysis of gas sensors is the pressure gap; a conventional surface analytical tool needs high vacuum (10^{-4} Pa), while gas sensors are usually employed in atmospheric pressure (10^{5} Pa).This problem has been partially overcome by recent operando techniques for surface characterization. In such a operando measurements, either effective differential pumping or a pressure separation technique, which is often called a high pressure cell, are typically utilized. With those techniques, surface analytical tool can be operated in (ultra-) high vacuum while keeping the pressure in the vicinity of a sample (near) atmospheric pressure. Those techniques are obviously useful to analyze gas sensing mechanism on surfaces. However, a high-speed evacuation system is expensive and a membrane for separating pressure limits applicable analytical techniques.

Besides above-mentioned operando measurements, a dynamic high pressure (DHP) technique has been proposed to analyze a device surface in operating condition. Briefly, it is a technique of pulsed-gas injection to a sample surface. The technique seems attractive considering economical cost and possible wide range of applicability. However, the number of reports concerning DHP is quite limited, and thus, it is not clear whether DHP is useful for surface analysis of gas sensors.

In the present study, we have developed a pulsed gas injection system of pure air combined with an ultra-high vacuum chamber and a fast pressure transducer. The pressure at the sample position reached at about 10^3 Pa and 10^4 Pa with pulse width of 10 ms and 100 ms, respectively, with the inlet pressure of 1 MPa. The background pressure was below 10^{-2} Pa with pulse width of 10 ms except for the duration of 1 s after the gas injection. We further developed a gas sensor measurement system combined with the pulsed gas injection system. In our preliminary experiment using a W-ZnO thin film gas sensor, we successfully observed substantial change of electric resistance with introducing the pulsed pure air by using a lock-in technique.

VT-TuP-2 Fundamental Study for Practical Applications of Ti-Zr-V NEG Coating to General Vacuum Systems*, **Makoto Okano**, A Niwata, S Kitamura,* JEOL Ltd., Japan*; Y Tanimoto, X Jin, M Yamamoto, T Honda,* High Energy Accelerator Research Organization (KEK), Tsukuba, Japan

Modifying the properties of surfaces has become essential to obtain a desired function in various ultra high vacuum (UHV) systems. Among such techniques, Ti-Zr-V non-evaporable getter (NEG) coating, originally developed at CERN[1,2] and being widely applied to particle accelerators, is one of the most promising functional coatings, as it provides high effective pumping speeds, low outgassing rates, and low secondary electron yields. Since these desirable properties are beneficial in any UHV systems, there has been an increasing demand for its widespread availability. Furthermore, NEG coating is expected to maintain UHV conditions in power-less situations; for example, its application to electron microscopes might enable long-sustained transportation and quick recovery to UHV. For these practical applications to general vacuum systems, we have started a fundamental study on NEG coatings, where the vacuum properties are measured by a build-up method and the durability of the pumping capacity is examined by repetitive cycles of air-exposure and activation. In order to establish a technique to deposit high-performance films on various vacuum chambers by magnetron sputtering, the coated surfaces are characterized by scanning electron microscope (SEM), energy dispersive X-ray spectrometry (EDS), and X-ray diffraction (XRD). The test tubes used in the build-up experiment are made of 304 stainless steel and measures 50 mm in diameter and 300 mm in length. One tube is coated with 0.7um Ti-Zr-V films and the other is uncoated. After 24 hours of stopping the sputter ion pump (SIP), the pressure in the uncoated tube increased from 2E-8Pa to 3E-6Pa, while the increase was suppressed from 6E-9 Pa to 1E-8Pa in the coated tube. Even after an additional build-up for 10 days, the coated tube was maintained under UHV conditions (7E-6Pa), and the pressure was recovered to 5E-8Pa in 5 hours after switching on the SIP. A comparison by residual gas analysis after the 24-hour build-up showed that the NEG coating improved 360-times for CO and 100-times for H_2. These results suggest a feasibility of the transportation of UHV systems without electricity. The presentation will include preliminary results of film characterization by the surface analyses, as well as pumping properties of the NEG coating.

References

1) C. Benvenuti et al., Vacuum 60 (2001) 57.

2) P. Chiggiato and P. Costa Pinto, Thin Solid Films 515 (2006) 382.

VT-TuP-3 Fabrication and Characterization of a Variable Conductance Vacuum Valve to Control Pressure Level for a High Vacuum System*, **Han Wook Song**, S Woo,* Korea Research Institute of Standards and Science, Republic of Korea

Fabrication of a semiconductor device requires a high precision and a high degree of cleanliness. For this reason, the semiconductor device is manufactured in a state in which the contact of the foreign substances contained in the air is completely blocked, that is, in a vacuum state (approximately around 0.1 Pa.) To adjust the required vacuum level, some apparatus such as a needle valve, a gate valve, and a butterfly valve were used to control the gas flow. Recently, we developed a variable-conductance vacuum valve to control the inlet pressure for vacuum chamber, which was modified from optical iris used in optics. The present conductance variable valve is characterized in that the conductive tuck adjusting portion and the conductance operating portion employing the iris structure do not have a physically contacted or coupled structure. And the housing has no mounting holes, fastening holes, or the like for coupling the conductance operating portions, so it has a conductance variable function that can completely block the fluid leakage of the valve without any separate parts such as packing, sealing, and O-ring. The guide section of the housing will have a first magnetic body, while the conductance control unit will have a second magnetic body in the mounting hole. Therefore, when the first body and the second body are moved in a circular direction by the attraction force, the first body within the guide unit also moves in a circular direction. The cross sectional area of housing and the conductance of fluid are proportional. When using the manufactured variable valve, it showed 2% reproducibility and 0.5% repeatability in pressure generation. In the future, we will make and evaluate a large variable valve that can be applied to high vacuum systems.

VT-TuP-4 Hellum Gas Transmission Rate of Elastomer Seal with a Back-up Ring Seal*, **Masaharu Miki**,* EM Technical Lab Inc., Japan*; S Nowatari, H Hanada,* IIDA Co., Ltd, Japan

Hellum gas transmission rate of elastomer seal with a back-up ring seal was studied using the metal-sealed Hellum leak detector. Three kinds of samples were prepared. One is an elastomer seal (JIS B 2401 V40) without a back-up ring seal. Second is the same size elastomer seal with a back-up ring seal which adheres to the atmospheric-side surface of the elastomer seal and is made of some resin. The last is the same one with a back-up ring seal except the seal surface of the back-up ring seal is not flat but having some structure. Hellum gas transmission rate was measured and evaluated. It was found that the elastomer seal with the back-up ring seal has very low Hellum gas transmission rate, which is about less than 10% of the case without a back-up ring seal. It is like the case of a metal seal. On the other hand, the difference of the seal surface of the back-up ring seals was not found. Anyway, the elastomer seal with the back-up ring seal must be useful as seals to make vacuum chambers up-grade which structure cannot permit to use any metal seals. Pumping-down curves on total vacuum pressure and residual gas pressure (O_2, H_2O , etc.) in a vacuum chamber using the elastomer seal with the back-up ring seal are under investigation.

VT-TuP-5 Improved NEG Sputter Deposition System*, **Philip Adderley**, M Stutzman,* Jefferson Lab

Jefferson Lab been using a DC sputtering system to coat the beampipe with a Ti-Zr-V non-evaporable getter coating for 20 years. A similar system has also been used to sputter coat large diameter chambers with ultimate pressures aproaching XHV(1). The approaching upgrade of the Jefferson Lab CEBAF injector will use NEG coated beampipes of varied diameters for the first 30 meters of the machine. We describe the improvements that are being made to the sputtering system to improve stability, increase monitoring capabilities, and improve NEG film adhesion and morphology.

1) M.L. Stutzman, P.A. Adderley, A.A. Mamun and M. Poelker, J. Vac. Sci. Technol. A **36** 031603 (2018).

VT-TuP-6 Concepts for Reduced Load UHV Sealing Applications*, Ryan McCall,* Technetics Group

Designing a robust vacuum connection that can deliver UHV or XHV leak rates, withstand high temperature bake-outs and minimize hardware/bolting size can be difficult to achieve. The design process is complicated even further with Aluminum flanges or when a large diameter or shaped seal is required.

This presentation will review UHV metal sealing concepts and will detail a seal option that significantly reduces seating load by concentrating contact stress to a small area machined into the seal surface. This combination of load concentration and material selection allows for a helium tight seal with much less load than a traditional metal seal without damaging the corresponding flanges and hardware. The resilient seal loading mechanism also allows the seal to perform well in temperature cycles or bake-outs.

VT-TuP-7 Quantitative Gas Analysis with Quadrupole Mass Spectrometers - Comparison and Limitations*, Gregory Thier,* *L Kephart,* Extrel CMS*; T Whitmore,* Henniker Scientific

There are many factors to consider when comparing the overall suitability of different quadrupole-based gas analyzers for a given application. These can be categorized into two main areas, inlet/interface suitability and quadrupole mass analyzer suitability.

The suitability of the quadrupole mass spectrometer determines very important figures of merit such as precision, stability and detection limit. The quadrupole mass spectrometer includes the ionization method, the transmission characteristics, and the quality of the driving electronics.

Unfortunately, these figures of merit are often misrepresented in the commercial literature and it's this confusion which we seek to address and clarify in this document by making a direct comparison between two different classes of quadrupole analyzers; a typical 6mm rod diameter RGA type instrument typical of many currently on the market, and a higher performance 19mm rod diameter quadrupole analyzer, typical of high end analytical analyzers used in research and industry. We compare these with nominally identical inlet/transfer conditions, so that only the mass spectrometer performance is under consideration. In doing so, we present a direct comparison as it relates the various figures of merit and attempt to remove some of the mystery surrounding confusing analyzer specifications so that potential users of this powerful analytical technique may query manufacturer specifications and therefore make more informed decisions.

The specifications that we will discuss are:

- Detection Limit (minimum and maximum detectable concentration)
- Speed of Analysis (measurement speed and response time)
- Analysis Precision (repeatability of measurements)
- Analysis Stability (long-term instrument stability)
- Dynamic Range (comparison of largest and smallest detectable signals)

We will study the above by assessing and comparing the performance of two instruments, the MAX300-CAT and the MAX300-LG. The MAX300-CAT is typical of the high-end RGA based gas analyzers, based upon 6mm quadrupole rod technology, whereas the MAX300-LG is a higher performing analyzer based on 19mm quadrupole rod technology and high-performance electronics.

VT-TuP-8 Recent Developments of Home-made UHV SPM Systems and their Applications*, Qing Huan,* *Z Wu, R Ma, G He, Z Gao, L Bao, J Yuan, K Jin, H Gao,* Institute of Physics CAS, China

Scanning probe microscope (SPM) is a powerful tool for studying physical and chemical processes at single molecular/atomic level. The first part of this report will introduce our R&D progresses on UHV-SPM systems, which includes the update of a 4-probe STM, Variable-temperature STM, Low-temperature SPM combined with MBE and optical accesses, and Low-temperature SPM combined with PLD et. al. The second part will mainly introduce some research works on graphene, organic functional molecules and so on which are carried out on these home-made systems.

VT-TuP-9 An Experimentally Backed Modeling of NEG Pump Operation During Saturation*, Derek Hammar,* Coe College*; Y Lushtak,* Cornell University

Non-Evaporable Getter (NEG) pumps are increasingly common in particle accelerator applications

because of their small size and their strong performance for hydrogen, the principal UHV gas. However, these pumps present a challenge to vacuum system design because their complicated

geometry results in unreasonably complicated vacuum simulations. This project seeks to build 3D

models of NEG pumps and their environments in AutoDesk Inventor and simulate their performance

in MolFlow, creating a database to NEG performance under various installation geometries and

attempting to simplify the pump geometry without sacrificing simulation accuracy. Key results are

verified experimentally

VT-TuP-10 3D printed Mini-Channel Plates – Vacuum Compatibility and Detector Performance*, Maram Alnahhas,* *J Moore,* Robot Nose Corporation

Conventional production of microchannel plates (MCPs) produces linear channels. Our simulations promise a significant improvement in time resolution by changing the geometry of the channels from straight to a zig-zag (Z) configuration, which drives the electrons to land on a specific surface in each gain stage, yielding higher time resolution. The sensitivity is improved as well by controlling the outer shape of the pores; replacing the circular pore pattern with hexagon or square will increase the open area ratio for the same MCP diameter. 3D printing MCPs not only enables this Z channel approach, but is a cost-effective method to produce charged particle detectors.

3dMCPs were created using a 70-micron resolution stereolithography printer. Both linear and Z channels were printed with 30:1 length to diameter (l/d) ratio. Graphite and other dopants have been used to change the resistivity of the printed material. In principle, the 3dMCP can then be coated for secondary emissions using ALD technology. Optical microscopy of the 3dMCP and its cross-section show that good uniformity can be attained throughout once the process was optimized.

To facilitate low vacuum flow testing of the 3dMCPs, a microcontroller based multi-vacuum gauge has been constructed. This device fits on a 2.75" Conflat flange with a built-in pressure gauge and OLED display. The gauges chosen are a Pirani pressure sensor calibrated with a capacitance manometer. To digitize the signals and establish serial connections between the electrical parts, the Trinket M0 MCU was used with a built-in 12-bit ADC and a reference voltage of 3.3v. I have also designed an enclosure that could easily attach to a flange.

An apparatus was built to measure the gain and pulse output characteristics of the MCPs. TauZero (τ0) consists of an ultrahigh vacuum chamber with 2kV electron and 20kV Ga^+ guns directed at multiple test 3dMCPs. The turbo pumped vacuum system is vibrationally isolated. τ0's electronics suite includes a 6 ½ digit DMM, 16 GHz digital oscilloscope, spectrum analyzer, a time-to-digital converter with 12ps resolution, and a digitizer with pulse height analysis software.

One of the main concerns regarding 3d printed materials is whether the plastic used will contaminate a high vacuum system. 3dMCPs were outgassed in a vacuum chamber while monitoring with a residual gas analyzer to collect data during the outgassing process. Vacuum did not damage the 3dMCPs and a drop of volatiles over 24 hours was measured. We concluded that the 3dMCPs are high vacuum compatible.

This work was supported by the DOE Office of Nuclear Physics.

Materials and Processes for Quantum Information, Computing and Science Focus Topic
Room B231-232 - Session QS+2D+EM+MN+NS+VT-WeM

Material Systems and Applications for Quantum Sciences

Moderators: Mena Gadalla, Harvard University, Kai Xiao, Oak Ridge National Laboratory

8:00am **QS+2D+EM+MN+NS+VT-WeM-1 Quantum Information at the Molecular Foundry - An Overview of New Toolsets for QIS Research***, **Adam Schwartzberg**, S Cabrini, D Ogletree, A Weber-Bargioni,* Lawrence Berkeley National Laboratory (LBNL)

The fundamental unit of quantum computation and sensing is the qubit, and many physical systems have been investigated for practical realization. These include superconducting Josephson junction circuits, color centers, and isolated cold atoms or ions. Superconducting qubit circuits (SCQBs) being one of the most promising avenues to quantum computation. However, there are limitations to their practical application due to noise sources which shorten their functional lifetime.

In this talk I will introduce a suite of integrated, high-fidelity fabrication instrumentation that will allow new communities of users to investigate the fundamental limits of state-of-the-art quantum systems at the Molecular Foundry. We will enable users to understand existing systems and design new ones by creating a quantum fabrication toolset for directed growth of conventional and novel materials, advanced lithography and pattern transfer paired with in- and ex-situ surface characterization.

Three key QIS fabrication capabilities at the Molecular Foundry:

A robotic fabrication cluster system with materials deposition, including atomic layer and physical vapor depositions, plasma etching, and analytical characterization instrumentation, all automated by and contained within a vacuum sample handling robot.

A high resolution electron beam writing system will allow quantum device patterning with complete flexibility in feature shape, density and size, enabling nanoscale feature control.

A low temperature transport measurement system will allow for the investigation of novel materials for superconductors and dielectrics and “close the loop” between design and fabrication, proxy measurements such as interface characterization, and actual performance of quantum computation and sensing elements.

This instrumentation suite will enable the elucidation of chemical composition, structure, location, and size of microscopic noise sources in a superconducting quantum system, understanding the fabrication steps that introduced such noise sources, and developing fabrication approaches that minimize their presence.

I will also discuss ongoing and new research directions at the Molecular Foundry through internal staff and external user research.

8:20am **QS+2D+EM+MN+NS+VT-WeM-2 Quantum Vacuum Metrology to Advance Quantum Science Capabilities***, **Jay Hendricks**, J Ricker, K Douglass,* National Institute of Standards and Technology (NIST)*; J Fedchak, J Scherschligt,* National Institute of Sandards and Technology (NIST)

NIST is developing a series of next generation pressure and vacuum standards that will serve as a basis for key vacuum technology platforms required for emerging quantum science applications. The production of quantum sensors and devices is anticipated to require extremely demanding process control with exact knowledge of background residual gas, process chamber pressure, and accurate measurement of gas pressure feedstocks.

In 2019, National Metrology Institutes around the world worked to redefine the international system of units, the SI, such that the base units are now based on fundamental constants.

Moving forward, the next generation of pressure and standards will provide a new route of SI traceability for the pascal. By taking advantage of both the properties of light interacting with a gas and that the pressure dependent refractive index of helium can be precisely predicted from fundamental, first-principles quantum-chemistry calculations, a new route of realizing the pascal has been demonstrated. This talk will briefly cover the classical methods of realizing pressure that have served the metrology community well for the past 375 years. And then will take a deeper dive into the next generation of light-based pressure standards that will enable the elimination of mercury manometers, replacing them with a smaller, lighter, faster, and higher precision standards. From a metrology stand point, the new quantum-based SI pascal will move us from the classical force/area definition, to an energy density (joules per unit volume) definition. Should the technique be further miniaturized, it will lead to a revolution in pressure metrology, enabling a photonics-based device that serves both a gas pressure sensor and a portable gas pressure standard all in one.

NOTE: this topic is appropriate for VT sessions as well but thought it would be interesting to the broader audience that is interested in emerging quantum-based technologies that are needed to advance the field of quantum science.

8:40am **QS+2D+EM+MN+NS+VT-WeM-3 Quantum Control of Spins in Silicon Carbide with Photons and Phonons***, **David Awschalom**, S Whiteley, G Wolfowicz, K Miao,* University of Chicago **INVITED**

There are numerous efforts to embrace solid-state defects and construct quantum systems to enable new information technologies based on the quantum nature of the electron. Current studies include semiconductors with incorporated point defects, whose quantum mechanical spin properties allow a fundamentally different means to process information. In particular, interfacing solid-state defect electron spins to other quantum systems is an ongoing challenge. Here we demonstrate electrically driven coherent quantum interference in the optical transition of single divacancies, enabling new control of the spin-photon interface [1]. By applying microwave frequency electric fields, we coherently drive the excited-state orbitals and induce Landau-Zener-Stückelberg interference fringes in the resonant optical absorption spectrum. Furthermore, we develop a stroboscopic X-ray diffraction imaging technique that provides direct imaging and quantitative measurement of local strain at the nanometer scale. In conjunction with the fabrication of surface acoustic wave resonators, we mechanically drive coherent Rabi oscillations between arbitrary ground-state spin levels, including magnetically forbidden spin transitions, allowing for acoustic quantum control of local spins in silicon carbide and the exploration of spin-phonon coupling in the solid state [2]. These properties establish divacancies as strong candidates for quantum communication and hybrid system applications, where simultaneous control over optical and spin degrees of freedom is paramount.

[1] K. C. Miao *et al*., arxiv: 1905.12780

[2] S. J. Whiteley *et al*., Nature Phys. **15**, 490 (2019)

9:20am **QS+2D+EM+MN+NS+VT-WeM-5 Tunable Control over InSb(110) Surface Conductance Utilizing Charged Defects***, **Robert Walko**, S Mueller, S Gant, J Repicky, S Tjung, E Lang, E Fuller, K Werner,* The Ohio State University*; F Bergmann,* Bergmann Messgeraete Entwicklung*; E Chowdhury, J Gupta,* The Ohio State University

In this work we present a scanning tunneling microscopy (STM) study of tip-induced switching of charge states in individual indium adatoms on the InSb(110) surface. These adatoms are deposited onto the surface by controlled voltage pulses between the STM tip and the surface. We observe them in two distinct charge states: positive and neutral. Adatom-induced band bending from the positively charged state has been observed to induce a tenfold increase in surface conductance relative to the charge neutral state, the effect of which can be observed >100nm away from the indium adatom. When the STM tip is brought sufficiently close to the defect, electrons can tunnel from the tip to the defect and cause the charge state to switch from positive to neutral. During imaging, this switching leads to a “crater” feature around the defect due to the lower conductance of the charge neutral state. The spatial extent of the crater can be tuned via the applied bias voltage, the tunneling set-point current, and photoillumination of the surface. We explain this phenomenon using a model of competing rates between the filling and emptying of the defect state, similar to dangling bonds on the Si(111) surface.

This work acknowledges funding from the DOE (# DE-SC0016379)

9:40am **QS+2D+EM+MN+NS+VT-WeM-6 Quantum Calligraphy: Writing Single-Photon Emitters in a Two-Dimensional Materials Platform***, **Matthew R. Rosenberger**,* U.S. Naval Research Laboratory*; C Dass,* Air Force Research Laboratory*; H Chuang, S Sivaram, K McCreary,* U.S. Naval Research Laboratory*; J Hendrickson,* Air Force Research Laboratory*; B Jonker,* U.S. Naval Research Laboratory

We present a paradigm for encoding strain into two dimensional materials (2DM) to create and deterministically place single photon emitters (SPEs) in arbitrary locations with nanometer-scale precision. Our material platform consists of a 2DM placed on top of a deformable polymer film. Upon application of sufficient mechanical stress using an atomic force microscope tip, the 2DM/polymer composite deforms, resulting in formation of highly localized strain fields with excellent control and repeatability. We show that SPEs are created and localized at these nanoindents, and exhibit single photon emission up to 60K. This ***quantum calligraphy*** allows deterministic placement and real time design of arbitrary patterns of SPEs for facile coupling with photonic waveguides, cavities and plasmonic structures. In addition to enabling versatile placement of SPEs, these results present a general methodology for imparting strain into 2DM with nanometer-scale precision, providing an invaluable tool for further investigations and future applications of strain engineering of 2DM and 2DM devices.

Reference: Rosenberger et al., "Quantum Calligraphy: Writing Single-Photon Emitters in a Two-Dimensional Materials Platform," *ACS Nano*, 2019, https://pubs.acs.org/doi/10.1021/acsnano.8b08730

11:00am **QS+2D+EM+MN+NS+VT-WeM-10 Challenges in Topological and Quantum Materials***, **David Alan Tennant**,* Oak Ridge National Laboratory **INVITED**

Quantum materials are rapidly advancing but still present great challenges. Topological quantum

materials in particular are receiving great attention as they provide potentially robust routes to

quantum information processing that are protected against decoherence processes. Among key

challenges are the prediction and realization of magnetic materials in the form of magnetic Weyl

semimetals and quantum spin liquids as ways of realizing exotic quasiparticles such as Majorana fermions

that can be used for application. These materials present new experimental challenges in terms of identifying their

quasiparticles and demonstrating quantum coherence in their ground states states. Here I will

show how we are using the integrated application of machine learning along with experiment and synthesis

to advance the discovery and understanding of these materials.

11:40am **QS+2D+EM+MN+NS+VT-WeM-12 Rare Earth Silicon Photonics Engineering for Quantum Applications***, A Nandi, X Jiang, D Pak,* Purdue University*; D Perry, E Bielejec,* Sandia National Laboratories*; Y Xuan, **Mahdi Hosseini**,* Purdue University

Controlling intermodal coupling between multiple excitations within a photonic material may enable the design of novel quantum photonic metamaterials exhibiting anomalous effects. Understanding the complex mode dynamics towards the engineering of system Hamiltonian has been the subject of intensive research in recent years. Here, we design an atomic lattice composed of nearly 1000 rare earth ion segments deterministically engineered in silicon photonic structures to modify the emission properties of erbium in silicon. We observe anomalous photon emission at the telecommunication wavelength from atoms geometrically arranged to reduce the propagation loss. Moreover, we map asymmetric emission lineshapes led by intermodal Fano-type interference of the atomic and photonic resonance modes. Our observation paves the way for designing active metamaterials and novel topological photonics with engineered linear and nonlinear interactions for broad applications in quantum information. Moreover, I will result for direct integration of rare earth crystals with silicon photonic chip for implementation of quantum optical memories. The approach can impact the fields of quantum communication and computation through, for example, developing superradiant single photon sources, the study of non-equilibrium many-body quantum dynamics, and engineering quantum transport in a scalable solid-state platform.

Chemical Analysis and Imaging Interfaces Focus Topic
Room A120-121 - Session CA+NS+SS+VT-WeA

Chemical Analysis and Imaging of Liquid/Vapor/Solid Interfaces I

Moderators: Juan Yao, Pacific Northwest National Laboratory, Andrei Kolmakov, National Institute of Standards and Technology (NIST)

2:20pm **CA+NS+SS+VT-WeA-1 Chemical Analysis and Imaging of Environmental Interfaces*, Vicki Grassian,*** University of Californfornia at San Diego **INVITED**

Environmental interfaces, defined as any surface in equilibrium with its surrounding environment, are ubiquitous. From this broad definition, there are a myriad of different types of environmental interfaces that include atmospheric aerosols, nanomaterials and indoor surfaces. This talk will focus on the use of different molecular probes including various spectroscopic and imaging techniques to investigate interfaces relevant to outdoor and indoor environments.

3:00pm **CA+NS+SS+VT-WeA-3 Liquid/Vapor Interfaces Investigated with Photoelectron Spectroscopy*, Hendrik Bluhm,*** Fritz Haber Institute of the MPG, Germany **INVITED**

Aqueous solution/vapor interfaces govern important phenomena in the environment and atmosphere, including the uptake and release of trace gases by aerosols and CO_2 sequestration by the oceans.[1] A detailed understanding of these processes requires the investigation of liquid/vapor interfaces with chemical sensitivity and interface specificity under ambient conditions, *i.e.*, temperatures above 200 K and water vapour pressures in the millibar to tens of millibar pressure range. This talk will discuss opportunities and challenges for investigations of liquid/vapor interfaces using X-ray photoelectron spectroscopy and describe some recent experiments that have focused on the propensity of certain ions and the role of surfactants at the liquid/vapor interface.

[1] O. Björneholm et al., Chem. Rev. **116**, 7698 (2016).

4:20pm **CA+NS+SS+VT-WeA-7 Methanol Hydration Studied by Liquid μ-jet XPS and DFT Simulations*, Jordi Fraxedas,*** Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Spain*; E Pellegrin, V Perez-Dieste, C Escudero,* CELLS-ALBA, Spain*; P Rejmak,* Institute of Physics PAS, Poland*; N Gonzalez, A Fontsere, J Prat, S Ferrer,* CELLS-ALBA, Spain

The advent of liquid μ-jet setups, in conjunction with X-ray Photoemission Spectroscopy (XPS), has opened up a plethora of experimental possibilities in the field of atomic and molecular physics [1]. Here, we present a combined experimental and theoretical study of the hydration of methanol at the aqueous solution/vapor interface. These are first experimental results obtained from the new liquid μ-jet setup at the Near Ambient Pressure Photoemission (NAPP) endstation of the CIRCE helical undulator beamline (100–2000 eV photon energy range) at the CELLS-ALBA synchrotron light source, using a differentially pumped SPECS PHOIBOS 150 hemispherical electron energy analyzer [2].The experimental results are compared with simulations from density functional theory (DFT) regarding the electronic structure of single molecules and cluster configurations as well as with previous experimental studies.

Methanol is the simplest amphiphilic molecule capable of hydrogen bonding due to its apolar methyl and polar hydroxyl groups. The results obtained from pure water at 600 eV photon energy emphasize the short range tetrahedral distribution as previously observed for crystalline and amorphous ice. We also find indications for ordering phenomena in water/methanol mixtures by the reduced O1s XPS liquid line width (as compared to pure water), which could be ascribed to the amphiphilic character of the methanol molecule. Regarding the C1s XPS lines, the vapor/liquid peak ratios allow for a quantitative determination of the methanol volume concentrations in both the vapor as well as in the liquid phase, that are corroborated by an analogue analysis of the valence band (VB) spectra. A detailed quantitative analysis of the water/methanol liquid VB XPS spectrum accounting for the photon energy dependence of photoemission cross sections confirms the atomic/orbital characteristics of the methanol molecular orbitals involved in the transitions and their pertinent intensities. From the decomposition of the liquid VB spectrum of the water/methanol mixture together with finite XPS probing depth we derive a methanol volume fraction of 43% for the outer liquid layers as compared to the nominal bulk liquid value of 37.5%. Finally, from the different binding energy (BE) shifts of the water/methanol liquid VB spectrum with respect to that of pure methanol, we develop a CH_3OH-$(H_2O)_3$ cluster-based model that relates these different BE shifts to the different MO hybridizations within that cluster.

[1] B. Winter, M. Faubel, Chem. Rev. 106 (2006) 1176.

[2] V. Pérez-Dieste, L. Aballe, S. Ferrer, J. Nicolàs, C. Escudero, A. Milán, E. Pellegrin, J. Phys. Conf. Ser. 425 (2013) 072023.

4:40pm **CA+NS+SS+VT-WeA-8 Survey of Ionic Liquid Interfaces under Vacuum and Ambient Conditions: An XPS Perspective*, Yehia Khalifa,*** Ohio State University*; A Broderick, J Newberg,* University of Delaware*; Y Zhang, E Maginn,* University of Notre Dame

Properties and behavior of Ionic Liquid interfaces tend to behave differently from their bulk counterparts. In this study the preferential enhancement of the lower molar concentration anion [TFSI] in a mixture of [C2MIM][OAc] and [C2MIM][TFSI] is shown in the top 17 Å via angle-resolved X-ray photoemission spectroscopy under ultra high vacuum conditions. This is supported by molecular simulations where a quantitative relationship is also established between the two techniques. This interfacial enhancement is not only unique to mixtures but is also displayed in a pure ionic liquid with a hydrophilic anion such as [HMIM][Cl] studied via ambient pressure X-ray photoemission spectroscopy. The surface of [HMIM][Cl] under vacuum and increasing pressures of water vapor was evaluated (maximum of 5 Torr, 27% relative humidity). Our quantitative results indicate a significantly larger mole fraction of water at the interface compared to the bulk with increasing pressures when compared to previously published tandem differential mobility analysis results on [HMIM][Cl] nanodroplets. Furthermore the reverse isotherms has shown that the water uptake on the interface is a reversible process. These results highlight the unique behavior of ionic liquid interfaces that can be exploited for smart materials design and application.

5:00pm **CA+NS+SS+VT-WeA-9 Ambient Pressure XPS Study of Gallium-Indium Eutectic (EGaIn) Surface under Oxygen and Water Vapor*, Meng Jia,*** *J Newberg,* University of Delaware

Liquid metals (LMs) have a combination of high thermal/electrical conductivity and excellent deformability. The application of LMs in the field of electronics has identified many opportunities for their use as stretchable electronics, self-healing conductors and interconnects. Gallium-Indium eutectic (EGaIn) is one of the leading alternatives to toxic liquid mercury because of its low vapor pressure, low viscosity, low toxicity and high conductivity. A surface oxide layer is known to form when EGaIn is exposed to ambient conditions. However, surface sensitive measurements of this chemistry occurring under ambient conditions are strongly lacking. Herein we present results from the interaction of oxygen and water vapor with the liquid-gas interface of an EGaIn droplet deposited on an W foil using ambient pressure X-ray photoelectron spectroscopy (AP-XPS). EGaIn was examined up to a maximum of 1 Torr pressure at 550 K. Results reveal that under ambient conditions both oxygen and water vapor form a Ga(3+) oxide (Ga_2O_3) as an outer layer, while a thin layer of Ga(1+) oxide (Ga_2O) resides between metallic EGaIn and the outer Ga(3+) oxide. Both gases were unreactive towards Indium under our experimental conditions. The oxidation kinetics in the presence of water vapor were much faster compared oxygen. Proposed reaction mechanisms will be discussed.

5:20pm **CA+NS+SS+VT-WeA-10 Laboratory-based Hard X-ray Photoelectron System for the study of Interfaces*, Susanna Eriksson,*** Scienta Omicron

Hard X-ray photoelectron spectroscopy (HAXPES) has traditionally found its application in the core topics of condensed matter physics, but the slowly growing number of beamlines worldwide has widened its appeal to other interest groups. HAXPES uses X-rays in the 2-10 keV range to excite photoelectrons, which are used to non-destructively study the chemical environment and electronic structure of materials.

In contrast to the very surface-sensitive XPS, HAXPES is much more bulk sensitive. This makes it applicable to bulk materials and structured samples, e.g. layered samples and heterostructures. In addition, its bulk sensitivity means that realistic samples can be investigated without the need of prior surface preparation. However, the number of existing HAXPES systems is very small and they are predominantly located at synchrotrons (approx. 20 beamlines worldwide) due to low photoionization cross sections necessitating high X-ray intensities, limiting their availability to users and applications.

This work presents a new laboratory-based instrument capable of delivering monochromated hard X-rays with an energy of 9.25 keV and a focused 30x45 μm^2 X-ray spot, giving excellent energy resolution of <0.5

eV. Systematic reference measurements are presented outlining the systems capability as well as the latest results from various application fields including energy related materials such as batteries.

Ultimately, this spectrometer presents an alternative to synchrotron-based endstations and will help to expand the number and range of HAXPES experiments performed in the future. HAXPES is a cutting edge characterisation method and the advancement of this technique will tremendously increase the potential to study an ever increasing range of inorganic materials and beyond.

Chemical Analysis and Imaging Interfaces Focus Topic
Room A120-121 - Session CA+NS+SS+VT-ThA

Progress in Instrumentation and Methods for Spectro-microscopy of Interfaces

Moderators: Jinghua Guo, Lawrence Berkeley National Laboratory, Andrei Kolmakov, National Institute of Standards and Technology (NIST)

2:20pm **CA+NS+SS+VT-ThA-1 Helium and Neon Ion Beams for the Imaging and Analysis of Interfaces***, **John A. Notte**, C Guillermier, F Khanom, B Lewis,* Carl Zeiss PCS, Inc. **INVITED**

The recently developed ORION NanoFab instrument provides a single platform with He^{+}, Ne^{+}, and Ga^{+} focused ion beams. The gallium beam is a conventional FIB and offers high currents and high sputter yields for material removal applications such as sample preparation or exposing sub-surface features. The He and Ne ion beams originate from a sub-nanometer ionization volume of the gas field ion source (GFIS) and because of this, can be focused to remarkable small probe sizes, 0.5 nm and 1.9 nm respectively. The He beam is now well established for high resolution imaging with surface sensitivity, long depth of focus, and the ability to image insulating surfaces without a conductive overcoating. The helium beam has also been used successfully in a variety of nanofabrication tasks such as lithographic exposure of resist, fine sputtering, beam chemistry, and precision modification of materials. The neon beam with its intermediate mass provides a higher sputtering yield, and with that, the ability to perform SIMS analysis with an unprecedented small focused probe size. A newly integrated magnetic spectrometer enables analytical capabilities on this same platform, with a lateral resolution limited only by the collision cascade. Features smaller than 15 nm have been detected. Together these complementary imaging modes can be combined to provide insights of morphology and composition at the smallest length scales.

In this talk the underlying technology of the NanoFab-SIMS will be introduced, as will the physics of the beam-sample interactions. The bulk of the presentation will provide a survey of results, both published and new, demonstrating how this instrument can serve in a variety of applications related to interfaces.

3:00pm **CA+NS+SS+VT-ThA-3 Interfacial Studies using Ambient Pressure XPS***, **Paul Dietrich**, A Thissen,* SPECS Surface Nano Analysis GmbH, Germany **INVITED**

Over the last decades XPS under Near Ambient Pressure (NAP) conditions has demonstrated its promising potential in a wide variety of applications. Starting from operando studies of surface reactions in catalysis, the applications soon have been enhanced towards studies of processes at liquid surfaces, mainly using freezing/melting cycles, liquid jets or liquid films on rotation disks or wheels. Since more than 15 years, the need for basic studies off fundamental solid-liquid interface chemistry has attracted growing interest. Dip-and-pull experiments at synchrotron sources finally also demonstrated, that in-situ and operando XPS in electrochemical experiments can be realized, significantly contributing to the basic understanding of modern energy converting or storing devices, like batteries, fuel cells, etc.

The development of pure laboratory NAP-XPS systems with optimized sample environments, like special sample holders, Peltier coolers and operando liquid cells combined with full automation and process control provides possibilities for preparation and analysis of a multitude of liquid samples or solid-liquid interfaces on a reliable daily base.

Interfaces of semiconductors with organic solvents are important for production processes and device operation. The first example presented shows the simplicity of obtaining relevant results on Silicon in different organic solvents without the need of highly sophisticated set-ups or special excitation sources beyond Al K_a.

Another example shows an operando study of metal corrosion in acetic acid. Moreover a versatile set-up is presented, allowing for studies of solid-electrolyte interfaces for example in Lithium ion batteries as a simple laboratory experiment.

Finally an outlook is given on the future perspective of applications and scientific contributions of routine operando XPS.

4:00pm **CA+NS+SS+VT-ThA-6 Operando Spectroscopy and Microscopy of the Electrode-Electrolyte Interface in Batteries***, **Feng Wang**,* Brookhaven National Laboratory **INVITED**

Real-time tracking structural/chemical changes of electrodes in batteries is crucial to understanding how they function and why they fail. However, in real battery systems electrochemical/chemical reaction occurs at varying length scales, leading to changes not only in the bulk but often locally at electrolyte/electrode interface. *In situ* X-ray techniques are typically employed for studying structural changes in the bulk electrodes and often limited by their poor spatial resolution in probing local changes at interface. Herein, we present our recent results from developing new *operando* spectroscopy and microscopy techniques, specialized for studying electrochemical/chemical reaction and structural modification of the solid-electrode surface and interface, *in the presence of the electrolyte and during battery operation*. Examples will be given to show how interfacial reaction during battery operation is visualized directly, allowing gaining insights into electrode/electrolyte design for practical use in batteries. New opportunities for combining *first principles* simulation and deep machine learning to complement and guide experiments will also be discussed.

4:40pm **CA+NS+SS+VT-ThA-8 Ultrasensitive Combined Tip- and Antenna-Enhanced Infrared Nanoscopy of Protein Complexes***, B O'Callahan,* Pacific Northwest National Laboratory*; M Hentschel,* University of Stuttgart, Germany*; M Raschke,* University of Colorado Boulder*; P El-Khoury,* Pacific Northwest National Laboratory*; **Scott Lea**,* Pacific Norththwest National Laboratory

Surface enhanced infrared absorption (SEIRA) using resonant plasmonic nanoantennas enables zeptomolar detection sensitivity of (bio)analytes, although with diffraction limited spatial resolution. In contrast, infrared scattering-scanning near-field optical microscopy (IR s-SNOM) allows simultaneous imaging and spectroscopy with nanometer spatial resolution through vibrational coupling to the antenna mode of a probe tip. In this presentation, we discuss our approach combining these two methods to image both continuous and sparse distributions of ferritin protein complexes adsorbed onto IR-resonant Au nanoantennas. The joint tip- and antenna-enhancement yields single protein complex sensitivity due to coupling with the vibrational modes of the bioanalytes. The coupling is revealed through IR s- SNOM spectra in the form of Fano lineshapes, which can be modelled using coupled harmonic oscillators. Through simulations of the recorded hyperspectral images, we extract the optical signatures of protein complex monolayers. This work paves the way for single protein identification and imaging through a combination of tip and antenna-enhanced IR nanoscopy.

5:00pm **CA+NS+SS+VT-ThA-9 Imaging and Processing in Liquid Gel Solutions with Focused Electron and X-ray Beams***, T Gupta,* National Institute of Standards and Technology (NIST)*; P Zeller, M Amati, L Gregoratti,* Elettra - Sincrotrone Trieste, Trieste, Italy*; **Andrei Kolmakov**,* National Institute of Standards and Technology (NIST)

Gels are porous polymeric scaffolds that can retain high volume fraction of liquids, can be easily functionalized for a specific need, can be made biocompatible and therefore, found numerous applications in drugs devilry, tissue engineering, soft robotics, sensorics, energy storage, etc. We have recently proposed a technique for micro-patterning and high-resolution additive fabrication of 3D gel structures in natural liquid solutions using electron and soft X-ray scanning microscopes [1]. The core of the technology is the employment of ultrathin electron (X-ray) transparent molecularly impermeable membranes that separate high vacuum of the microscopes from a high-pressure fluidic sample. In this communication, we report on effects of the beam and exposure conditions on to the degree of crosslinking of pristine and composite PEGDA hydrogels. We found that cross-linking occurs at very low irradiation doses. The size of the crosslinked area saturates with the dose and bond scission occurs at elevated radiation doses what has been supported with O 1s and C 1s XPS spectra evolution and prior research [2]. These chemically modified regions can be selectively etched what enables an additional partnering option for the gelated features with a spatial resolution of ca 20 nm. Finally, we defined the imaging conditions for guest particles in composite hydrogels in its liquid state during the crosslinking process. We were able to observe the electrophoretic migration of sub 100 nm Au nanoparticles inside the gel matrix.

References

[1] T. Gupta *et al.*, "Focused Electron and X-ray Beam Crosslinking in Liquids for Nanoscale Hydrogels 3D Printing and Encapsulation," *arXiv preprint arXiv:1904.01652,* 2019.

[2] N. Meyerbröker and M. Zharnikov, "Modification and Patterning of Nanometer-Thin Poly (ethylene glycol) Films by Electron Irradiation," *ACS applied materials & interfaces,* vol. 5, no. 11, pp. 5129-5138, 2013.

5:20pm **CA+NS+SS+VT-ThA-10 In Situ TEM Visualization of Solution-based Nanofabrication Processes: Chemical Wet-etching and Capillary Forces***,* ***Utkur Mirsaidov,*** National University of Singapore, Singapore **INVITED**

Controlled fabrication of 3D nanoscale materials from semiconductors is important for many technologies. For example, scaling up the density of the transistors per chip requires the fabrication of smaller and smaller vertical nanowires as channel materials [1]. Two key processes essential to the fabrication of these devices is a precise etching of the nanostructures and the damage-free solution based cleaning (damage occurs during post-clean drying due to capillary forces). However, very little is known about both of these processes because it is extremely challenging to visualize etching and cleaning with solutions directly at the nanoscale. Here, using in situ liquid phase dynamic TEM imaging [2-4], we first describe the detailed mechanisms of etching of vertical Si nanopillars in alkaline solutions [5]. Our design of liquid cells includes a periodic array of patterned nanopillars at a density of 1.2×10^{10} cm^{-2}. We show that the nanoscale chemical wet-etch of Si occurs in three stages: 1) intermediates generated during alkaline wet etching aggregate as nanoclusters on the Si surface, 2) then the intermediates detach from the surface before 3) dissolving in the etchant.

Next, we describe the capillary damage of these high-aspect-ratio Si nanopillars during drying after the solution-phase cleaning. Our results reveal that drying induced damage to nanopillars occurs in three distinct steps. First, as water evaporates from the surface patterned with nanopillars, water film thins down non-uniformly leaving small water nanodroplets trapped between the nanopillars. Second, the capillary forces induced by these droplets bend and bring the nanopillars into contact with each other at which point they bond together. Third, droplets trapped between the nanopillars evaporate leaving the nanopillars bonded to each other. We show that even after the nanodroplets finally evaporate, interfacial water covering the nanopillars act as a glue and holds the pillars together.

Our findings highlight the importance of being able to visualize the processes relevant to nanofabrication in order to resolve the failure modes that will occur more frequently as the device sizes get even smaller in the future.

[1] C. Thelander et al, Mater. Today 9 (2006), 28−35.

[2] M. J. Williamson et al, Nature Materials 2 (2003), p. 532.

[3] H. Zheng et al, Science 324 (2009), p. 1309.

[4] U. Mirsaidov et al, Proc. Natl. Acad. Sci. U.S.A. 109 (2012), p. 7187.

[5] Z. Aabdin et al, Nano Letters 17 (2017), p.2953.

[6] This work was supported by Singapore National Research (NRF-CRP16-2015-05).

Author Index

Bold page numbers indicate presenter

Author Index