Flat Panel Displays
Room 313 - Session FP+VT-TuA
Emissive Displays and Device Reliability

Moderator: D. Temple, Microelectronics Center of North Carolina

2:00pm **FP+VT-TuA1 Development and Characterization of Cu-Li Alloy Edge Field Emission Devices@footnote 1@*, J.C. Tucek,*** *A.H. Jayatissa, A.R. Krauss, O. Auciello, D.M. Gruen, D.C. Mancini, N. Moldovan,* Argonne National Laboratory

Thin coatings (0.5 - 1 monolayer in thickness) of alkali metals applied to field emission devices are known to significantly enhance field electron emission. However, alkali metals are both physically and chemically unstable in layers exceeding a few Å in thickness, and therefore, it is extremely difficult to fabricate and maintain, during operation, such thin layers on FEAs. Lithium alloy films developed at Argonne National Laboratory provide very stable, low work function coatings that maintain a segregated monolayer of lithium on the surface of the alloy, even under adverse environmental conditions or ion bombardment. These Li-based alloy films have been incorporated into edge emission devices which have low emission thresholds (~3 V/µm), high emission current densities (~10 A/cm@sup 2@), and are physically robust. These devices have been operated in a continuous emission mode for up to 270 hours. After an initial decrease in the emission current level, the emission from the Cu-Li films reach a constant level at approximately 60% of the initial current level, in accord with the stability and the long-lived nature of the Cu-Li films. These devices have been tested in inert gas atmospheres at pressures up to 0.1 mTorr, and they emit (at 50% of the high vacuum level) without catastrophic failure. In addition, we will discuss experiments using a simulated flat panel display configuration and PEEM/FEEM imaging which provide information about the emission uniformity of these edge emitters. Finally, work on applications of the Cu-Li films in gated emission devices will be discussed. @FootnoteText@ @footnote 1@Work supported by the U.S. Department of Energy, BES-Material Sciences, under Contract W-31-109-ENG-38, ONR, and the Office of Naval Research and DARPA under contract N00014-97-F0905.

2:20pm **FP+VT-TuA2 Field Emission Characteristics of Carbon Nanotubes*, B.R. Chalamala,*** *K.A. Dean, R.H. Reuss,* Motorola, Inc. **INVITED**

We will present a summary of our recent work on the field emission characteristics of carbon nanotubes, and discuss their application in functional vacuum microelectronic devices like field emission displays. Our study has two primary goals: gain a deeper understanding of the fundamental mechanisms, and obtain an insight into the impact of practical issues on device performance. In particular, we will present detailed studies on the emission characteristics of individual single walled carbon nanotubes including current saturation mechanisms, device behavior under adverse vacuum conditions, along with high resolution field emission images showing detailed structure.

3:00pm **FP+VT-TuA4 Current Density Saturation in FED Phosphors*, J.S. Lewis,*** University of Florida*; G.O. Mueller, R. Mueller-Mach, T. Trottier,* Agilent Labs*; P.H. Holloway,* University of Florida

In recent years interest in low voltage phosphors has been prompted by the development of field-emission displays (FED's) which operate in the 0.5-6 kV range. Taking into account factors such as dwell time, power density, intrinsic efficiency, and penetration depth, the current densities involved in FED operation are of similar magnitude as those used in CRT's and projection tubes. While brightness typically increases with current, efficiency decreases at higher current densities. Due to the different operating conditions, increased characterization and understanding of saturation at low voltages is needed. Quantification of current density is difficult, since electron beams used to excite the phosphors generally exhibit a Gaussian current distribution. This leads to variation of current density, and potentially saturation effects, over the beam area. Gaussian beam shapes cause more severe saturation in the center of the beam spot where current density is higher, and 'blooming' effects cause a change in beam size or shape as current increases. Deconvolution of these effects is difficult, but new experimental techniques have been developed which for the first time allow the determination of saturation effects in terms of absolute efficiency (under FED conditions). An approach was developed for the determination of the current distribution, and thus the saturation of intrinsic efficiency is obtained as a function of true local current density. The data can be used to model performance under any arbitrary current distribution. Results will be presented for a variety of traditional CRT and projection tube phosphors, as well as newer phosphors for use in FED's. The mechanisms for saturation will be discussed. *This work partially supported by the Phosphor Technology Center of Excellence.

3:20pm **FP+VT-TuA5 Cathodoluminescence from Thin Film versus Powder Phosphors*, L.C. Williams,*** *B. Abrams,* University of Florida*; W. Roos,* University of the Orange Free State*; P.H. Holloway,* University of Florida

Thin film cathodoluminescent (CL) phosphors have a number of potential advantages over powder phosphors, such as better mechanical integrity, better thermal heat sinking, more efficient use of material, and better planarity. However most CL screens use powder phosphors due to better brightness, efficiency, and crystallinity. In the current work, we have examined the effects of thin films versus powders on the rate of degradation of ZnS:Mn in residual vacuum gases. The ZnS:Mn thin films were RF planar magnetron sputter deposited onto glass/ITO substrates at a growth temperature of 160°C. The powders were simply cold compacted into shallow stainless steel sample holders. Degradation was shown to occur by the Electron Stimulated Surface Chemical Reaction (ESSCR) mechanism, in which the electron beam dissociated adsorbed oxidizing molecular species (e.g. H@sub 2@O) to cause conversion of luminescent ZnS:Mn to non-luminescent ZnO:Mn. The degradation was faster at low primary beam energy (0.5keV) versus high energy (5keV). Degradation was dependent upon the gas pressure and electron dose (versus time of exposure). Degradation of as deposited thin films was different from that for films annealed at 750°C for 5 minutes; this will be interpreted in terms of the point defect density of as deposited versus annealed phosphor films. After correction for the true surface area of powders versus films, the rate of degradation will be compared. The mechanisms leading to the different degradation rates for films versus powders will be discussed.

3:40pm **FP+VT-TuA6 Reliability of Silicon-based Field Emission Displays*, T. Akinwande,*** Massachusetts Institute of Technology **INVITED**

PLEASE SEND US AN ABSTRACT. Thank you.

4:20pm **FP+VT-TuA8 Illumination Sources for Laser-based Displays*, B. Bischel,*** Gemfire Corporation **INVITED**

PLEASE SEND US AN ABSTRACT. Thank you.

5:00pm **FP+VT-TuA10 Oxide Phosphor TFEL Devices Fabricated by Magnetron Sputtering with RTA*, T. Minami,*** *H. Toda, T. Miyata,* Kanazawa Institute of Technology, Japan

High luminance thin-film electroluminescent (TFEL) devices using various oxide phosphor thin films have been recently reported. However, a high luminance could only be obtained in these TFEL devices by postannealing in various atmospheres at high temperatures about 1000@super o@C. In this paper, we describe a procedure for producing high luminance TFEL devices with an oxide phosphor thin-film emitting layer prepared without high temperature postannealing: magnetron sputtering with rapid thermal annealing (RTA). TFEL devices were fabricated by depositing oxide phosphor thin films onto thick sintered BaTiO@sub 3@ insulating ceramic sheets. A Ga@sub 2@O@sub 3@:Mn or ZnGa@sub 2@O@sub 4@:Mn thin film was deposited by r.f. magnetron sputtering onto a substrate mounted on a rotating platform; a thin film was deposited onto the substrate when it passed over the target, and subsequently, RTA was performed on the deposited film when it passed over the halogen lamps. The sputter deposition under a platform rotation of 1-2 r.p.m. was carried out in an Ar+O@sub 2@ sputter gas atmosphere at pressures of 0.2-8 Pa with an rf power of 120 W. High luminance green emissions were obtained in TFEL devices using either a Ga@sub 2@O@sub 3@:Mn or a ZnGa@sub 2@O@sub 4@:Mn thin-film emitting layer prepared without postannealing at high temperatures under optimized deposition conditions. The Ga@sub 2@O@sub 3@:Mn and ZnGa@sub 2@O@sub 4@:Mn TFEL devices driven by a sinusoidal wave voltage at 1 kHz exhibited luminances of 24 and 200 cd/m@super 2@, respectively.

Incorporating Principles of Industrial Ecology
Room 304 - Session IE-TuA
Green Manufacturing

Moderator: P.M. Beauchamp, Jet Propulsion Laboratory

2:00pm **IE-TuA1 Challenges in Bringing Green Manufacturing Technologies to the Clean Room Floor*, S. Raoux,*** Applied Materials **INVITED**

The semiconductor industry is undertaking major research and development efforts to reduce the environmental impact of its manufacturing processes. In particular, technologies have been introduced to eliminate atmospheric emissions of global warming compounds, reduce solid waste and conserve energy and water resources. At each technology node, semiconductor fabrication processes are amenable to change, and implementation of sustainable manufacturing practices should be favored. However, the stringent requirements of the semiconductor fabrication process render the introduction of novel manufacturing techniques a challenge. In this talk, we present innovative concepts that have been developed and integrated within semiconductor fabrication tools. Emphasis is placed on point-of-use (POU) solutions and environmental engineering using plasma technologies. We review the requirements that must be met by green technologies to be integrated to a complex manufacturing environment. We also present arguments to demonstrate that environmentally benign manufacturing methods can be developed and implemented in an economically viable way.

2:40pm **IE-TuA3 Eliminating Perfluorocompound Gas Emissions from CVD Chamber Cleans***, **P.J. Maroulis**, A.D. Johnson, W.R. Entley,* Air Products and Chemicals, Inc. **INVITED**

Perfluorocompond (PFC) gases such as CF4, C2F6, and NF3 are used extensively in semiconductor manufacturing processes. The largest volume use for these gases is for chamber cleaning following chemical vapor deposition (CVD). PFCs have long atmospheric lifetimes and absorb strongly in the infrared region of the electromagnetic spectrum where the earth's atmosphere would otherwise be transparent. Because of their infrared absorbances and persistence, PFCs are suspected of contributing to global warming. Through the World Semiconductor Council (WSC) the global semiconductor industry has voluntarily committed to reduce its cumulative emissions of perfluorocompounds. For the U.S., Europe, and Japan, PFC emissions will be reduced to 90% of 1995 levels by 2010 with some companies announcing even more aggressive reduction targets. Based on industry growth projections, substantial reductions for individual processes will be necessary to achieve these targeted levels. Both process optimization of traditional C2F6 based in situ cleans and substitution of NF3 for C2F6 in situ cleans are effective strategies for reducing the environmental impact of installed CVD tools. For new CVD tools, the manufacturers of semiconductor process equipment have developed and introduced a new remote NF3 cleaning technology that essentially eliminates PFC emissions. The combination of these three strategies, optimization of traditional C2F6 based in situ cleans, the substitution of NF3 for C2F6 in in situ cleans, and the implementation of the remote clean technology, has effectively solved the semiconductor industry's PFC issue. This presentation will contain data demonstrating the effectiveness of these strategies. In essentially all cases, perfluorocompounds emissions have been reduced by 50% to >99%.

3:20pm **IE-TuA5 Meeting IBM's PFC Emission Goals: Using the IBM In Situ Dilute NF@sub 3@/He Plasma Clean in Production on the Applied Materials 200 mm P5000 Lamp-Heated CVD Toolset***, **C.M. Hines**,* IBM Microelectronics*; W.R. Entley, R.V. Pearce, A.D. Johnson,* Air Products and Chemicals, Inc.

The major use of perfluorocompounds (PFCs) in semiconductor manufacturing is for residue removal following thin film deposition in chemical vapor deposition (CVD) chambers. One promising strategy to reduce PFC emissions in CVD chambers is the use of alternative clean gases that have lower global warming potentials and inherently higher utilization efficiencies (the percentage of the PFC that is consumed during the clean process) than the traditionally used carbon based PFCs, CF@sub 4@ and C@sub 2@F@sub 6@. Using this strategy, IBM developed a one-step in situ dilute nitrogen trifluoride/helium (NF@sub 3@/He) clean to replace the process of record (POR) C@sub 2@F@sub 6@-based cleans used in their Applied Materials (AMAT) 200mm Precision 5000 lamp-heated (DxL) CVD chambers. Successful implementation of the dilute NF@sub 3@/He clean into production is considered key to IBM meeting its PFC reduction goals. Using quadrupole mass spectrometry (QMS) and Fourier transform infrared (FTIR) spectroscopy the process emissions of IBM's POR C@sub 2@F@sub 6@-based cleans and the new one-step dilute NF@sub 3@/He clean following deposition of both phosphosilicate glass (PSG) and tetraethylorthosilicate (TEOS) oxide were quantified. For TEOS oxide deposition the one-step dilute NF@sub 3@/He clean reduced the MMTCE value of the clean by 99 % with respect to the POR C@sub 2@F@sub 6@ clean. For PSG deposition, the one-step dilute NF@sub 3@/He clean reduced the MMTCE value of the POR clean by 96 %. In addition, the one-step dilute NF@sub 3@/He clean significantly reduced the total combined volumetric emissions of F@sub 2@ and HF compared to the POR C@sub 2@F@sub 6@ cleans. This presentation will include an overview of the implementation of the NF@sub 3@/He clean, current production data including tool performance (particles, mean time between wetstrips, etc.), and clean time/emissions comparisons between the POR C@sub 2@F@sub 6@ cleans and the one-step NF@sub 3@/He clean.

3:40pm **IE-TuA6 Treatment of Wastes from Chemical Mechanical Polishing Operations***, **S. Raghavan**, Y. Sun, J. Baygents,* University of Arizona **INVITED**

Chemical mechanical planarization (CMP) of dielectrics and metals has emerged as one of the most important techniques used in the fabrication of integrated circuits. In this technique, dielectric and metal films are globally and locally planarized using particulate slurries made from submicron-sized alumina and silica particles. A multi platen CMP tool can typically process 40 wafers per hour at a slurry consumption of approximately 100 ml/min/wafer. The aforementioned tool, if integrated with a cleaner, will require two to three gallons per minute of DI water. The mixing of CMP waste with the post-CMP cleaning waste typically results in a waste stream that is a very dilute dispersion of solids containing approximately 500 to 5000 ppm solids. In the case of metal CMP, the waste is likely to contain metal ions, unreacted oxidant such as hydrogen peroxide, residual corrosion inhibitors and other additives that are present in the slurry. Wastes from copper CMP may contain anywhere between 10 and 40 ppm of dissolved copper, in the uncomplexed and complexed form. By the year 2002, chemical mechanical planarization processes are expected to account for thirty percent of water consumed in a fabrication facility. Because of this statistics, increasing pressure is put upon fabrication facilities to treat the CMP wastes and recycle the water. Additionally, environmental regulations at the local and national level demand that solids and copper ions be removed before disposal of the water to publicly owned treatment facilities. In this presentation, an overview of the CMP waste problem will be provided and various techniques available for the treatment of CMP wastes will be critically reviewed.

4:20pm **IE-TuA8 Advanced Chemicals for Semiconductor Processing***, **E.R. Sparks**, W. Wojtczak, S.A. Fine,* ATMI **INVITED**

Three of the challenges to semiconductor processing are shrinking dimensions, copper metallization, and low-k dielectric materials. These challenges have been successfully addressed with a new group of water-based chemicals that fortuitously have very favorable properties. - As lithographic dimensions shrink, etching and other processing parameters become more stringent. The residues created from photoresist during these proceses often incorporate fluorocarbon residues, and silicon and metal oxides that are impossible to remove with traditional chemicals. - New processes using copper damascene metallization have additional constraints, as many traditional chemicals are not benign to copper. - Higher speed devices are attainable with low-k dielectric materials, but these materials have special chemical requirements. Advances have been made to meet all three of these requirements by formulating chemical mixtures that are more benign, both environmentally and regarding health issues, than previously possible. These blends are water-based, water-rinsable, and free of regulated solvents, i.e., "green". The resulting technology has a very favorable cost of ownership due to lower costs related to abatement and disposal, compared to more traditional solvent blends.

5:00pm **IE-TuA10 High Throughput Process for Photoresist Stripping and Residual Polymer Removal in a Via Post-Etch Process***, **M. Boumerzoug**, Q. Geng, H. Xu,* Ulvac Technologies Inc.*; S. Gu,* LSI Logic Corporation*; S. Goh,* Silterra (M) Sdn. Bhd.*; T. Meyer, J. Seaton,* LSI Logic Corporation

In fabricating advanced IC, a multi-level interconnect scheme is commonly used and plasma etch is applied to form metal lines and via holes. During the plasma etch, a sidewall polymer is formed to control the etch profile. After the etch, the sidewall polymer needs to be removed completely to insure a good via contact resistance. Typically, a very aggressive amine based chemical solvent is needed to clean up the sidewall polymer. As the design rule shrinks and aggressive zero overplot of the metal line and via plug is used to minimize the die size, some degree of misalignment between via plug and metal lines is inevitable. Wet chemical based post etch cleaning starts to show problems for the misaligned via and metal because they may attack exposed Ti, W and Al. An advanced dry clean process has been developed for removing post etch polymer. In addition, the dry clean process offers a lower cost of ownership (COO) than the wet clean process and is much safer and environmentally friendly. This technology utilizes the combination of microwave downstream and non-damage ion assisted processes to strip chemically altered and damaged photoresist and clean residue according to the chemical composition of each layer. The ion-assisted process is also found useful in stripping the photoresist at high rate. After this dry process, no wet strippers are needed; thus, the high cost and environment and safety concern associated with chemicals can be eliminated. In some cases, this dry clean process becomes an enabling technology for avoiding Ti and W-plug attack occurring in the wet cleaning processes. Split lots of wafers, which have two layer metal, were processed by the all-dry processes and tested electrically. The via chain resistance, metal bridging yield, metal continuity and electrical CD are all equal or better than the control wafers which were processed by wet chemicals.

Vacuum Technology
Room 201 - Session VT-WeM
Sorption Processes and Leak Detection

Moderator: J.F. O'Hanlon, University of Arizona

8:20am **VT-WeM1 The United States Constitution and Vacuum Technology***, **C.R. Tilford**,* Consultant, U.S. **INVITED**

The Charters of Freedom, the official copies of the United States Declaration of Independence, Constitution and Bill of Rights, were hermetically sealed in 1952 in glass and lead encasements filled with humidified helium. Deterioration of the inside glass surfaces has become evident in recent years, and is believed due to elevated water vapor concentrations, which can also be a direct threat to the parchment documents. The National Archives and Records Administration and the National Institute of Standards and Technology have undertaken to construct new encasements that will keep oxygen concentrations below 0.5% over 100 years, maintain a stable humidity level, and include mechanical and broadband optical access for gas sampling and spectroscopic monitoring. Prior to disassembly of the existing encasements, gas samples are extracted for humidity measurement and mass spectrometric analysis. This project presents several difficult vacuum technology challenges, including hard-sealing large glass windows to lightweight structures (for public viewing of the documents), helium leak testing the sealed encasements without evacuation, measuring humidity of small-volume gas samples, and extracting clean samples from the small-volume solder-sealed encasements. In all cases the solutions are constrainted by the absolute necessity to avoid perturbing the documents or over-stressing the lightweight encasements. To date, the gas sampling and reencasement process has been carried out for three pages of the Constitution. This talk will describe the vacuum techniques used and present the experiences and results to date.

9:00am **VT-WeM3 Measurements of Photon Stimulated Desorption from Thick and Thin Oxide of KEKB Collider Copper Beam Chambers and a Stainless Steel Beam Chamber@footnote 1@***, **C.L. Foerster**, C. Lanni,* Brookhaven National Laboratory*; K. Kanazawa,* KEK, Japan

Photon Stimulated Desorption(PSD) from KEKB factory copper chambers was measured at the National Synchrotron Light Source(NSLS), located at the Brookhaven Laboratory. The KEKB is an asymmetrical collider recently constructed in Ibaraki, Japan. The collider utilizes two UHV ring chambers, one for a 3.5 GeV positron beam and the other for a 8 GeV electron beam, for B-meson studies. Two each, one meter long, 94mm inner diameter, chemically deoxidized copper beam chambers with conflat end flanges, were provided by KEKB to the NSLS, for measurment of PSD. PSD and specular reflection were measured on NSLS VUV ring beamline U9a. It has been reported that a high temperature air bake on large stainless steel vacuum systems reduces the need for a vacuum bake. To determine the effect of surface oxide, following the initial PSD measurment, the chambers were chemically cleaned and then oxidized in air for a week at 250 °C. PSD was remeasured after the air bake. A similar process and measurment was performed on a stainless steel beam chamber, with the exception of oxidation at 450°C. After the chambers were installed on beamline U9a, they were exposed to a minimum of 10@super23@ photons direct from the source having a critical energy of 595 eV, striking at an incident angle of 100 mrad. The major PSD yields for hydrogen, carbon nonoxide, carbon dioxide, methane, and water vapor are reported as a funtion of accumulated photon flux, incident surface oxide, and chamber preparation. The results are compared with other PSD measurments on NSLS beamlines and those of other laboratory publications for copper and stainless steel. @FootnoteText@ @footnote 1@Work performed under the auspices of the U.S. Department of Energy, under contract DE-AC02-98CH10886.

9:20am **VT-WeM4 Study the Exposure Dose-Dependent Photon Stimulated Desorption Phenomena***, **G.Y. Hsiung**,* SRRC, Taiwan*; K.-Y. Young,* Institute of Nuclear Science, NTHU, Taiwan*; Y.J. Hsu,* SRRC, Taiwan*; J.-R. Chen,* SRRC and Institute of Nuclear Science, NTHU, Taiwan

The photon stimulated desorption (PSD) is studied by using the synchrotron radiation white light of critical energy at 2.14 keV from the 1.5 GeV Taiwan Light Source (TLS). The samples of various materials, e.g. aluminum alloys, OFHC, etc. are installed in a chamber at a beam line of SRRC for exposure measurement. The sample is water cooled during the exposure to the synchrotron light that the variation of temperature on the surface is < 0.2 degree C. A quadrupole mass spectrometer is used to measure the desorbed gas molecules by PSD in the exposure chamber. The result shows a decrease of the PSD-rate for each gas after a long time exposure of photon beam on the samples. The measured photoemission yield on the sample during exposure also decreases. The curves of pressure rise of each PSD-gas versus the time during the exposure show various kinds of trend with different time lag of the peak. The desorbed molecules including H2O, O2, CO, and CO2, have the time lag longer than those of H2 and hydrocarbon molecules. The longer beam dose exposed on the sample, the longer time lag of PSD peak trended. The phenomenon of exposure dose-dependent PSD relates to the surface condition of the exposed samples. A Secondary Ion Mass Spectroscopy (SIMS) system is built in the exposure chamber to assist the in-situ surface characterization. The correlation between the yield of both PSD and photoemission and the surface concentration during and after the exposure will be compared. The phenomenon of exposure dose-dependent PSD is described and compared.

9:40am **VT-WeM5 Study of Desorption of Carbonaceous Gas Molecules from Copper Surfaces under Electron Bombardment***, **M. Nishiwaki**,* The Graduate University for Advanced Studies, Japan*; S. Kato,* KEK, Japan

Adoption of oxygen free copper has been recently begun to vacuum chambers of particle accelerators such as the KEKB accelerator that is a two ring electron-positron collider. Due to irradiation of the energetic particles and/or exposure to residual gas, however, the copper surface composition should be easily altered and consequently would give instable vacuum property because the passive surface cannot form on copper material which is different from other materials with passive surface such as stainless steel and aluminum. In this study, we aim to make clear about the mechanism about the adsorption and desorption on the copper surface using some isotope gas species. The copper surfaces to which some surface treatments were carried out were exposed to isotope gas species of @super 13@C with a known quantity in an ultra high vacuum. Afterwards, electron stimulated gas desorption (ESD) rates from these sample surfaces were measured using throughput method with a calibrated residual gas analyzer quantitatively. By using the isotope gas, desorbed gas under electron bombardment from the surface on which @super 13@C related gas molecules adsorb can be distinguished from desorbed @super 12@C related gas molecules which consist of diffused carbon atoms from the bulk since @super 13@C atoms do not exist in the bulk. Preliminary experimental results showed that enhancement of carbon diffusion to the surface under the electron bombardment occurred at a high sample temperature. This might suggest that the origin of carbon in the carbonaceous desorbed gas molecules such as CO and CH4 is not the top surface but the bulk possibly in a electron penetoration depth. Surface characterization of the copper materials will be also done using x-ray photoelectron spectroscopy in the adsorption and desorption processes of the isotope gas.

10:20am **VT-WeM7 Vacuum Characteristics of Sprayed Metal Films***, **M. Minato**, H. Iwamoto,* Vacuum Metallurgical Co., Ltd., Japan

The need to reduce particles in semiconductor equipment or data storage equipment is increasing. In recent years, barrier and glue layers on shielding have been used to reduce particles generated in physical vapor deposition equipment. For this purpose, spray coatings are applied to shield components after contaminations are removed. Although the sprayed metal films are exposed to vacuum in a vacuum chamber, their vacuum characteristics have seldom been investigated. The conventional spray coatings are usually done under atmospheric conditions. In order to obtain a layer that has a better vacuum characteristic, spray coating in a chamber filled with an inert gas was developed. Outgassing characteristics of sprayed aluminum films and titanium films were investigated by using the conductance modulation method. Sprayed titanium film produced in an inert gas system showed a lower outgassing rate than that produced in an atmospheric condition.

10:40am **VT-WeM8 Edison's Vacuum Coating Patents***, **R.K. Waits**,* Consultant

Among the more than 1,000 patents bearing Edison's name are several for vacuum coating processes. In 1894 Edison was granted a patent on the "Art of Plating One Material on Another." The patent described coating by evaporation in a vacuum by direct resistance heating or arc heating, using a continuous current. Edison called the process "electro vacuous deposition." He prophetically wrote that "the uses of the invention are almost infinite". Edison also employed sputter deposition. In 1900, Edison applied for a patent on a "Process of Coating Phonograph Records." Issued in 1902, the patent describes using a "silent or brush electrical discharge" produced by an induction coil. Edison had found a way, perhaps accidentally, to use high-voltage alternating current to deposit a metal; the pressure was higher and deposition was by sputtering rather than evaporation. The National Phonograph Company, one of Edison's many enterprises, used the sputtering process to deposit a thin layer of gold on wax phonograph cylinder masters that could then be electroplated to form molds to mass-produce celluloid duplicates. The resulting cylinders were touted as "Gold Moulded." The method was used for 20 years, from 1901 to 1921. It enabled the reproduction of cylinder grooves less than 0.001-inch deep at a density of 200 grooves per inch. From 1913 to 1921, 10-inch-diameter Edison Diamond Disc phonograph records were made using the same method. Sputtering was abandoned as it could not be scaled up to produce the 12-inch discs that were introduced in 1927.

Vacuum Technology
Room Exhibit Hall C & D - Session VT-WeP
Poster Session

VT-WeP1 Study of Uncertainty of a Constant Volume Flowmeter, ***D. Tian,*** Lanzhou Institute of Physics, P.R. China, P.R.China; *X. Wen,* Lanzhou Institute of Physics, P.R. China

A constant volume flowmeter was built in Lanzhou Institute of Physics (LIP). It can calibrate mass flow meters. In order to find and reduce the systematic errors, its uncertainty is calculated and analyzed at first. The range of the flowmeter is 1.7x10@super-3@-85 Pam@super3@/s (1 sccm-50 slm) with uncertainty (1@sigma@) less than 1.2%. Then, a lot of experiments are accomplished by calibrating the mass flow meters. The measurement data of two mass flow meters prove that the flowmeter has good repeatability and long-term stability. Because the systematic errors are still under discussion, we have to prove our supposition by comparison study at last. The range of constant pressure flowmeter developed in our laboratory formerly is 1x10@super-3@-10@super-8@ Pam@super3@/s, with uncertainty less than 2%. For carrying out the comparison between these two flowmeters, an accurate mass flow meter whose range is 1-10 sccm is used as transfer standard. The mass flowmeter is calibrated by two flowmeters respectively. The result shows that the agreement of these two standards is better than 1.5%. The comparison is mainly dependent on the linearity and stability of spinning rotor gauge, and the uncertainty resulting from these two factors is about 0.5%. The short-term repeatability of the mass flow meter is also an error source of comparison, and the uncertainty resulting from this factor is approximately 0.2%. The big systemic error is not found in the tests and calibration reliability has been ensured through the above discussions.

VT-WeP2 Development of the Quadrupole Mass Spectrometer with the Bessel-Box Type Energy Analyzer : Function of the Energy Analyzer in the Partial Pressure Measurements, ***N. Takahashi,*** *H. Akimichi, T. Hayashi,* ULVAC Japan, Ltd., Japan; *Y. Tuzi,* ULVAC Corporation, Japan

We have obtained several advantages of the newly developed quadrupole mass spectrometer (QMS) with the Bessel-Box type energy analyzer for the accurate measurement of partial pressures in high to extreme high vacuum. The analyzer is placed between the ionizer and the quadrupole assembly of QMS. The gas phase ions and the electron stimulated desorption (ESD) ions generated in the ionizer are separated by the analyzer, because of the difference of kinetic energies between them. As the overlapping of the gas phase ions and ESD ions gives the complex mass spectra, the elimination of ESD ions by the energy analyzer improves the spectra to simpler ones. The accurate measurement of partial pressures was made use of the simple mass spectra of gas phase ions which were given by the new QMS. The sensitivity of new QMS for the very small amount of impurities in the atmosphere of relatively higher pressure was also improved down to 10ppb of the total pressure owing to the reduction of background signal. The background signal is much reduced by the geometrical structure of the energy analyzer which prevents the ion collector with secondary electron multiplier from the irradiations of vacuum ultraviolet rays and soft x-rays generated in the ionizer. The discrimination between the non-dissociative molecular ions and the fragment ions with same mass to charge ratio (m/z) is also the important factor for the accurate measurement of partial pressures. The energy spectra of those ions are determined by the mechanism of ion formation such as ionization process, fragmentation process, etc. Thus, the spectra of each m/z ions are expected to apply for the discrimination mentioned above.

VT-WeP3 A Summary of Quick Disconnect Vacuum Flanges, ***M. Mapes,*** Brookhaven National Laboratory, usa

In accelerator environments especially proton machines, high background radiation necessitates the need for quick disconnect vacuum flanges. The use of quick disconnect flanges significantly reduces the dose of radiation received by workers when installing or removing vacuum chambers in the accelerator. Over the course of many years there have been many different designs used for these flanges at Brookhaven National Laboratory for such machines as the AGS, Booster and RHIC. Several different flanges with apertures as large as 14" diameter were also evaluated for use in the SNS project. A summary of various quick disconnect flanges used at Brookhaven as well as some commercially available flanges and their evaluation results are presented.

VT-WeP4 Continuous Determination of the Gas Composition during Pump-down of Vacuum Chambers, ***N. Mueller,*** Balzers Instruments, Liechtenstein, Principality of Liechtenstein; *P. Schoch,* Balzers Instruments, Liechtenstein

The gas composition during pump-down of vacuum chambers starting at atmospheric pressure is an important information for the evaluation and design of pumping stations. Nevertheless, this composition is rarely determined on-line, as there are no sensors available that directly allow for gas specific analysis over a wide pressure range. To overcome this problem, a differentially pumped quadrupole mass spectrometer with a unique inlet system has been developed. This instrument allows for continuous gas analysis in the pressure range from 1000 mbar down to 1E-3 mbar. Pump-down curves of different pumping stations (e.g. turbo-pumped systems with rotary vane pumps, diaphragm pumps etc.) have been determined. The results of these analysis will be presented and discussed.

VT-WeP5 Hydrogen Outgassing from Titanium Modified Layers with Various Surface Treatments, ***Y. Mizuno,*** Nippon Valqua Industries, Ltd, Japan; *A. Tanaka,* ULVAC-PHI, Inc., Japan; *K. Takahiro,* Tohoku University, Japan; *T. Takano, Y. Yamauchi, T. Okada, S. Yamaguchi, T. Homma,* Chiba Institute of Technology, Japan

In an extreme high vacuum (XHV) system, hydrogen outgassing is the most important factor to obtain vacuum pressure below 1.0x10@super -10@Pa. Titanium is an interesting material for applications in XHV construction. This work aims to be clear about a correlation between hydrogen outgassing and surface structures of pure titanium in vacuum technology. The titanium surfaces were prepared following treatments such as chemical (CP), electrical (EP), buffing (BP) and mechano-chemical polishing (MCP). Characterization of oxide layers has been carried out using Auger electron spectroscopy and angle-resolved x-ray photoelectron spectroscopy, and a cross section of modified layer has been observed with transmission electron microscopy and an optical microscope for metal/scale. The hydrogen distribution in a surface region was measured by using elastic recoil detection analysis. The oxide thicknesses were from 20 to 50 nm, although the finished titanium surfaces were covered with TiO@sub 2@ for CP, EP, BP and MCP, and also TiO was formed under the top layer for MCP. The thick modified layers (about 1µm) on surfaces were made in BP and MCP processing, and the modified layers had extremely high-density distribution of hydrogen (H/Ti about 1-2). Thermal desorption spectroscopy measurements indicated that the desorption behavior of hydrogen was not strongly depending on the thickness of oxide layer, and the hydrogen outgassing rates were less than 4.0x10@super -7@Pa.m.s@super -1@ at room temperature. We will report the results of the relation between the quantities of desorbed hydrogen gas and the structure of modified layers on titanium polished surfaces.

VT-WeP6 Friction Force Measurement of Type 304 Stainless Steel in a High Vacuum, ***A. Kasahara,*** *M. Goto, M. Tosa, K. Yoshihara,* National Research Institute for Metals, Japan

Vacuum friction measurement system based on Bowden-Leben type system was successfully developed. The system can evaluate sliding friction coefficient under changing load from 0.2N to 0.98mN and at changing atmospheric pressure from 1E+5Pa to 1E-8 Pa. The friction measurement was carried out on typical vacuum materials samples as type 304 austenitic stainless steel sheets after such surface treatments as chemical polishing, mechanical polishing or electrochemical buffing. Chemically polished steel shows the lowest friction coefficient as the decrease of the vacuum pressure and as the decrese of the load due to low desorption of adsobate on the surface. The friction measurement especially under the load less than about 10mN in an atomosheric pressure shows that surface adosobate changed by surface roughness of polished steels could have an large effect on friction force. While, the measurement under the pressure less than 1E-5Pa shows little effect by surface absobate on friction force. The measurement results therefore conclude that Amonton-Coulomb's law is valid in measuring friction force under low load in a high vacuum.

VT-WeP7 Surface Cleanness of Substrates Transported with Levitation Transfer System Installed in an Extreme High Vacuum Integrated System, ***M. Tosa,*** *A. Kasahara, M. Goto, K. Yoshihara,* National Research Institute for Metals, Japan; *Y.S.K. Kim, K.S.L. Lee,* Sungkyunkwan University, Korea

The extreme high vacuum (XHV) integrated process with magnetic levitation transports has been developed in order to transfer substrates among vacuum chambers without any contamination on the ultraclean surface. The XHV integrated process has five main lin e chambers, six sidetrack line chambers, connector chambers and six vacuum instrument chambers for surface analyses and film preparation. Levitation transports using superconducting magnet system and electromagnet system are installed into the line chamb ers because they have no sliding part to generate dust particles as well as outgassing which may damage the ultraclean substrate surfaces and environment. The levitation transports can transfer substrates among connected six chambers in the pressure change of less than 10@super -10@ Pa. Cleanness of transported substrates surfaces was observed by a scanning auger electron microprobe with submicron analysis area. Substrates surfaces of a copper sheet and a stainless steel sheet that were argon ion sputter-cleaned in the auger analysis chamber were kept clean without any adsorption of oxygen nor carbonate during the levitation transportation among the auger analysis chamber and the film preparation chamber. Surfaces of copper film and stainless steel film on steel substrates prepared in the film preparation chamber were also kept clean after the transportation from the film preparation chamber to the auger analysis chamber.

VT-WeP8 Production, Installation and Performance Evaluation of Extruded Aluminium NEG-coated Vacuum Chambers for the European Synchrotron Radiation Facility (ESRF)*, P. Chiggiato,* *A. Escudeiro Santana, V. Ruzinov,* CERN, Switzerland*; R. Kersevan,* ESRF, France

In order to comply with new European rules concerning the maximum allowable radiation dose for non-exposed workers, the ESRF has started a program for reducing the pressure in the undulator straight sections. This has led to the development of new narrow-gap extruded aluminium vacuum chambers coated with a Ti-Zr-V non-evaporable getter film on the whole inner wall surface. Several aluminium chambers of different dimensions have been coated and their vacuum characteristics have been evaluated. Two of them (5 m long, 74x11 mm elliptical section), have been installed onto the 6 GeV storage ring of the ESRF. Their performances during the vacuum conditioning under an intense synchrotron radiation flux of about 10@super 17@ photons sec@super -1@ m@super -1@ will be reported, together with other details of their operation.

VT-WeP9 Cleaning of Artificial Contamination on Aluminum Surface for Ultra-high Vacuum Treated in Supercritical Fluid and Evaluated with FT-IR*, T. Momose*, *H. Mishina,* Miyagi National College of Technology, Japan*; Y. Ikushima,* National Industrial Research Institute of Tohoku, Japan*; K. Tatenuma,* Kaken Corp., Japan*; T. Goto, M. Takahara,* Miyagi National College of Technology, Japan

To decrease outgassing rate of the surface for ultra-high vacuum materials, clean surface is required. We have paid attention on native contamination of the surface.@footnote 1@ Here, cleaning test of the artificial contamination which can be deposited on the surface during treatments is carried out using supercritical fluid(SCF) CO@sub2@ with high solubility for organic materials. Triglyceryde is selected as a contamination because it is the main ingredient of grease of human body. The triglyceryde was deposited on mirror surface of aluminum circular discs(5 mm in diameter) by evaporating ether-triglyseride solutions. The disc was kept in SCF CO@sub2@ for a half hour at 40°C and a fixed pressure. The surface was evaluated from the CH@sub2@- and CH@sub3@- peaks of FTIR spectra. The standard lines of the peaks were obtained from the ones of FT-IR as a function of the density of ether-triglyceride solution. Removing rate was calculated from the ratio, (Lo-Li)/Lo x 100 %, where Lo is the peak height before treatment and Li the one after treatment. The deposited thickness between one µm and 21 µm was proportional to a square root of density of the solution (1%-30%). Precision of removing rate was ±13 %. The removing rate was proportional to pressure, 40 to 100 % in the range from 100 atm to 250 atm, where it was 100 % in the range from 250 atm to 300 atm. The data showed that the cleaning using SCF CO@sub2@ is promising to remove artificial contamination like the ones on the order of µm thick. @footnote 1@ T.Momose et.al, JVST, A17(4), Jul/Aug, 1999, 1391.

VT-WeP10 CESR Phase-III Interaction Region Vacuum Chamber*, Y. He,* *Y. Li, N.B. Mistry, S. Greenwald,* Cornell University

Two 115" long copper UHV chambers for the Cornell Electron Storage Ring (CESR) Interaction Region were fabricated. These chambers are a part of the "Phase-III" upgrade project for the CESR storage ring. They incorporate several novel features including a remotely engaging differentially pumped Viton O-ring sealed UHV flange, two RF shielded bellows joints, and inner stepped masking for synchrotron radiation. The fabrication of these chambers incorporates multi-stage electron beam welding to maintain the strict tolerance required for installation through superconducting and permanent quadrupole magnets. Before final welding, a series of EB welding setup tests were done to work out a welding procedure for optimizing welding parameters and avoiding contamination in the weld zone. This paper will describe the design, fabrication, welding, leak checking, and final UHV performance testing of these chambers.

VT-WeP12 Monte Carlo Direct Simulation of Rarefied Flow in the Cylindrical Chamber of an Orifice-flow System*, Y.W. Chang,* Precision Instrument Development Center, R. O. C., Taiwan, R. O. C.

The orifice-flow system has been commonly used in the calibration and measurement of the vacuum systems. Such a system usually consists of a vacuum chamber in which two cylindrical or spherical halves separated by a plate with the orifice in the center. For the application of the orifice-flow system, calculating the correct conductance of the orifice is the most important thing to do. However the actual flow condition inside the chamber, such as the gas density distribution and gas flux distribution, also restricts the accuracy of the calibration or measurement. In this paper the flow field inside a cylindrical vacuum chamber of an orifice-flow system is investigated using the direct simulation Monte Carlo (DSMC) method. A known gas flow is introduced to the upper chamber through a port in the center of the top plate. We simulate cases in which the outlet boundary is set to be in vacuum or given a known pressure that represents a vacuum pump. The observation is focused on the pressure distribution in these cases. In each case, baffles are added in the upper and lower chamber after the flow reaches a steady state. Baffles in the orifice calibration system are used to improve the uniformity of the gas density distribution and the gas flux distribution. Therefore the variations of the pressure distribution and the velocity field in the chamber after baffles are added are particularly investigated.

VT-WeP13 The Topology of Molecular Flow in Axial Compressor*, P.A. Skovorodko,* Institute of Thermophysics, Russia

An approximate representation of the real geometry of the axial flow compressor by its plane version is widely used in theoretical models of the gas flow in the molecular pump. To analyze the accuracy of such kind of approaches the numerical algorithm for simulation the free molecular flow in the real geometry of the compressor is developed. The algorithm is based on the well known test particle Monte Carlo method. The pumping process in the considered case is completely characterized by two values of direct and back transmission probabilities. The main problem to be solved during the simulation of molecule motion in the tract is to find the point of intersection of their trajectory, which represents a straight line, with stationary or moving surfaces of the compressor units, where the diffuse-specular reflection of molecule with some accommodation coefficient is assumed. Two types of molecular pump are considered: the Holweck pump with spiral grooves placed on the rotor, and the multi-stage turbomolecular compressor with flat-plate blades. The results obtained for real geometry demonstrate higher compression ratio and are in better agreement with available experimental data in comparison with those obtained for plane version of geometry. The difference between two approaches is higher for higher rotor speed. The main reasons for such difference are the topology of axial flow and non-inertial character of rotating system of reference. The developed algorithm may be used to optimize the design of compressor operating in the free molecular conditions.

VT-WeP14 Rapid Cool Dual Slot Load Locks For LCD*, A. Hosokawa,* *W. Blonigan, S. Kurita,* Applied Materials Inc.

Rapid cooling of 680mm x 880mm glass substrate was demonstrated in the dual slot load locks @footnote 1@ of Applied Materials AKT 5500 CVD system. It takes 33 sec to cool the substrate from 400°C to 60°C with the uniformity of ±5°C. To accomplish this, two techniques were used. Helium equivalent to partial pressure of 9 torr was injected at the initial stage of venting. Two cooling plates were located above and below the substrate and the distance of the cooling plates was reduced to 8 mm when cooling. Rapid cool dual slot load locks reduced the system cost by eliminating expensive machined components and a more powerful pump. Uniform cooling enabled reliable substrate handling and eliminated undesirable stress on the substrate upon cooling compared with the conventional 12 slot load locks. @FootnoteText@ @footnote 1@ Shinichi Kurita, Wendell Blonigan, Akihiro Hosokawa, US Patent pending #7828.7017, Dec 1999.

VT-WeP15 Experimental and Theoretical Study of a Differentially Pumped Absorption Gas Cell used as a Low Energy-pass Filter in the VUV Photon Energy Range*, B. Mercier,* *L. Nahon, O. Dutuit, C. Prevost, R. Thissen, G. Bellec, M. Compin,* LURE, France

In order to separate the fundamental synchrotron radiation from the high harmonics emitted by an undulator, a low photon energy-pass filter has been designed and built, insuring a high spectral purity on the VUV SU5 beamline at Super-ACO. It consists in an absorption cell filled with rare gases and separated from the ultra-high vacuum of the storage ring and of the beamline by a double differential pumping obtained with thin capillaries, and whose designed has been optimized by numerical computation of pumping speed. Admission pressures in the range of 100 Pa in the central part of the filter have used without any degradation of the upstream or downstream ultra-high vacuum. The measured attenuation factors above the energy cut-off are above 10@super 5@ and 10@super 2@ (and certainly above 10@super 3@ with ultimate pressure of Ne) for respectively argon and neon used as absorbing gas, with no measurable attenuation of fundamental radiation. A sophisticated numerical approach performed in the intermediate regime, taking into account the geometry of the whole absorption cell including the first pair of capillaries, has been developed, allowing reliable predictions of the expected attenuation coefficients for any given configuration of the filter.

VT-WeP16 DSMC Study of Plume Flows in Cryogenic Vacuum Facility*, **M.S. Ivanov**, G.N. Markelov,* Institute of Theoretical and Applied Mechanics, Russia

The study of plume flows has been an interesting research subject area of rarefied gas dynamics in the past. Experimental techniques and various engineering approaches were mainly employed for such studies. The recent resurgence of interest in the subject is prompted by the design of a new generation of satellites and space stations for which an accurate prediction not only of force and heat loads produced by the plumes, but also of contamination is needed. Therefore, a comprehensive study of plume structure including core flow, periphery flow and backflow is very important. For correct simulation of small thruster plumes in experimental facilities, it is necessary to have reasonable low background pressure levels. Main feature of new high vacuum plume test facilities STG (DLR) and CHAFF-IV (USC) is a novel cryogenic array, where the expanding plume gas hits a complex-structured cryosurface and freezes immediately. Nevertheless, disturbance of the plume is possible due to the penetration of condensate vapor and of plume molecules that do not stick immediately to the condensate. Therefore, it is necessary to supplement experimental modeling of plume flows by numerical simulation of the plume flow inside the facility taking into account the influence of incomplete condensation of plume molecules. It will allow one to determine a region where a plume flow is undisturbed as in space for different thruster and facility operating conditions. The main objective of the paper is a numerical study of thruster plume flows under low-density conditions in a cryogenic vacuum facility with consideration of background pressure caused by incomplete condensation of plume molecules on the cryogenic array.

Surface Science
Room 209 - Session SS2+VT-WeA
Adsorption and Desorption Phenomena I

Moderator: C.M. Friend, Harvard University

2:00pm **SS2+VT-WeA1 The Role of Two-dimensional Compressibility in Physisorption, Competitive Adsorption and Dynamic Displacement***, **G.A. Kimmel**, Z. Dohnálek, R.S. Smith, B.D. Kay,* Pacific Northwest National Laboratory **INVITED**

We have investigated the physisorption of gases (Ar, N@sub 2@, CH@sub 4@, etc) on Pt(111) with modulated beam techniques, beam reflection measurements and temperature programmed desorption (TPD). The kinetics of adsorption and desorption for systems where the coverage is larger than ~0.8 monolayer (ML) is dominated by the two-dimensional compression of the adsorbate layer. In particular, at coverages near 1 ML the repulsive interaction between adsorbates increases causing an approximately linear decrease in binding energy as the coverage increases. The formation of the first monolayer is complete when the binding energy of the adsorbates in the compressed first layer is equivalent to the binding energy of an adsorbate in the second layer (i.e. when the chemical potential of the first and second layers are equal). Evidence for this compression arises in the TPD of physisorbed gases from Pt(111) which reveal a non-zero, nearly constant desorption in the temperature range between the desorption peaks of the "first" and "second" monolayers. Modulated beam experiments also support this interpretation. In that case, the Pt(111) surface is pre-covered with ~1 ML of gas and then exposed to gas pulses of varying duration (~0.05 s - 1.0 s) and the desorbed/reflected flux is monitored. Another example where the two dimensional compression of the adsorbate layer is important occurs when the "competitive" adsorption of two gases is examined. In these experiments, an adsorbate can be displaced/desorbed when the surface is exposed to a gas which has a higher binding energy to the substrate. We will present a simple model for the binding energy as a function of coverage which explains the observed adsorption/desorption kinetics for a variety of systems.

2:40pm **SS2+VT-WeA3 Molecular Adsorption and Growth of n-butane Adlayers on Pt(111)***, **J.F. Weaver**,* University of Florida*; M. Ikai, A. Carlsson, R.J. Madix,* Stanford University

The molecular adsorption of n-butane and the growth of n-butane adlayers on Pt(111) have been investigated using molecular beam techniques, temperature-programmed desorption and low-energy electron diffraction. Our results indicate that four adlayer phases develop sequentially as the n-butane coverage increases from the submonolayer to second layer ranges at surface temperatures near 98 K. The structural properties of the adlayer and the kinetics for adlayer growth will be discussed in detail. Interestingly, although the changes in adlayer structure significantly affect the rates of n-butane desorption and surface diffusion, the adsorption probability of n-butane on Pt(111) is found to increase smoothly with increasing coverage. This finding indicates that the long-range arrangements and orientations of molecules in the n-butane adlayer have a negligible influence on the intrinsic adsorption dynamics, suggesting that the energy transfer processes that facilitate adsorption are highly localized.

3:00pm **SS2+VT-WeA4 Optical Effects of Monolayer and Multilayer Adsorption: Formic Acid and Methanol on Cu(100)***, **C.-L. Hsu**, E.F. McCullen, R.G. Tobin,* Tufts University

We have studied the adsorption of formic acid (HCOOH) and methanol on epitaxial Cu(100) films at 125 K in both the monolayer and multilayer regimes, using infrared reflectance and dc resistance measurements and visible-light ellipsometry. The results are analyzed using an electron scattering model for reflectance changes due to chemisorbed monolayers, and a macroscopic three-layer model for physisorbed multilayers. For methanol, which is only physisorbed on Cu, the infrared reflectance increases linearly with film thickness (determined ellipsometrically) in agreement with the three-layer model. For formic acid the first monolayer is chemisorbed and scattering of conduction electrons from the adsorbates leads to an initial decrease in reflectance, together with an increase in the electrical resistance of the Cu film. At higher formic acid exposures physisorbed multilayers form, leading to a reflectance increase similar to that observed for methanol. This behavior is qualitatively consistent with expectations, but there are some surprising features. As formic acid exposure increases, the initial reflectance drop continues even after the resistance change is largely complete, even though both effects are believed to result from the same process. The subsequent rapid rise in reflectance suggests that the sticking coefficient is much lower for the first layer than for subsequent layers. Possible explanations for these effects will be discussed.

3:20pm **SS2+VT-WeA5 Precursor-mediated Dissociation and Trapping Desorption of Oxygen on Cu(001)-2@sr@2x@sr@2-O***, **M. Yata**, Y. Saitoh,* National Research Institute for Metals, Japan

The adsorption and desorption of oxygen on Cu(001)-2@sr@2x@sr@2-O has been studied by molecular beam method. Angular and time-of flight distributions have been measured for scattering oxygen from the surface. The time-of flight distributions can be fitted by nonshifted Boltzmann distributions. This means that the oxygen molecules are trapped at the surface in a precursor state and subsequently desorb from the surface. The translational temperature of the desorbing oxygen is lower than the surface temperature, which suggests that there is no barrier for desorption from the precursor state. The dissociative sticking probability of oxygen increases as the translational energy of incident oxygen decreases. This probability also increases with increasing surface temperature. These results suggest that the adsorption of oxygen on the Cu(001)-2@sr@2x@sr@2-O surface proceeds via a precursor-mediated dissociation process rather than by a direct activation process. This is contrast to the dissociative adsorption of oxygen on clean Cu(001) in which the dissociation occurs by direct collisional activation. There exists a competition between dissociation reaction and desorption once the oxygen molecule is trapped in the precursor state. We have estimated the difference in activation energies between the dissociation and desorption of 330 meV. The effect of tensile stress on the dissociative adsorption reaction of oxygen on the Cu(001)-2@sr@2x@sr@2-O surface will be also discussed.

3:40pm **SS2+VT-WeA6 The Effect of Deposition Pressure on Adsorbate Structure and Coverage: Oxygen on W(110)@footnote 1@***, D.E. Muzzall,* University of California, Davis*; C.S. Fadley,* University of California, Davis and LBNL*; **S. Chiang**,* University of California, Davis

In most prior surface science studies, it has been assumed that total exposure, rather than pressure and time as independent variables, controls the types of adsorption structures formed. The importance of deposition pressure as a variable, however, was recently suggested in a study of the kinetics of the low pressure adsorption of oxygen on W(110) using X-ray photoelectron spectroscopy (XPS)and diffraction.@footnote 2@ As a more quantitative measure of such effects, we have used ultrahigh vacuum scanning tunneling microscopy (STM), low energy electron diffraction (LEED), and XPS to explore the adsorbate structures and the coverage dependence of O/W(110) as a function of deposition pressure at room temperature. For the same total adsorbate exposure in Langmuirs (L), we find that changes in deposition pressure of as little as a factor of 3 cause significant changes in the apparent structures, domain sizes (e.g., of (1x2)O), and adsorbate coverage in monolayers. Total coverages derived from STM data using a software thresholding technique indicate that a critical dosing pressure exists for both the (2x1) and (2x2) structures, 1 x 10@sup -9@ and 3 x 10@sup -9@ torr respectively, below which coverage does not increase with increasing exposure time. This indicates that an equilibrium condition has been reached, from which surface free energies for both of these structures can be derived.@footnote 3@ Finally, in addition to the ordered (1x2), (2x2), and (1x1) structures for O/W(110), we have characterized a new fourth ordered structure by LEED and STM. The structure formed for oxygen exposure of 3 to 6 L and coexisted with the (1x2) structure. The primitive unit cell is a rectangle, 0.77nm x 1.37nm, with 15 W and 6 O atoms and has the matrix notation ((3,-1),(0,5)) relative to the W(110) substrate. @FootnoteText@ @footnote 1@ Supported by NSF DMR-9522240. @footnote 2@ Y. X. Ynzunza et al, Surf. Sci., in press. @footnote 3@ P. Liu et al, Surf. Sci. 417 (1998) 53.

4:00pm **SS2+VT-WeA7 STM Investigation of Benzene Adsorption on Ag(110)***, **K.F. Kelly**, J.J. Jackiw,* Pennsylvania State University*; J.I. Pascual, H. Conrad, H.-P. Rust,* Fritz Haber Institute, Germany*; P.S. Weiss,* Pennsylvania State University

We have investigated the adsorption of benzene on Ag(110) using the scanning tunneling microscope. We found that the molecules preferentially adsorb above step edges at 66 K. The preference for step edge adsorption is attributed to the Smoluchowski effect enhancing the empty states to which charge is donated from the @pi@ orbitals of the benzene. However, there is no adsorption at the [001] steps. A lack of free charge due to a gap in the Ag Fermi surface along that direction reduces the Smoluchowski effect and thus the adsorption at these steps. After further deposition at 4 K, we find that benzene forms a weakly adsorbed hexagonal monolayer. The monolayer is imaged at large tip-sample separations and is transparent upon closer approach. The interaction of benzene molecules with steps and point defects reduces this transparency.

4:20pm **SS2+VT-WeA8 Scanning Tunneling Microscopy and Spectroscopy of Metal Tetraphenylporphyrins on Au(111)***, K.W. Hipps,* ***D.E. Barlow****, L. Scudiero,* Washington State University

STM images of metal(II) tetraphenylporphyrin monolayers on Au(111) are presented for several transition metal ions. The constant current images clearly reflect the electronic nature of the metal ion used. Scanning tunneling spectroscopy (dI/dV curves) also allows one to differentiate between the metal complexes. The primary electroactive states, as shown by tunneling spectroscopy, are those involving both occupied and unoccupied molecular orbitals close to the Fermi energy of the Au(111) substrate. Scanning tunneling spectroscopy results for the negative sample bias region are compared to Ultra-violet photoelectron spectra of these same compounds on Au.

4:40pm **SS2+VT-WeA9 Theory of Oxygen Adsorption on Ag(111): A DFT-GGA Investigation***, W. Li,* Fritz-Haber-Institut der Max-Planck-Gesellschaft, Germany*;* ***C. Stampfl****,* Northwestern University*; M. Scheffler,* Fritz-Haber-Institut der Max-Planck-Gesellschaft, Germany

O/Ag(111) is an important system with unique catalytic behavior for several large-scale industrial processes, e.g., ethylene epoxidation and partial oxidation of methanol to formaldehyde. In spite of its importance, very little is known about the behavior of O at Ag(111) (which depends sensitively on pressure and temperature) on the microscopic level, and the precise atomic location and chemical nature of the various O species that form, e.g. on-surface, subsurface, in-surface. Using density-functional theory within the generalized gradient approximation, we investigate the interaction between oxygen and Ag(111). We found that the interaction between silver and oxygen is very weak. Adsorption becomes unfavorable for coverages between 0.33 and 0.50, with respect to the gas molecule O@sub 2@. Compared to hcp site, the fcc site is preferable, and the difference in adsorption energy differs by less than 0.17 eV/atom for the whole range of coverage considered. Strong charge transfer from silver to oxygen has been found due to the large difference in electronegativity between oxygen and silver, and results in a significant change in work function, which increases monotonically with oxygen coverage. Experimental studies report that at elevated temperatures two ordered phases form: a (4x4) structure (T@>=@400K),@footnote 1@ and a high-temperature (@sr@3 x @sr@3)R30° (T@>=@800K)@footnote 2@ structure. With respect to the latter, a surface substitutional site has been proposed. Our results show that this structure is unfavorable. For subsurface adsorption we find that oxygen prefers the octahedral site, but at coverage 0.33 it is also endothermic with respect to free O@sub 2@. We discuss alternative geometries for this phase. @FootnoteText@ @footnote 1@ G. Rovida et al., Surf. Sci. 43, 230 (1974); C. I. Carlisle et al., Phys. Rev. Lett. 84, 3899 (2000). @footnote 2@ B. Pettinger et al., Phys. Rev. Lett. 72, 1561 (1994); X. Bao et al. Phys. Rev. B 54, 2240 (1996).

5:00pm **SS2+VT-WeA10 Adsorption of Propylene on Clean and Oxygen Covered Au(111) and Au(100)***,* ***K.A. Davis****, D.W. Goodman,* Texas A&M University

The adsorption of propene on Au(111) and Au(100) was investigated using temperature programmed desorption (TPD) and high resolution energy loss spectroscopy (HREELS). A desorption activation energy of 9.4 kcal/mol and very small (< 25 cm@sup -1@) shifts of the vibrational frequencies from their gas phase values indicate that the interaction of propene with the surface is weak. Energy loss spectra suggest that propene adsorbs with its molecular plane tilted slightly with respect to the surface plane. Atomic oxygen, chemisorbed on the gold surfaces, was characterized using TPD and low energy electron diffraction (LEED), and its interaction with propene investigated. HREEL spectra of propene on the oxygen covered surfaces show shifts in the intensities and frequencies of the -CH@sub 2@ related vibrational features. Small amounts of product with masses 56 and 58 amu were observed for propene adsorbed onto a 0.4 ML oxygen-covered surface.

Vacuum Technology
Room 201 - Session VT-WeA

Vacuum Gas Dynamics

Moderator: J.L. Provo, Sandia National Laboratories

2:00pm **VT-WeA1 A Test Problem for the Holweck Pump***,* ***J.C. Helmer,*** AVS Fellow

The general principles of molecular drag pumping have been understood since since W. Gaede's work in 1913, but it is curious that approximate models have not existed to explain the operation of the Gaede and Holweck molecular pumps over the range of practical application. The laminar flow model for the one-dimensional Gaede pump is now complete. One would infer that the wide channel, Holweck pump model is a two dimensional generalization of the Gaede model. This generalization has not been achieved, although some specific CFD (computational fluid dynamics) solutions have been published.@footnote 1,2@ Our analytic investigation of the Holweck case shows that there is no solution with a parallel flow field, and that compressibility introduces rotation. An approximate solution at high flow rate has been obtained for wide Holweck channels, which illustrates how these issues are resolved. A major difference between the Gaede and Holweck pumps is in the form of the leakage, which is parallel to the channel in the former, and across the channel in the latter. The problem of leakage-limited operation will be discussed. In practical cases the channel depth is small, and the the solution in this dimension is known as a case of Couette-Poiseuille flow. The Holweck geometry may then be idealized in two-dimensions, as a parallelogram lying in a plane with a drag vector of arbitrary direction. @FootnoteText@ @footnote 1@ K. Nanbu & S. Igarashi, "Three-dimensional low-density flows in the spiral grooves of a turbo-molecular pump", Computers Fluids, 21(2), pp221-228, 1992 @footnote 2@ H-P Cheng, R-Y. Jou, F-Z. Chen, Y-W. Chang, "Flow investigation of Siegbahn vacuum pump by CFD methodology", Vacuum 53, pp 227-231, 1999. "Three-dimensional flow analysis of spiral-grooved turbo booster pump in slip and continuum flow", J. Vac. Sci.. Technol. A. 18(2), 543-551, Mar/Apr 2000 .

2:20pm **VT-WeA2 Significance of Bulk Flow Velocity for Turbopump Design***,* ***M.H. Hablanian,*** Varian Inc.*; R. Cerruti,* Varian Inc., Italy

Initially, studies of many aspects of the pumping mechanism of turbomolecular pumps were approached from the high-vacuum side rather than from atmospheric pressure. Therefore, some significant parameters, well known from the discipline of fluid mechanics, have been neglected. One such parameter is bulk fluid stream velocity, which can be a significant engineering consideration for creating an optimized design. Due to the enormous densification ratios achieved in modern turbomolecular pumps, especially of the hybrid or compound variety, the flow velocity at the exit end of the pump is often near zero. This induces a stagnant condition, particularly when backing pumps are very small, allowing, for example, increased back-diffusion of light gases (hydrogen and helium). In addition, the presence of the nearly stagnant gas produces adverse effects on power consumption, which is very significant in newer hybrid turbopumps that can reach 100 mbar exhaust pressure. Attempts to create a single algorithm for a design using one type of impeller do not produce a scheme for a viable pump. The selection of appropriate different types of impellers for the entire pump structure seems to be the best method for optimizing overall performance.

2:40pm **VT-WeA3 A Quantitative Test of Slip-Flow Theory using the Spinning Rotor Gauge***,* ***J.P. Looney,*** National Institute of Standards and Technology*; J. Setina,* Institute of Metals, Slovenia

Although a theory for gas slip flow has been in existence from the time of James Maxwell, no quantitative test of slip flow theory has been undertaken. Typically the slip flow theory of Maxwell is used to extract momentum accommodation coefficients from gas flow data. This is one method for 'measurement' of gas accommodation coefficients. However, this assumes that slip-flow theory is correct and that there is indeed proportionality between the magnitude of the momentum accommodation at the surface and the gas 'slip'. No test of this conjecture has been reported to the author's knowledge. In this talk I will report on the simultaneous and independent measurement of gas momentum accommodation and gas slip coefficients for a group of six spinning chrome steel spheres (spinning rotor gauges) and for four gases (H2, He, N2, and Ar). The results of these experiments clearly demonstrate the proportionality between the gas slip and momentum accommodation. A detailed comparison of these measurments with slip-flow theory will be made.

3:00pm **VT-WeA4 Power Dissipation in Gaede Stages of Turbomolecular-drag Pumps in Viscous High-pressure Regime**, ***R. Cerruti***, *S. Giors, J.C. Helmer, A. Netti,* Varian Vacuum Technologies, Italy

Drag Gaede stages are used for extending the operating range of turbomolecular pumps to higher pressures. A practical limit to high pressure operation is set by the power dissipated by these stages, which comes mainly from the friction inside the gas boundary layer. The power has then a direct impact on the rotor temperature and the electrical consumption of the motor. In a previous paper we presented a transitional power consumption model, which allowed to predict the power consumption of a given drag stage up to about 10 mbar, correctly capturing the effect of the transition from molecular to viscous regime, but failing above a critical pressure. @footnote 1@ The present work is aimed to extend the model to higher pressures ranges, where turbulence and other instabilities can not be neglected: above a certain pressure the rotor and stator boundary layers get affected by the centrifugal force field, their structure becomes pressure dependent and eventually turbulent. The simple viscous model is extended in order to incorporate these effects through the definition of an "eddy viscosity", which is a pressure dependent parameter introduced by Prandtl turbulent mixing length theory. The model results, showing the power dissipation growing with pressure in the high pressure regime, are compared with experimental power consumption measurement up to 100 mbar, on single drag stages with different dimensions, different rotational speeds and different gases. The model is aimed to be used in the optimization of the multistage Gaede pumps at very high pressure. @FootnoteText@ @footnote 1@ R. Cerruti, M. Spagnol, J. C. Helmer, "Power dissipation in turbomolecular pumps at high pressure", J. Vac. Sci. Technol. A 17(5), 3096-3102, Sept/Oct 1999.

3:20pm **VT-WeA5 Modelling Micro-Channel Flows with DSMC and a Particle Continuum Method**, ***T.J. Bartel***, *M.A. Gallis,* Sandia National Laboratories

Advances in micromachining technology have enabled fabrication of MEMS devices. Even at atmospheric pressures, flow through these devices can range from rarefied to transitional due to the length scale and the mean free path. The Direct Simulation Monte Carlo (DSMC) technique, a direct particle based simulation of the Boltzmann equation, is an appropriate and accurate simulation tool for these devices; however, the computational expense of determining subsonic flows is very large. The major issue is one of statistical resolution: the computational particle velocities are at their thermal speeds while the mean gas velocity is at M ~ 0.01. We will present a overview of the issues of using DSMC and show results for micro-channel flows obtained with our massively parallel version. We have developed a new strategy which accelerates convergence to the steady-state. In this method, we have define the computational particle as a mass per time quantity (rho*V*A). Now the computational phase space is not stochastic, but is deterministic based on the resonance time of each computational particle in a cell. This formulation greatly reduces the statistical noise and computational expense experienced in pure particle simulations. We use a Langevin formulation for the viscous and pressure forces. We use the DSMC method to obtain a spatial varying model for the transport properties (similar to a turbulence model) to extend the validity of the continuum method to non-continuum flows. We will compare results from this new method with DSMC and discuss future work. This strategy is more robust and computationally efficient than split domain methods: DSMC is used for a portion of the domain and a continuum solver for the remainder.

3:40pm **VT-WeA6 Flow of Moderately Rarefied Gases Through Short Circular Tubes**, ***S.A. Tison,*** Millipore Corporation

The conductance of vacuum geometries is very important for design of vacuum systems. In particular the conductance of cylinders has been exhaustively studied because of its predominant use in vacuum components. While the conductance is well established for these geometries under high rarefied conditions@footnote 1@ the conductance in the transition between rarefied flow and continuum flow is less understood. In particular, phenomena such as the Knudsen minimum identified in long tubes almost a century ago is still an active area for theoretical and experimental study. While long tubes are known to have mimimums in conductance, sometimes less than 20% of the free molecular value, sharp edged orifices do not exhibit this pattern. It is logical to assume that there must exist a relatively short tube which exhibits traits intermediate to long tubes and sharp edged orifices. A series of conductances with length to diameter ratios (L/D) from 100 to 2 have been experimentally studied and compared to transition flow models. Data includes Knudsen numbers from 0.01 to 10 for a variety of noncondensable gases. Results indicate reasonable agreement with models@footnote 2@ and show the disappearance of the Knudsen minimum for short tubes (L/D)=2. @FootnoteText@ @footnote 1@ Clausing, P., Ann. Physik (5) 12, 961 (1932) @footnote 2@ Arkillic, E., and Breuer, K.S., AIAA paper 93-3270, (1993).

4:00pm **VT-WeA7 A Method for Calculation of Gas Flow in the Whole Pressure Regime Through Ducts of Any Length**, ***R.G. Livesey,*** BOC Edwards, UK

Useful approaches to the calculation of gas flows in the molecular-continuum transition region have been presented by a number of authors. These have covered particular conditions such as long ducts or orifices with a large pressure difference for example. There is, however, no generally applicable method which enables calculation under all conditions. A particular area of difficulty is the isentropic-molecular transition. The paper presents a simple model which enables calculation for all conditions of long or short ducts and large or small pressure differences. Results are found to agree well with published data.

4:20pm **VT-WeA8 Conic Peak/Dimple Roughness Model for Explaining the Reduction of Flow Rate through Passages with Rough Walls**, ***T. Sawada,*** *W. Sugiyama, M. Yabuki,* Akita University, Japan

Passages with rough walls allow for smaller conductance for rarefied gas flow than passages with smooth walls. For the purpose of clarifying the effects of surface roughness on rarefied gas flow through passages, surface roughness is modeled by circular-conical peaks and dimples with the same base radius. Cones (peaks and dimples) are located in a statistical manner. Cone height and depth are also determined in a statistical manner from the measured angle distributions of actual surface roughness. The following are assumed in the model: (1). Cones are optional in contact with one another. (2). Cones higher than 1.2r(r: radius of base circle) are cut at the height of 1.2r and the upper parts are removed, but the top flat faces are not open for molecules to fly into. (3) The distance traveled by molecules between collisions with cone surfaces on the same macroscopic surface does not affect the macroscopic transfer of molecules. (4) Molecules do not collide with one another during their travel on a macroscopic surface. (5) Molecules are regarded as hard spheres and they scatter on cone surfaces according to cosine law. (6) The height of cone roughness is much smaller than the height of the passage. The calculated results predict well the measured reduction of free molecule and near free molecule flow conductance through channels composed of two flat plates.

4:40pm **VT-WeA9 Free Jets in Vacuum Technologies**, ***A.K. Rebrov,*** Institute of Thermophysics, Russia **INVITED**

The knowledge on gas expansion into vacuum or a low density background was of a paramount importance for the development of vacuum technologies throughout their history. The variety of gas sources, of flow parameters in sources and parameters of background gas state sets the problem of jet flows as vast for the analysis. But the classification of flows is possible. The first step is division of gas expansion into vacuum and in a background. The expansion into vacuum can be considered separately for different types of sources (orifices, capillaries, flat slots, Laval nozzles) under different channel Knudsen numbers. The discharge coefficients, the plume of molecular flow, the structure of the free jet, relaxation processes in the jet, the gas mixture issue represent the main interest. By the expansion of gases into a background from some source the structure of jets in the regimes from free molecular to turbulent flow is defined by the source and state of the background gas. The available results of investigations allow to determine the location of different zones and character of flow, including the evaluation of relaxation of the internal energy and condensation effects. New problems of vacuum technologies are in need of determination of the flow parameter distribution with high accuracy. New computational methods can be used for this purpose. The direct simulation Monte Carlo (DSMC) method became a powerful instrument for study of jet flows. It has depreciated attempts to extend the continuum approach on cases of flows with effects of rarefaction. The hybrid DSMC / fluid methods raise the role of computational simulation, taking into account difficulties of experiments. New achievements in theory can provide not only optimization of technology but extraction of physical knowledge by industrial testing as well.

Surface Science
Room 209 - Session SS2+VT-ThM
Adsorption and Desorption Phenomena II

Moderator: J.C. Hemminger, University of California, Irvine

8:20am **SS2+VT-ThM1 Alkali Metal and H@sub 2@O Co-adsorption and Reaction on Graphite(0001)**, ***M.A. Gleeson***, *D.V. Chakarov, B. Kasemo,* Chalmers University of Technology and Göteborg University, Sweden

A comparative study of alkali metal (Na, K, Cs) adsorption, co-adsorption and reaction with H@sub 2@O on the basal plane of graphite has been performed. Water molecules are stabilised by interaction with alkali atoms, and undergo coverage and temperature dependent reactions. The surface solvation number is similar for all three alkali metals at low coverages (3 to 4 H@sub 2@O molecules per alkali atom). The critical alkali coverage for reactive co-adsorption at 98 K ranges between 0.1 to 0.25 ML. Reaction between H@sub 2@O and the alkali metals leads to the formation of hydroxide, hydride and oxide species on the surface. Additional peaks appear in the water desorption spectra due to alkali-stabilised H@sub 2@O and hydroxide decomposition. Decomposition of alkali oxides at high temperature can result in oxidation of the graphite and subsequent CO@sub 2@ evolution. Similarities and differences between the alkali metals are discussed.

8:40am **SS2+VT-ThM2 Adsorption of Hydrogen on Clean and Alkali-modified Low-index and Stepped Copper Surfaces**, *L. Thomsen,* Odense University/University of Southern Denmark*;* ***J. Onsgaard,*** Odense University/University of Southern Denmark, Denmark*; P.J. Godowski,* University of Wroclaw, Poland*; S.V. Hoffmann,* University of Aarhus, Denmark*; L. Bech, P. Moller,* Odense University/University of Southern Denmark

The interest for adsorption of low molecular gases like H and CO@sub 2@ on alkali-modified copper surfaces stems from the promoting role of the alkali metals in heterogeneous catalysis. Due to the substantial lowering of the work function with the addition of the alkali metal, pronounced changes in the adsorption and reaction properties of the copper surfaces are observed. The adsorption of atomic hydrogen on clean and potassium-modified Cu(110), Cu(100) surfaces and the stepped Cu(115), Cu(117) and Cu(112) surfaces has been studied. Typically, two hydrogen-induced states in the valence band have been found on the clean crystal and assigned to one state receding in the subsurface and another state at the surface of the crystal. Two states due to hydrogen are also observed on the potassium-modified surfaces and assigned to a potassium-hydrogen bond and a copper-hydrogen bond. Coadsorption of H and CO@sub 2@ on the K/Cu surface results in formation of formate with high efficiency on the most corrugated surfaces.

9:00am **SS2+VT-ThM3 Angle Resolved Photoemission Study on Adsorption and Desorption of Cobaltocene on Cu(111)**, ***J. Choi,*** Louisiana State University*; P.A. Dowben,* University of Nebraska, Lincoln

The molecular adsorption and desorption of cobaltocene, Co(C5H5)2, on Cu(111) have been studied by angle resolved photoemission spectroscopy (ARPES). We have measured the molecular orientation and bonding of adsorbed cobaltocene on Cu(111). Photoemission results indicate that the initially adsorbed surface species closely resembles that of molecular cobaltocene. The shift in photoemission binding energies relative to gas phase is largely independent of the molecular orbital. The molecule is adsorbed with cyclopentadienyl (C5H5) ring ligands parallel to the surface at 150K, and the molecular axis normal to the surface at the low coverage (below 10 Langmuir). The molecularly adsorbed cobaltocene loses the normal preferential orientation, at the higher coverages. Furthermore, molecular orientation is strongly affected by annealing temperature, indicating that there are more than one molecular adsorption states. With increasing of temperature, molecularly adsorbed cobaltocene on Cu(111) is desorbed.

9:20am **SS2+VT-ThM4 Angle Effects on the Nucleation of Polymeric Thin Films from Molecular Cluster Deposition: Molecular Dynamics Simulations**, ***Y. Hu,*** *S.B. Sinnott,* The University of Kentucky

Cluster beam deposition of organic material is thought to result in thin-film formation through rapid chemical reactions that occur at the impact site between the cluster and the surface. These reactions occur on the order of a few picoseconds and so are ideal for study with atomistic simulations. In this work, classical molecular dynamics simulations are used to investigate the effect of incident angle on the nucleation and growth of polymeric thin films through organic molecular cluster deposition. The classical reactive empirical bond order method is used in the simulations.@footnote 1@ The specific system under study consists of clusters of ethylene being deposited on a diamond and amorphous carbon substrate at room temperature at various incident angles. The results show how the incident angle affects the nucleation of a thin film from the deposition. In addition, the dependence of this angle effect on substrate rigidity is investigated. This work is supported by the National Science Foundation (CHE-9708049). @FootnoteText@ @footnote 1@ S.B. Sinnott, L. Qi, O.A. Shenderova, D.W. Brenner, in Chapter 1 of Volume IV of ADVANCES IN CLASSICAL TRAJECTORY METHODS, Molecular Dynamics of Clusters, Surfaces, Liquids, and Interfaces, Ed. W. Hase (JAI Press, Inc., Stamford, CT, 1999), pp. 1-26.

9:40am **SS2+VT-ThM5 Geometrical Structure and Orientation of Metal Tetraphenylporphyrins on Au (111)**, *K.W. Hipps,* ***L. Scudiero,*** *D.E. Barlow,* Washington State University

Geometrical structure and orientation of metal tetraphenylporphyrins on Au (111). Metal (II) tetraphenylporphyrin (MTPP) complexes adsorbed on polycrystalline Au and Au (111) are studied by Fourier transform reflectance-absorption infrared (FT-RAIR), X-ray Photoelectron Spectroscopy (XPS) and Scanning Tunneling Microscope (STM). XPS and FT-RAIR data indicate that the chemical composition of those complexes is preserved when they are vapor deposited on Au. FT-RAIR data also suggests that the first few adsorbed layers are oriented with the porphyrin ring parallel to the Au surface. STM images are presented for several transition metal ions. At low coverage, STM images show monolayer islands randomly distributed on Au (111) and high-resolution images display a square unit cell.

10:00am **SS2+VT-ThM6 Experimental and Theoretical STM Imaging of Xylene Isomers on Pd(111)@footnote 1@**, *D. Futaba, J.P. Landry,* ***A. Loui,*** *S. Chiang,* University of California, Davis

We have performed both theoretical and experimental studies of the three isomers of xylene, C@sub 6@H @sub 4@(CH@sub 3@)@sub 2@, adsorbed on Pd(111). Simulated scanning tunneling microscope (STM) images, calculated using a relatively simple computational method based on extended Hückel molecular orbital theory (EHT), showed no observable differences in surface features between occupied and unoccupied states images, nor between adsorption on the various high symmetry binding sites. The calculated binding energies suggest that xylene molecules prefer to bind in particular orientations on hollow and bridge sites. The computed images for xylene on Pd displayed almost identical surface features and symmetries as those calculated on Rh(111).@footnote 2@ Using STM and low-energy electron diffraction (LEED), we imaged the characteristic surface structures and investigated the molecular ordering for the three isomers on Pd(111). Experimental STM images showed each of the isomers exhibiting the characteristic geometries predicted by EHT. Both meta(m-)xylene and ortho(o-)xylene are characterized by an overall triangular shape, with m-xylene nearly equilateral. Para(p-)xylene shows a distinct diamond shape. M-xylene molecules adsorbed to upper step edges, usually with one side of the molecule aligned with the step edge and parallel to the close-packed directions of the Pd lattice. Only the p-xylene isomer showed long range order, forming a hexagonal structure with the long axes of the molecules parallel to each other. Translation and rotation of p-xylene molecules between consecutive scans were observed for the saturated Pd surface, causing disorder in previously ordered regions. @FootnoteText@ @footnote 1@ Supported by NSF CHE-95-20366 and UCOP CLC. @footnote 2@ D. N. Futaba and S. Chiang, Surf. Sci., 448, L175 (2000).

10:20am **SS2+VT-ThM7 Reactions of cis-, trans-, and 1,1-dichloroethene on Pd(111) Studied by TDS, LITD, and STM**, *D.E. Hunka, D.M. Jaramillo,* University of California, Davis*; D.C. Herman,* University of North Carolina, Chapel Hill*; K.D. Lormand, D. Futaba, S. Chiang,* ***D.P. Land,*** University of California, Davis

Chloroethylenes are the among the most abundant groundwater and soil contaminants. Catalytic degradation on transition metal surfaces offers a promising method for the alleviation of this ubiquitous problem. Large differences in the reaction rates of the various compounds have been observed. However, little is known about the reaction mechanisms or the origin of these rate differences. In aqueous solutions, for example, cis-dichloroethylene (cis-DCE) reacts an order of magnitude more slowly on Fe than do trans- or 1,1-DCE. The reactivities do not follow any monotonic trends in dipole, solubility, or bond strength. Addition of Pd to Fe catalysts has been shown to increase the rate of reaction for some of these species by orders of magnitude. We have undertaken to study the reactivity of the three isomers of DCE on Pd(111). As in aqueous solution, the cis isomer reacts very differently from the other two isomers. Decomposition on Pd(111) occurs below room temperature and H@sub 2@ is evolved with C and Cl remaining on the surface to very high temperatures. In contrast, both trans- and 1,1-DCE rearrange to yield chlorinated intermediates that decompose in two steps above room temperature liberating HCl. Some subtle differences exist in the reaction mechanisms, but both are drastically different from the cis isomer. Laser-induced thermal desorption and conventional thermal desorption with FT mass spectrometry, infrared spectroscopy, scannin tunneling microscopy and other surface techniques are used to elucidate the surface reaction mechanisms and energetics.

10:40am **SS2+VT-ThM8 Wet Oxidation of CO on Pt(111)***, **J. Bergeld**, D.V. Chakarov, B. Kasemo,* Chalmers University of Technology and Göteborg University, Sweden

Presence of small amounts of OH is found to initiate the CO oxidation on Pt(111) surface. We have studied water coadsorption with CO on atomic oxygen precovered platinum surface with temperature programmed desorption (TPD) and found distinct relationship between the low temperature, @beta@@sub 3@ peak intensity and the presence and amount of coadsorbed OH. High initial CO coverage is another prerequisite for the low temperature start of the reaction. We are proposing and discussing several feasible mechanisms of the phenomenon, giving preference to autocatalytic reaction between CO and OH at the boundaries of ordered CO and oxygen/hydroxyl islands.

11:00am **SS2+VT-ThM9 The Behavior of Zirconium Surfaces in the Presence of Oxygen, Nitrogen, and Hydrogen Containing Adsorbates***, **Y.C. Kang**, D.A. Clauss, R.D. Ramsier,* University of Akron

Zirconium and its alloys exhibit a unique combination of physical properties that have led to their widespread use as structural materials in fission reactors as well as in a variety of chemical engineering applications involving harsh environments. Common to these applications is the presence of oxygen, nitrogen, and hydrogen containing moieties. Mechanistic studies of the chemistry of such species on zirconium surfaces are necessary to answer fundamental questions which cannot be addressed by phenomenological models of environmentally assisted degradation in these systems. As part of an effort to address these questions, low energy electron diffraction (LEED) and temperature programmed desorption (TPD) techniques have been applied to the adsorption of water, nitric oxide, and ammonia on Zr(0001) surfaces. Water adsorption at 180 K at exposures above 0.75 L results in water desorption in a broad TPD feature near 550 K. Data from LEED indicate that this adsorption does not result in ordered layers until 700 K annealing, and that the formation of ordered structures depends on exposure and annealing conditions. Low exposures of nitric oxide and ammonia at 160 K results in essentially no thermal desorption features, but high (greater than 20 L) ammonia exposures results in the production of water during TPD experiments and the formation of complex residual LEED patterns. These TPD and LEED data indicate a competition between the kinetics of recombination and desorption with those of diffusion involving the near-surface regions.

11:20am **SS2+VT-ThM10 Chlorosilane Adsorption on Clean Si Surfaces: STM and FT-IR Studies***, **M. Nishizawa**, T. Yasuda, S. Yamasaki,* Joint Research Center for Atom Technology (JRCAT), Japan*; M. Shinohara, Y. Kimura, M. Niwano,* Research Institute of Electrical Communication (RIEC), Japan

Understanding the interaction of silane and chlorosilane molecules, (SiH@sub n@Cl@sub 4-n@), with Si surfaces is the base for atomic-scale control of Si growth. A Si(111) surface exhibits the DAS structure which has 7 kinds of dangling bonds with different electron occupancy, while a Si(100) surface reconstructs to the asymmetric-dimer structure. We are interested in the interaction of chlorosilane with these qualitatively different surfaces. This paper discusses structures of SiH@sub 2@Cl@sub 2@-chemisorbed Si(111)-(7x7) and Si(100)-(2x1) surfaces. We have employed STM to identify reaction sites, and FT-IR to probe their local structure. In the STM topographs for adsorption on the Si(111)-(7x7) surface, reacted adatom sites appear darker than the unreacted ones. At a low coverage, we find that SiH@sub 2@Cl@sub 2@ molecules preferentially react with corner adatoms in the unfaulted half of the (7x7) unit cell to produce surface species - SiH@sub 2@Cl and -Cl. Komura et al. proposed a structural model in which the - SiH@sub 2@Cl group is adsorbed on the corner-hole atom.@footnote 1@ Our STM results agree with this model. On the other hand, FT-IR spectra measured for this surface showed two sharp peaks at 2108 cm@super -1@ and 2123 cm@super -1@. These peaks are tentatively assigned to the symmetric and asymmetric Si-H stretching vibrations of the surface - SiH@sub 2@Cl group. However, the observed peak positions of the Si-H stretching vibrations are much lower than those predicted from the semi-empirical formula by Locovsky.@footnote 2@ The reason for this discrepancy is under consideration. Results for the Si(100) surface will be reported at the presentation. This study, partly supported by NEDO, was performed at JRCAT under the joint research agreement between NAIR and ATP. @FootnoteText@ @footnote 1@ T. Komura et al., Appl Surf. Sci. 130 (1998) 23. @footnote 2@ G. Lucovsky, Solid State Commun. 29 (1979) 571.

11:40am **SS2+VT-ThM11 A Far-IRAS Study of Water Adsorption on V@sub2@O@sub3@(0001)***, **M.J. Pilling**,* University of Wisconsin, Milwaukee*; D.S. Toledano,* Yale University*; C.J. Hirschmugl,* University of Wisconsin, Milwaukee*; V.E. Henrich,* Yale University

The high brightness of a synchrotron radiation source has been utilized to investigate adsorption occurring on a single crystal transition metal oxide surface with far infrared reflection absorption spectroscopy (IRAS). The adsorption of H@sub2@O, H@sub2@@super18@O and oxygen on V@sub2@O@sub3@(0001) was investigated between 154K and 224K. Infrared absorption bands at 992 cm@super-1@ and 1040cm@super-1@ are observed in the spectra above and below the desorption temperature of multilayer water, indicating the presence of a chemisorbed surface species.

Vacuum Technology
Room 201 - Session VT-ThM

Pumps and Large Vacuum Systems

Moderator: J.C. Helmer, AVS Fellow

8:20am **VT-ThM1 Design, Construction and Maintenance of Large Vacuum Systems***, **K.M. Welch**,* Consultant **INVITED**

Most good vacuum technicians know how to define the sources and sinks in large systems. We are conversant in gauging, pumps, flanges and seals, valves, leak detection, control systems, etc. We understand gas desorption mechanisms, beam scattering phenomena, the properties on a variety of esoteric materials, and other such art forms of our trade. This technical competence is necessary, but not sufficient for successful project execution. The keystone to the successful execution of any project resides in the planning, the planning methodology, and then the effective communication of that plan to facilitate coordination and engender cooperation. This seems rather mundane. But, it is truly the management challenge of any major project. Planning must be made with insight to the technical, fiscal, temporal, safety, and human relations components of the project. We must effectively communicate with management, sponsoring agencies, project organizations, service groups, staff, and with vendors. Most of Deming's 14 quality assurance tenants relate to creating an enlightened environment of good communications. All projects progress along six distinct, closely coupled, phases. The six phases are in a state of perpetual change. These project phases and their elements are discussed, along with a few management tools which have proven of value in the planning and execution of major projects.

9:00am **VT-ThM3 Design of the US Spallation Neutron Source Ring Vacuum Systems***, **H.C. Hseuh**,* Brookhaven National Laboratory*; M. Mapes,* Brookhaven National Laboratory, usa*; D Pate, L. Smart, J. Tang, R. Todd, D. Weiss,* Brookhaven National Laboratory

Brookhaven is undertaking the design, construction and commissioning of the accumulator ring and the beam transport lines for the 1 GeV US Spallation Neutron Source. A vacuum of 1x10@super -9@ Torr or less is required in the ring to minimize the beam-residual gas ionization. All internal surface of the ring vacuum chamber walls will be coated with TiN to minimize the secondary electron yields thus avoiding the potential mulit-pactoring and e-p instability observed at some proton and positron storage rings. The layout of the ring and transport line vacuum systems, the design of the vacuum chambers, vacuum pumps and other hardware are presented. The calculated pressure distribution in the ring and the transport lines will be given. Development of the TiN coating process will be described. The architecture of the vacuum instrumentation and controls based on serial network links, PLCs and EPICS will also be presented. *Work performed under the auspices of the U.S. Department of Energy.

9:20am **VT-ThM4 The Interesting and Important Problem of Water in Vacuum Systems*, H.F. Dylla,*** Jefferson Lab **INVITED**

The author will review the phenomenology of water adsorption/desorption in vacuum systems. A review of the literature of outgassing shows that for unbaked metals, the outgassing is dominated by water, and the outgassing rate (Q) obeys a power law of the form Q = Q0 t -a, where a is near unity. A series of outgassing measurements@footnote 1@ have been performed on well characterized stainless steel surfaces which show that the outgassing power law exponent can vary from a = 0.7 - a = 1.2 as the metal surface is exposed from extremely dry N2 to increasing partial pressures of H2O. Relatively simple engineering formulae exist which quantify the amount of adsorbed/desorbed H2O as a function of exposure pressure, time and temperature. Models have been developed consistent with these data which invoke the oxide layer as the source volume for the outgassing and assume that the outgassing rate is limited by diffusion from the near surface region. Alternative models for outgassing of water have been described which assume surface desorption as the only source term.@footnote 2@ The author will discuss the additional measurements and modeling that are needed to achieve a more sophisticated understanding of water outgassing from metal surfaces. This work supported by US DOE Contract No. DE. @FootnoteText@ @footnote (1)@ Minxu Li and H.F. Dylla, J. Vac. Sci. Technol. A11, 1702 (1993); A12, 1772 (1994); A13, 1872 (1995). @footnote (2)@ P.A. Redhead, J. Vac. Sci. Technol. A, 13, 467 (1995).

10:00am **VT-ThM6 Large Motion Feedthrough Designs for Ultra Accurate Positioning in Vacuum*, T. Bisschops,*** Philips Research, The Netherlands

In the near future machining of special materials or substrates and e.g. semiconductor lithography will require an ultra clean gaseous or vacuum atmosphere. Large workpieces or substrates will need to be positioned at high speed (e.g. 20 m/s) with high acceleration (e.g. 2 g) and high accuracy (e.g. 5 nm). For industrial heavy duty applications large, differentially pumped, motion feedthrough designs have been developed. Feedthrough designs that allow for long stroke (e.g. 0.5 m) X, Y, Z, phi, theta positioning with high accuracy and for vacuum applications in the 10e-6 to 10e-8 mbar range will be presented.

10:20am **VT-ThM7 Design and Operation of Scroll Type Dry Primary Vacuum Pumps*, A. Liepert,*** *P. Lessard,* Varian Vacuum Technologies

Since being rediscovered two decades ago, scroll technology has been successfully adapted to vacuum use. Several innovations have allowed scroll-type pumps to produce vacuums lower than 10 mtorr; the pumps are used in many applications requiring an inexpensive, dry, long-lived pump. In this article, we detail the scroll design procedure, focussing on the tradeoffs between the need for sufficient vacuum and low manufacturing cost. In particular, the bearing and axial seal design are detailed. As an illustrative example, we consider the design requirements for a high helium compression scroll design for use in leak detectors. We also present guidelines for proper pump operation, including the need for gas ballasting, limits on high pressure operation and proper pump isolation schemes.

10:40am **VT-ThM8 Influence of the Production Parameters on the Vacuum Properties of Ti-Zr-V Non-evaporable Getter Films***, C. Benvenuti,* ***P. Chiggiato****, S. Clair, J.B. Clark, P. Costa Pinto, A. Escudeiro Santana, V. Ruzinov, I. Wevers,* CERN, Switzerland

Non-evaporable thin film getters of various composition have been produced by sputtering. Among the about 20 materials which have been studied, the lowest activation temperature (about 180°C) has been displayed by a Ti-Zr-V coating obtained from a cathode made of intertwisted elemental wires. In order to optimise the vacuum properties of this coating, the production parameters have been varied, namely sputtering configuration (diode or magnetron), discharge gas, deposition rate, discharge voltage, substrate nature and temperature during coating. The films have been analysed by electron microscopy, electron stimulated desorption, ultimate pressure, pumping speed and rare gas degassing rate measurements. The results are presented and discussed.

11:00am **VT-ThM9 Influence of the Elemental Composition and Crystal Structure on the Vacuum Properties of Ti-Zr-V Non-evaporable Getter Films***, C. Benvenuti, P. Chiggiato, A. Mongelluzzo,* ***A. Prodromides****, V. Ruzinov, M. Taborelli,* CERN, Switzerland*; F. Lévy,* EPFL, Switzerland

Non-evaporable thin film getters of various composition have been deposited by sputtering. Among the 20 materials that have been studied, the coating with the lowest activation temperature (about 180 °C) has been found in the Ti-Zr-V system sputter-deposited from a cathode made of intertwisted wires of the constituent elements. In an attempt to reduce the activation temperature, Ti-Zr-V films of various composition have been deposited by means of a dedicated three-cathode planar magnetron sputtering configuration, and then characterised by Auger electron spectroscopy and pumping speed measurements. We have found that the lowest activation temperatures and the highest pumping speeds are obtained only in a confined zone of the Ti-Zr-V system, corresponding to an amorphous or nanocrystalline structure. Important and irreversible reductions of the getter film pumping speed are observed when the film structure is modified by heating.

11:20am **VT-ThM10 Miniature Vacuum Pumps*, J.W. Weed*[1]*,*** Sandia National Laboratories **INVITED**

Miniature analytical instruments that operate in a rarified gas environment will require vacuum pumping systems that are of suitable performance, size, weight, and power consumption. A subset of these analytical instruments will require throughput pumping systems, that is systems that exhaust pumped gas to the external environment rather than capturing it. Vacuum pumps are available in both capture and throughput configurations. Most "normal" sized gas analytical systems in use today are equipped with throughput pumping systems because of sampling and total mass flow requirements. This talk will describe existing pumps and efforts to miniaturize them. Performance and design criteria will be explored focusing on creating specifications based on overall system requirements. Problems with shrinking existing designs as well as several novel designs will be considered. Some new microfabrication processes will be described with an eye towards techniques that will be helpful in the fabrication of miniature vacuum pumping systems. *Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

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[1] **Featured Speaker - Science and Technology in the 21st Century**

Thursday Afternoon, October 5, 2000

Vacuum Technology
Room 201 - Session VT-ThA

Pressure and Flow Measurements

Moderator: N. Peacock, HPS Division, MKS Instruments

2:00pm **VT-ThA1 A Practical Guide to the use of Bayard-Alpert Ionization Gauges*, J.H. Singleton,*** Consultant **INVITED**

The Bayard Alpert (BA) ionization gauge is the most common device used for the measurement of pressure in vacuum systems. There are however many potential problems in the use of the gauge and in the interpretation of the data that it provides. Perhaps the most basic problem is that the sensitivity of the gauge is substantially different for the common gases encountered in a vacuum system, including hydrogen, argon and nitrogen: if the gas composition is unknown, the absolute pressure cannot be determined. Nevertheless, in many systems, where the gas composition remains constant from day to day, the reading from a BA gauge can serve as a meaningful indicator of relative pressure. But if something goes wrong in the system, such as a water leak, the gauge alone can provide virtually no information as to the problem. This paper is primarily directed to the many other problems that can afflict a gauge; it is an attempt to give practical guidance on the use of a gauge, such as the appropriate connection to a system, and the operating techniques which can be used in order to obtain meaningful data. The topics addressed include gas pumping, by generation of ions, and by chemical interactions at the gauge filament; the change in gas composition by interaction at the gauge filament, and errors in pressure measurement including Barkhausen-Kurtz oscillations, electron stimulated desorption, and the x-ray effect. Factors which dictate the specific BA gauge selection, such as the method used for outgas, and the selection of the electron emitter, will also be discussed.

2:40pm **VT-ThA3 The Ultimate Resolution of Commercial Spinning Rotor Gauges*, J. Setina,*** Institute of Metals and Technology, Slovenia

The resolution of a spinning rotor gauge (SRG) depends primarily on the precision of measurement of the rotor deceleration rate and on the stability of the rotor residual drag. The ultimate resolution of the SRG can be achieved only when the ambient conditions allow stable residual drag. Our measurements of the residual drag were done in a sealed vacuum system with glass and stainless steel SRG thimbles and a small appendage ion pump. The system was placed in a thermostat together with the SRG suspension head. The suspension head was fixed to the laboratory wall virtually vibration free. The imprecision of the deceleration rate measurements is determined by the rotor frequency and the integration time. Old versions of SRG controllers were limited to the integration time of 30 seconds and the rotor operation frequency was preset to the narrow window of 405 to 415 Hz. Some new versions of controllers allow the extension of the integration time to 60 seconds and the operation of the rotor at frequencies up to 800 Hz. In the present study we varied the integration time and rotor frequency and observed the statistical distributions of sequential readings of the rotor residual drag. We found some instabilities of the gauge immediately after the re-acceleration of the rotor. Such instabilities were not reported previously and can affect the accuracy of pressure measurements. We also found that operation of the rotor at higher speeds increases the frequency dependence of the residual drag.

3:00pm **VT-ThA4 Extending the Upper Pressure Limits of Cold-Cathode Gauges*, B.R.F. Kendall,*** Elvac Laboratories*; E. Drubetsky,* Televac Division of the Fredericks Company

Processes occurring in magnetron-type discharges at normal and elevated pressures are compared. As pressures rise into the micron range, an increasing fraction of electron-molecule interactions occur at less than ionizing energies, and more of the ions collide with molecules on their way to the cathode. This results in fundamental changes in the discharge behavior. Discharge currents have been measured as a function of pressure and voltage up to 1 Torr for a number of magnetron and inverted magnetron electrode configurations. Additional experiments covered AC and pulsed operation. Practical aspects of high-pressure operation such as sputtering, electrode heating and the formation of polymer films are reviewed. The possibility of operating a double inverted magnetron at pressures approaching 1 Torr is discussed. Simple extended-range gauges of this type could replace complicated hybrid gauge combinations in some applications.

3:20pm **VT-ThA5 An Absolute Vacuum Gage Based on the Q Value of the Vibration of a Silicon Micro Cantilever*, Y. Kawamura,*** Fukuoka Institute of Technology, Japan

The Q value of a silicon micro cantilever has been measured in vacuum under the condition of ultra micro amplitude of the vibration. The maximum Q value of about 30000 was obtained in the vacuum of 1x10-6 torr. The measured Q value was in good agreement with the theoretical calculations based on the momentum exchanges between the cantilever and gas molecules. This system can be expected to be applied to a new type of absolute vacuum gage.

3:40pm **VT-ThA6 Performance of the Axial-symmetric Transmission Gauge Improved for the Measurement of Wide Pressure Range*, H. Akimichi,*** *N. Takahashi, T. Hayashi, Y. Tuzi,* ULVAC Japan, Ltd., Japan

The axial-symmetric transmission gauge (AT gauge) is originally developed for the pressure measurement in extreme high vacuum . The Bessel-Box type energy analyzer is placed between the ionizer and the ion collector with a secondary electron multiplier (SEM). The analyzer prevents the SEM from the effects of soft x-rays and electron stimulated desorption (ESD) ions produced in the ionizer. The lower limit of the pressure measurement was estimated to be about 10 @super -12@ Pa. The higher limit, however, was restricted to about 10 @super -6@ Pa due to the limit of pulse resolution of the SEM. In order to expand the pressure measurement up to high vacuum range (~ 10 @super -2@ Pa), the SEM was replaced by a Faraday cup type ion collector. The sensitivity factors of the gauge calibrated by the Conductance Modulation Method through the pressure range of 10 @super -10@ to 10 @super -6@ Pa were (6.7 ± 0.2) x 10 @super -3@ Pa @super -1@ for nitrogen and (2.3 ± 0.04) x 10 @super -3@ Pa @super -1@ for hydrogen, respectively. Comparison of the AT gauge to the extractor gauge (EG) and the spinning rotor gauge also gave the sensitivity factor of (5.8 ± 0.1) x 10 @super -3@ Pa @super -1@ for nitrogen in the pressure range of 10 @super -8@ to 10 @super -2@ Pa. When oxygen was introduced into the system with an AT gauge and a conventional EG, the nominal pressure readings of the EG showed higher values than those of the AT gauge. The difference increased with the increment of oxygen pressure and exposure, and decreased to zero by the bake-out of the system during the pumping process. The results show that the ESD ions, originated from the oxygen adsorbed on the grid surface of ionizer, are effectively separated from the gas phase ions by the energy analyzer in AT gauge.

4:00pm **VT-ThA7 Study of Thermal Transpiration of Capacitance Diaphragm Gauge by DSMC Method*, M. Hirata,*** *S. Nishizawa,* Electrotechnical Laboratory, Japan*; K. Watanabe,* CRC Corporation, Japan

Capacitance diaphragm gauge (CDG) is one of the most important vacuum gauges in low and middle vacuum ranges. Sensor head of a high precision CDG is kept for 45°C in order to minimize zero drift from room temperature fluctuation. The difference of temperature between the sensor head and the vacuum chamber gives a non-linear sensitivity of the gauge depending on the pressure less than 130 Pa due to thermal transpiration effect. Change in the sensitivity of about 4 % between molecular flow regime and viscous flow regime is significant for metrological use of the gauge. Empirical equation is widely used to explain the effect.@footnote 1@ In this study, by using a direct simulation Monte Carlo (DSMC) method @footnote 2@, pressure distribution in the connecting tube of the gauge was obtained under the pressure range from molecular flow regime to viscous flow regime (10@super -2@ - 10@super 2@ Pa) with taking account of temperature distribution along the connecting tube. Furthermore, the pressure dependence of sensitivity of CDG for several gases was derived from the pressure difference between the hot and cold ends. It was in good agreement with the pressure dependence of sensitivity obtained by static expansion system experimentally. The pressure distribution inside the connecting tube explains the mechanism of thermal transpiration phenomenon. This method can be also applied for complicated real system. @FootnoteText@ @footnote 1@ T.Takaishi and Y.Sensui, Trans.Faraday Soc. 59, 2503(1963). @footnote 2@ G.A.Bird, "Molecular Gas Dynamics and the Direct Simulation of Gas Flows", Clarendon, Oxford (1994).

4:20pm **VT-ThA8 Intelligent Flow Measurement and Control*, G.H. Leggett,*** *S.A. Tison, K. Tinsley,* Millipore Corporation

Vacuum processes typically use mass flow controllers for delivery of stable and known flow of gas to the process chamber. A variety of techniques are used for gas measurement and control, but the most prevalent is based on thermal transfer between a heated tube wall and the gas stream. This class of mass flow controller is referred to as a thermal mass flow controller.

These instruments have been in use for over 20 years and have evolved with time. Most recent versions are digital controllers which allow for digital setpoints and digital outputs. While advances have been made, MFCs are still custom manufactured for a particular gas and flow range, and their accuracies with process gases is typically no better than +/-5%. A new thermal based MFC has been developed which is capable of operating over extended ranges (500 to 1 flow ratios) and is able to achieve accuracies with process gases to within 1% of the MFC full scale. These accuracies are attained by using theoretical and empirical based techniques for relating the flow of the calibration gas to that of the process gas. Similar techniques are used for tuning of the MFC to ensure typical response times of one second. This paper describes the design, control techniques, calibration processes, and verification data for a thermal based mass flow controller with typical semiconductor process gases.

4:40pm **VT-ThA9 Summary of the Extreme High Vacuum and Surface Conditioning Workshop***, G.R. Myneni,* Jefferson Lab, US

Summary of the Extreme High Vacuum and Surface Conditioning Workshop The Vacuum Technology Division, the Mid-Atlantic Chapter of the AVS and the Jefferson Lab have sponsored a workshop on Extreme High Vacuum and Surface Conditioning at Jefferson Lab in June 2000. The main focus of the workshop was the limitations of various pumps in achieving XHV. The deliberations included kinetic pumps (turbo-molecular pumps), and capture pumps (ion pumps and cryopumps). Discussions on improvements in vacuum measurement techniques, extreme sensitivity helium leak detection practices, as well as the calibration of such advanced instrumentation systems were an integral part of the workshop. The various topics of interest that were covered in technical sessions include: applications of XHV technologies, a quantitative understanding of virtual leaks, means to eliminate or reduce the various gas sources in XHV systems, XHV materials, XHV vacuum system fabrication methods, XHV technology standards and development of low cost XHV systems. High lights of this workshop will be presented in this talk.

MEMS
Room 309 - Session MM+VT-FrM
MEMS Actuators, Pumps, Power Devices, and Tribology

Moderator: R. Robbins, Texas Instruments

8:20am **MM+VT-FrM1 Micromechanical Devices for Force Measurement**, ***T.W. Kenny,*** Stanford University **INVITED**

In recent years, many researchers have adapted lithography, deposition and etching techniques from the IC processing community to the fabrication of micromechanical sensors. Many of the signals that these sensors are intended to detect are expressed as forces which stress or deflect the micromechanical structure. As sensors are miniaturized, these forces naturally become smaller, and techniques for detection are required to improve. Our research group has been engaged in a variety of activities, all of which share an interest in improving the force detection capability of microinstruments. In this talk, an overview of these activities will be presented, beginning with simple strain-gauge sensors (micronewtons), sensors based on tunneling displacement transducers (nanonewtons), AFM cantilevers (piconewtons), and ultra-thin force sensing cantilevers (attonewtons). Opportunities for exciting scientific measurements will be highlighted, and challenges for application of MEMS devices to these measurements will be discussed.

9:00am **MM+VT-FrM3 Developing MEMS Vacuum Pumps**, ***E.P. Muntz,*** University of Southern California **INVITED**

There are no satisfactory MEMS vacuum pumps; particularly unavailable are vacuum pumps that can handle the flow required for MEMS scale, continuous sampling instruments. The two obvious paths to creating such pumps, adapting current technology to MEMS scales or inventing new MEMS friendly technology, are discussed. The first path has been tried to some extent and not been successful, the second has been studied and a few possibilities are under investigation. A generic scaling study of expected trends in vacuum pumping performance as size is reduced to the MEMS scale is presented. It indicates that in practically all cases present vacuum pumps scaled to MEMS dimensions are not very attractive. New technologies that may offer more attractive possibilities are discussed. The degree of attraction is measured in terms particularly applicable to MEMS devices; the energy required per unit of upflow in the pump and the pump volume per unit of upflow. Both of these need to be sufficiently small to permit self consistency in energy use and size in order to allow local integration of the pumps with the MEMS devices that require vacuum pumping. For instance the full potential of instruments such as a MEMS sampling mass spectrometer can only be achieved if the pumps have power or space requirements equal to or preferably significantly less than the instrument itself. It is concluded that with new pumping technologies that have been identified, it may be possible to provide satisfactory MEMS vacuum pumping performance. However, this will only come to pass if a determined research and accompanying development program is created.

9:40am **MM+VT-FrM5 Miniaturized Fuel Cell for Portable Power**, ***H.L. Maynard,*** *J.P. Meyers,* Lucent Technologies, Bell Laboratories

We are developing a silicon-based miniaturized fuel cell to power 0.5-20 W portable telecommunication, computing, and personal entertainment devices. Fuel cells provide a 5-10x improvement in energy storage over advanced rechargeable batteries, allow "instant recharge" (with the insertion of a fuel cartridge), and enable sustained operation away from the power grid. The fuel cell is a methanol-based proton-exchange membrane (PEM) device. Our design is implemented in silicon to leverage advanced silicon processing technology, expertise and facilities. Applying silicon processing techniques to the fuel cell structure enables precise control over the thin-film properties and interfaces, enabling optimization of the critical three-phase region of ionic conductivity, electronic conductivity and gas and/or fluid permeability. Additionally, using a wafer-based approach minimizes production costs, instead of individually constructing and assembling the components. The advantages and disadvantages of two designs will be discussed: a two-wafer bipolar design and a single-wafer integrated monolithic structure. We discuss key integration issues including: thermal management, water control, air movement, fuel delivery, and power conditioning. We will also present preliminary experimental results.

10:00am **MM+VT-FrM6 Nanotribology and Stiction Studies of Surface Micromachined Electrostatic Micromotors Using An Atomic Force/Friction Force Microscope**, *S. Sundararajan,* ***B. Bhushan,*** The Ohio State University **INVITED**

Microelectromechanical systems (MEMS) which involve relative motion often encounter tribological problems that undermine and sometimes even prevent device operation. One such problem is that of static friction or stiction. An atomic force/friction force microscope (AFM/FFM) allows for direct measurements on fabricated devices, components and their surfaces. The AFM can be used to study tribological properties of surfaces that exhibit stiction. Nanotribological studies have been conducted on surface micromachined polysilicon micromotors for the first time using a commercial AFM/FFM. Surface roughness parameters (RMS, peak-to-valley distance, skewness and kurtosis) and nanoscale adhesion and friction properties of various surfaces of the motor were measured. Different surfaces of the motor components exhibit different surface roughness and friction properties. A novel technique to measure the stiction encountered in these motors using an AFM has been developed and is described. Using this technique, the effects of humidity and rest time on stiction in the motors have been studied. The mechanisms responsible for stiction in such devices are discussed. Meniscus forces between the mating surfaces of the motor may be the cause of the observed stiction. The real area of contact between the mating surfaces is an important factor affecting meniscus forces. The use of perfluoropolyether (PFPE) liquids as lubricants to reduce friction and stiction for such MEMS devices is investigated.

10:40am **MM+VT-FrM8 Characterizing Coupled MEM Oscillators for Array Applications**, ***R. Baskaran,*** Cornell University; *K.L. Turner,* University of California, Santa Barbara

MEM Oscillators have been successfully used as accurate sensing and actuation elements. We present a system of electrostatically coupled (by interdigital placement of the movable combfingers) torsional MEM oscillators. This design aims at studying the electrostatics of torsional systems and dynamics of variable coupling strength oscillators for distributed systems applications.@footnote 1@ The configuration allows design of elements with out-of-plane motion at locations across a large area without long springs/suspended structures, eliminating complex modes of oscillations close to operating frequencies and processing issues of large released structures. By design, each of the oscillators can be used for either capacitive sensing or actuation,like in a distributed control network. With integrated tips, the present design also lends itself to applications like AFM/STMs. We have designed, fabricated (with the SCREAM process) and characterized a 2-oscillator system. A high-accuracy(~4nm) laser vibrometry technique is used to get phase and amplitude of the displacement and velocity for various forcing voltages. Experiments have been performed to extract the electrostatic and dynamical parameters (represented by a coupled harmonic model) of the system. Experimental results show a near complete energy sharing (equal area under the Amplitude-Frequency curve) between the two oscillators in the primary resonance.'Beat' phenomenon i.e Amplitude modulation, typical of coupled systems, was observed in the impulse response as well as in the amplitude 'build up' to resonance. The phase relationship between the two oscillators will be useful to characterize the coupling mechanism and is presently under investigation. Future work involves extending the system to multiple oscillator arrays. @FootnoteText@ @footnote 1@Gabriel.K., Jarvis.J., Trimmer.W "Small machines, Large opportunities" Micromechanics and MEMS Classical and Seminal papers to 1990(IEEE).

11:00am **MM+VT-FrM9 Tunable Mechanical Oscillator**, ***M.K. Zalalutdinov,*** *B. Ilic, A. Zehnder, J.M. Parpia, H.G. Craighead,* Cornell University

It has been demonstrated that cantilever beam can resonate at various frequencies when driving force is applied locally, at different points along the beam. The tip of a scanning tunneling microscope (STM) engaged at the cantilever surface is driven in the Z-direction, acting as driving point-source with a subAngstrom amplitude. Cantilever motion was detected by the Scanning Electron Microscope incorporated into a UHV STM system and a spectrum analyzer was used to monitor the modulation of the videosignal, actuated when electron beam crosses the vibrating cantilever. Low stress silicon nitride cantilevers were fabricated using conventional bulk silicon micromachining techniques and coated with a 300Å Au/Pd film in order to provide good tunneling conditions. In this paper we present the results obtained with a 225x20x0.6 µm cantilever. When the driven STM tip was positioned above the bulk part of the sample, near the base of the beam, the conventional cantilever mode was excited with the resonant frequency

9,7kHz. When the STM tip is moved so that it engages the cantilever surface, an additional local constraint is placed on the beam's motion, altering the vibrational mode and causing the shift of the eigenfrequency. We detected a continuous increase of the resonant frequency (up to 25kHz) as the STM tip was moved along the center line from the base to the middle of the beam. This continuous variation of the resonant frequency has numerous possible applications, and was accomplished without a significant change in the Q. We have analyzed the measured deflection vs position using a model of the beam motion and found good agreement over the range we have studied. Possible realization of tunable micromechanical oscillators, based on the concept of a drive induced by the application of the local stress will be discussed.

11:20am **MM+VT-FrM10 Thermal Characteristics of Microswitch Contacts***,* ***X. Yan****, N.E. McGruer,* Northeastern University*; S. Majumder,* Analog Devices*; G.G. Adams,* Northeastern University

Electrostatically actuated microswitches and relays have been developed at Northeastern University.@footnote 1@,@footnote 2@ Devices are approximately 100 @micron@ x 100 @micron@ in area and operate with an actuation voltage of 50-60 V, corresponding to a contact force of 100-150 microNewtons. The contact resistance varies less than 0.5 @ohms@ over 10@super 7@ cycles, with 4-10 mA current cold-switched. Switches have also been tested up to 10@super 9@ cycles with less than 0.5 @ohms@ variation in contact resistance, and with 330 mA of current for up to 18 cycles. The contacting bodies are a "drain" electrode approximately 0.2 @micron@ thick, and a pair of cylindrical bumps 1 µm in radius protruding from a 6 µm thick cantilever. The actual contact area is much smaller and consists of one or more small asperities. In this paper we study the microswitch contact properties at high currents. Finite element electrical and thermal models have been developed using ANSYS, and the modeled current handling limits are compared with experiments. Modeling shows that for a range of switch designs with thin-film drains, the highest temperature is located within the drain rather than at the contact interface, and this location moves further away from the contact interface as the drain thickness decreases or the length of the drain trace increases. Experiments confirm these trends, and show that switches fail catastrophically due to evaporation of the drain trace metal. SEM analysis of contact surfaces at various current densities is also presented. SEM analysis shows that even at the highest currents at which the trace metal evaporates, the contact surfaces typically show relatively little damage, mainly material transfer from one contact surface to the other. @FootnoteText@ @footnote 1@ S. Majumder, N. E. McGruer, "Study of Contacts in an Electrostatically Actuated Microswitch", Proceedings of 44th IEEE Holm Conference on Eletrical Contacts, pp 127-132 (1998) @footnote 2@ P.M. Zavracky, S. Majumder, and N.E. McGruer, "Micromechanical Switches Fabricated Using Nickel Surface Micromachining," J. Microelectromechanical Systems, Vol. 6, pp 3 (1997)

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